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Accounting for unintended moisture sources in hygrothermal building analysis

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SUMMARY:
Moisture control analysis of building envelope components by hygrothermal simulation is state-of-the-art today and widely applied by architects and engineers. Compared to simple dew-point calculations, transient simulations according to existing standards (e.g. EN 15026-2009) have greatly improved the possibilities of moisture control analysis. However, the underlying assumption of building components without imperfections have remained a weak point, because unintended moisture sources due to e.g. rain-water penetration or air convection may have significant effects in real life. The new draft of the WTA guideline 6-2, whose original version served as blue-print for EN 15026, takes hygrothermal simulations a step further by introducing auxiliary models that account for unintended moisture sources likely to occur in building components, assembled and installed in best practice manner. Because bad workmanship is ruled out, applying these models offers the opportunity to differentiate between design errors and installation failures. Other guideline improvements include new boundary condition aspects such as safety margins for indoor climate conditions and consideration of envelope shading. Since capillary active insulation materials have become more popular in recent years a more accurate determination of liquid transport characteristics is also proposed. The new items in WTA 6-2 are summarized and their impacts on hygrothermal simulation results are discussed.

1. Introduction

Moisture in the building structure impairs thermal performance and accelerates ageing and degradation. Therefore moisture control has always been an issue for architects and engineers. Despite an improvement in construction quality, moisture problems have not diminished accordingly. This may partly be due to increasing energy savings requirements. More insulation and better air-tightness have resulted in lower temperatures at the exterior layers of the building envelope and higher indoor humidity. This increases the risk of interstitial condensation and reduces the drying potential. However, adequate moisture control design can help to prevent problems even in the most energy efficient structures. The necessary design tools are there but they have to be applied the right way. While it is fair to assume that a building has been erected according to best practice, a perfect seal against water, vapour or air entry is difficult to achieve. Therefore, the consideration of imperfections should be part of moisture control assessments based on hygrothermal simulation.

Another safety issue represents the choice of the exterior and interior boundary conditions. While at first sight it seems to make sense to select severe climate conditions and an unfavourable behaviour of the occupants, experience shows that even well-proven constructions may fail under these circumstances. Therefore a more sensible approach is desirable. Last but not least it is important that the material properties employed for the calculations represent the characteristics of the materials according to their intended use. This paper describes how the new draft of the WTA guideline 6-2

(WTA 2013) deals with all these issues. It also summarizes the background and rational for the new or modified items in the guideline.

2. Moisture control design by hygrothermal simulation

In the past, moisture control meant for most practitioners steady state vapour control calculations – often called dew-point or “Glaser” calculations – that were performed to determine whether there is a risk of harmful interstitial condensation in the building assembly during the heating season. However, due to numerous simplifications the results of these calculations may be misleading especially when short-term loads such as solar vapour drive or bulk water entry cannot be excluded. Therefore, modern hygrothermal simulation tools that calculate the transient temperature and moisture conditions in building envelope components under realistic boundary conditions have been increasingly applied by architects and engineers. To arrive at comparable results pertinent application standards for hygrothermal simulations have been developed which are under continuous revision in order to accommodate new approaches and feed-back from users.

The first guideline on moisture control analysis by hygrothermal simulation was issued in 2002 by the WTA, an association dealing with preservation and renovation of heritage constructions and rehabilitation of the building stock (WTA 2002). Five years later the European Standard EN 15026 (2007) which is largely based on the WTA guideline was published. However, both documents do not contain any information on how to deal with small defects in the building envelope. Parallel to the standard work in Europe a slightly more comprehensive standard on moisture control design has been developed in North-America (ANSI/ASHRAE 2009). As a result of numerous damage cases linked to rainwater penetration into constructions with rendered facades (Cheple & Huelman 2000), this standard has been the first that proposed the consideration of the effects of small leaks in the exterior finishes of exposed walls.

3. New items in hygrothermal simulation guideline WTA 6-2

Compared to the version from 2002 the new draft of WTA 6-2 (2013) allows the consideration of imperfections in the building envelope by simplified models. It also shows a way of dealing with ventilated cavities and contains some new information concerning boundary conditions. The new draft recognizes the problem of determining the material properties as accurately as possible for the intended use by a chart that recommends the test method as function of moisture range. This issue has come up in the context of capillary active insulation materials. These vapour permeable materials are supposed to prevent condensation at the cold side by compensating the diffusion flux with an opposed liquid flux. This means, liquid transport in capillary active insulation materials has to achieve a considerable magnitude well below 100% RH. Most of the currently employed methods have been designed to determine liquid transport properties in the high moisture range, i.e. when the majority of capillaries are filled with water. These methods turned out to be inappropriate to accurately determine liquid transport in the hygroscopic range. Therefore a new determination method has been developed by Binder et al. (2013) that tests the properties of interior insulation materials under the boundary conditions close to the real situation in practice application.

Since validation of the employed models is essential, the guideline now refers to some benchmark examples. One of the most important issues of a hygrothermal analysis is the interpretation of the results. Therefore a new chapter on result evaluation has been added which summarizes current assessment procedures. Concerning limit criteria it refers to existing WTA guidelines (e.g. WTA 6-3 (2007) and WTA 6-4 (2009)) as well as to a guideline on wood decay that is still in the making.

3.1 Rainwater penetration through imperfection in the exterior finish

As already mentioned the American moisture control standard ANSI/ASHRAE 160 (2009) requires the consideration of small rainwater leaks through the exterior finish which may result from gaps or cracks at joints and connections. It states: “In the absence of specific fullscale test methods and data for the as-built exterior wall system being considered, the default value for water penetration through the exterior surface shall be 1% of the water reaching that exterior surface. The deposit site for the water shall be the exterior surface of the water-resistive barrier. If a water-resistive barrier is not provided, then the deposit site shall be described and a technical rationale for its selection shall be provided.” In the case of ETICS on external walls the rainwater deposit site is likely to be the surface of the load bearing masonry beneath the insulation (see FIG 1).

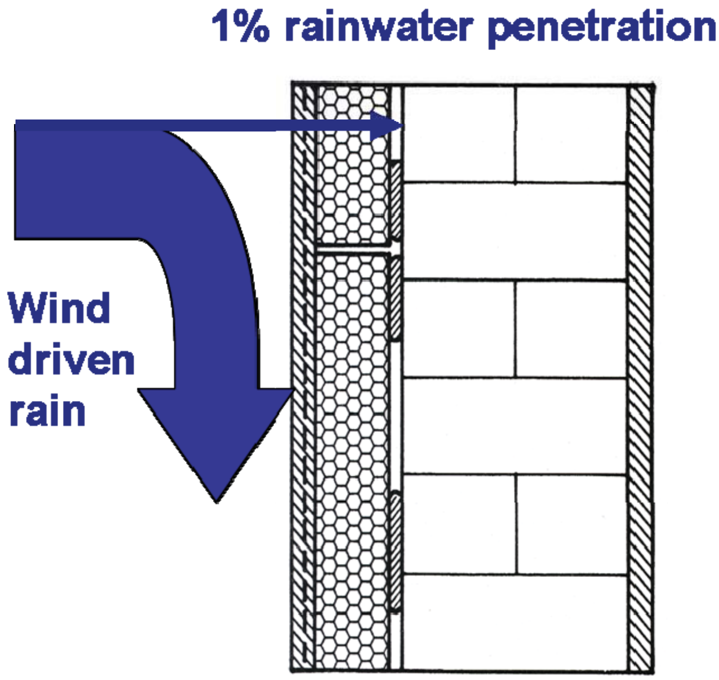

FIG 1. Example that shows the most likely deposit location for rainwater penetrating through leaks at joints and connections of a masonry wall with ETICS

It is obvious that neither the leaks nor the wind driven rain exposure are evenly distributed over the building envelope. But the standard committee chose this simple one-dimensional approach as a method to consider the effects of complex bulk water penetration phenomena observed in practice. The rainwater leakage rate proposed in the standard is not meant to be a worst case scenario. It is not based on field test results but on hygrothermal simulations (Desjarlais et al. 2001) that showed that more than 1% of rainwater penetration may be detrimental for a large portion of existing wooden wall structures. A recent literature review (Van Den Bossche et al. 2011), analysing data of leakage rates measured on different wall structures, confirmed the appropriateness of the “1% leakage” in ANSI/ASHRAE Standard 160. Therefore the rationale of this standard was also adopted for the new WTA guideline 6-2.

3.2 Moisture sources due to air flow through the building envelope

The convective moisture entry due to defects in the vapour respectively air control layer is a multidimensional effect, which cannot be captured directly by a one-dimensional calculation. However, also the application of multidimensional simulation tools hardly solves the problem, because the exact configuration of leakages is generally unknown and the complexity of relevant flow paths is exceeding the capacity of most models. Therefore it has been decided to choose an approach that doesn't simulate the flow itself, but concentrates on the effects of vapour convection and subsequent condensation by introducing a moisture source inside the construction.

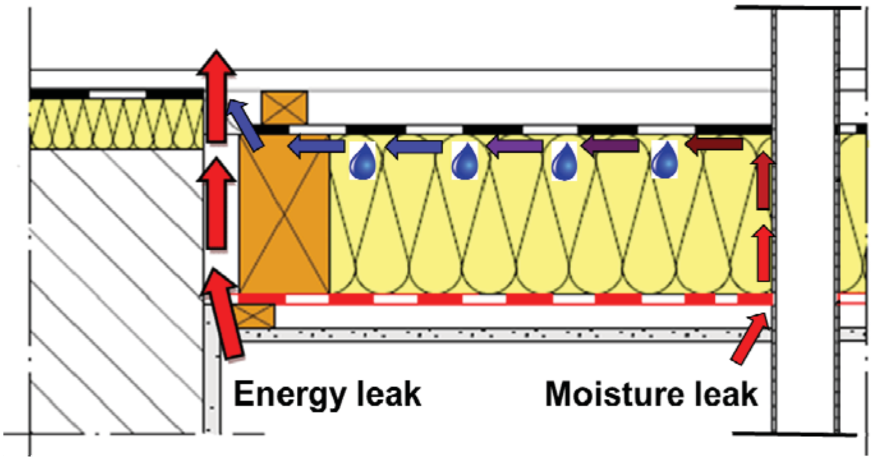

FIG 2. Indoor air leaking through a roof at joints and connections. If the flow path is short, it will be heated up by the air flow and only energy is lost. If the air flow creeps along the cold side of the structure before it finds its way out, its temperature may drop below the dew-point of the indoor air and cause condensation.

Based on experimental results from TenWolde et al. (1989), a simplified model to quantify the moisture sources due to vapour flow through the building envelope has been developed and checked for plausibility (e.g. Künzel et al. 2011). The model assumes that vapour contained in the indoor air, penetrating the envelope via so-called moisture leaks, condenses at the cold side of the insulation (see FIG 2). In contrast to energy leaks where the air remains warm because it flows in a short way from the room towards the outside, moisture leaks are small and tortuous channels where the air flow is slow and cools down in flow path. They represent only about 10% of all leaks in the building component. The position of the condensation plane has to be selected by the user. Its temperature, governed by the transient boundary conditions, is simulated without taking the latent heat of condensation into account. The right choice of this position depends on the construction. It must be cold enough for condensation to occur and it must be easily accessible for the indoor air that has penetrated the interior lining or air barrier. Examples are the exterior sheathing of wood frame walls or roofs and the interface between the interior insulation and the original wall after thermal retrofits of plastered masonry structures. The convective moisture source is equal to the amount of condensate that forms when the indoor air temperature is cooled down to the temperature of the selected condensation plane in the building assembly. Any increase in sorption water content that could occur in reality by the temperature drop is neglected. In order to remain on the safe side convective drying is excluded, i.e. the moisture accumulated by air convection can only dry out by vapour diffusion or liquid transport.

Thus the amount of condensation (moisture source S_{CL}), which results from vapour convection at the selected condensation plane p, is determined for each time step according to the following equation:

$$S_{CL} = k_{CL} \cdot \left(c_i - c_{sat,p}\right) \cdot (P_i - P_e) \qquad (1)$$

where S_{CL} moisture source due to vapour convection through the component (kg/(m²h))

k_{CL} air permeance of the "moisture leaks" of the component (m³/(m²·h·Pa))

c_i water vapour concentration of the indoor air (kg/m³)

$c_{sat,p}$ water vapour saturation concentration at predefined plane p (kg/m³)

$P_i - P_e$ air pressure difference over the considered envelope component (Pa)

The air pressure difference is assumed to be due to buoyancy effects and pressure differentials generated by ventilation systems. Wind pressure effects are disregarded because they are difficult to determine and do not act on the building envelope in a continuous manner. Based on investigations in Künzel et al. (2011) the air permeance of the moisture leaks is set to 1,9·10-6 $m^3/(m^2s \cdot Pa)$ [0,007 $m^3/(m^2h \cdot Pa)$] for envelope components installed according to best practice. Buildings with higher k_{CL} would represent malpractice. Building components that can handle the moisture loads due to air convection are well-designed. Those that fail under these circumstances should either be redesigned or special care must be taken during installation which may include continuous moisture monitoring.

3.3 Boundary conditions

For the exterior boundary conditions EN 15026 (2007) recommends either hourly meteorological data of ten consecutive years or moisture design reference years that represent the worst year out of ten years. Alternatively an average year may be taken and 2 K may be added or subtracted every hour in order to arrive at a severe warm or cold year. WTA 6-2 (2013) discourages the use of severe meteorological data for assessing the long-term performance of building components because in reality sequences of such years are extremely rare and their repeated application may predict component failure of well-proven systems. Therefore the use of severe data files should be confined to the simulation of one year, preferably after a sequence of average years.

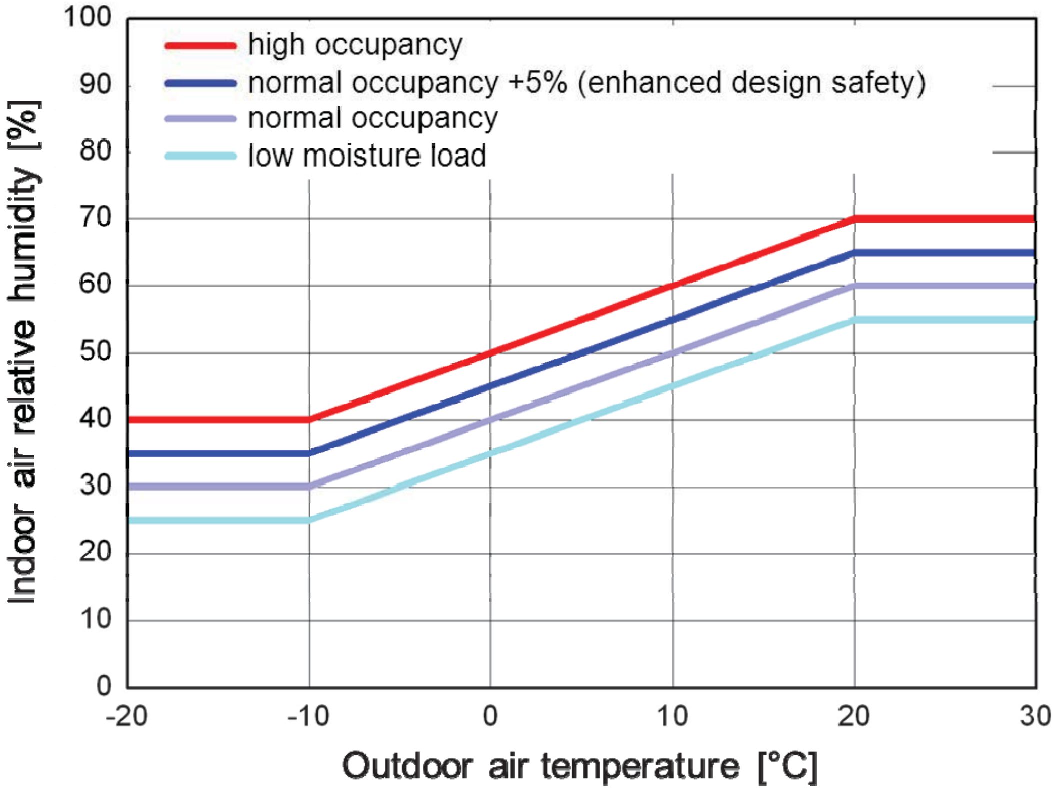

FIG 3. Chart to determine indoor RH from outdoor temperature according to WTA 6-2 (2013)

The recommended choices of indoor climate conditions are very similar in both documents. The widely used simplified method to determine indoor temperature and RH as function of outdoor temperature (Annex C in EN 15026) has been slightly refined (see FIG 3). The functions to determine the indoor temperature and humidity for normal and high occupancy are identical. Because the indoor boundary conditions for normal occupancy in WTA 6-2 guideline from 2002 resulted in somewhat higher indoor humidity levels than the current function in EN 15026, the new draft of this guideline also proposes an increment of 5% RH to enhance the design safety of buildings with normal occupancy. However, for standard design purposes, indoor RH calculations based on the graph for normal occupancy in EN 15026 are still considered appropriate.

Since the guideline is also applicable to retrofit design, the assumption of having indoor conditions as derived for normal occupancy may limit the choice of retrofit measures. Therefore, it may make sense to choose the correlation for a low moisture load with indoor RH being 5% lower than that for normal occupancy, if a low moisture load can be guaranteed by adapted ventilation or dehumidification. Also non-residential buildings may be well represented by this category. However, it must be realized that moisture control design based on low indoor humidity levels set strict limits to other building operation modes.

4. Conclusions

The consideration of imperfections of the building envelope and its moisture related consequences represents an important step to improve the prediction performance of hygrothermal simulation tools. Unintended moisture sources due to rainwater penetration or vapour convection have often been a cause of severe structural damage. Therefore it is essential to increase the safety of moisture control design especially for light-weight structures. The approaches laid down in the WTA guideline 6-2 help to assess the moisture tolerance of building components with respect to different construction details and climatic parameters. Moisture damage risks caused by inadequate drying potentials, e.g. due to vapour tight layers on both sides of the construction, will be discovered and measures to improve the assembly can be evaluated. Finally, the balance between wetting and drying can be determined more realistically when the effects of potential defects are included in the hygrothermal simulation model.

So far, the results of simulations that included the consideration of imperfections according to the new WTA guideline have been very encouraging, i.e. they confirmed practical experience. However, there is a great need to improve the moisture source models and to elaborate their input parameters. This necessitates the investigation of typical imperfections of different constructions by especially designed laboratory and field tests. One of the most important issues is to differentiate between unavoidable moisture sources and bad workmanship. If consensus can be achieved about the definition of best practice for different construction types, hygrothermal simulation will not only lead to safer design, it will also be possible to use simulation tools for building forensics. That means, if a construction has failed, the simulations may show whether the architect or the installer is to blame.

5. Acknowledgements

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