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Combined heat, air, moisture modelling: A look back, how, of help?

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ABSTRACT

Trials to model combined heat, air, moisture transfer in and through building assemblies started in the 1930-ties, when the first methodologies surfaced that coupled steady state vapour diffusion to steady state heat transport. Thanks to H. Glaser and his papers published end of the 1950-ties, that diffusion/conduction approach gained physical correctness. Some 13 years later, capillary suction was added as transport mechanism. At that time, computer software already helped solving models that linked transient heat transport to moisture transfer by diffusion and suction in composite assemblies. Later, air got included as carrier for heat and vapour while increased computer power allowed analyzing two- and three-dimensional geometries. After 2000, the turn from the assembly to the whole building level gained attention.

Although the theory looks well established and the computer software, actually available, quite complete, still it does not always help explaining and curing the damage cases, encountered in practice. As built complicates things and physics related pitfalls remain: simulations base on too simple drawings, inability to correctly include airflow, overlooking pressure and gravity driven water flow, uncertainty in material properties, difficulties to grasp the real initial and boundary conditions, the complexity of the envelope/building interactions, etc.

1. Introduction

Moisture causes many of the damages, noted in buildings. Mould, mildew, rot, frost, salt attack, corrosion, cracks, blisters and swelling, all link to wetness. Instead, airflow doesn't harm unless when acting as carrier for heat and moisture in and through building assemblies with often deplorable consequences. In fact, air in- and exfiltration, wind washing, indoor air washing and air looping, all may degrade thermal performance and moisture tolerance. Heat hangs in between as temperature changes force materials to expand and contract, a movement too often transposed into stress and strain with crack formation as possible consequence. Frost damage in turn requires both: highly humid materials and temperatures fluctuating from above to below 0 °C.

The aim of combined heat, air, moisture modelling now is to predict the changes in temperature and moisture content within building assemblies, the initial situation and varying boundary and ambient conditions induce. Additional objectives are quantifying related energy, durability, comfort and indoor air quality issues. In the early twentieth century, only testing allowed evaluation. Then, stepwise more complete physical approaches surged till from the nineteen seventies on the models and related computer tools became approximate enough to move prediction closer to reality. Today, softwares look so complete and nice that many practitioners believe they have the tools in hand to prevent and cure deficient heat, air, moisture responses of building assemblies, even whole buildings. Question of course is if that ambition complies with all experiences gained in practice. With the aim to critically assess the issue, the paper starts with a historical overview on how modelling evolved. Then the basics are refreshed, followed by a discussion on the facts, actual models still struggle with.

2. The history of heat, air, moisture modelling

2.1. Blaming vapour diffusion

The first attempts to better understand deficient moisture tolerance focused on heat and vapour transfer. According to Rose [1], interest in the USA surfaced by the mid 1930-ties, when insulating the cavities in timber-framed envelopes started and first reports about related outside sheathing paint peeling were

Abbreviations: CFD, computerized fluid dynamics; REV, representative elementary volume; NMR, nuclear magnetic resonance.

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published. As a result the belief grew that insulation drew moisture into the exterior layers and itself and thus, should not be used. Teesdale, who worked at the US Forest Laboratories, however defended its usage although he stated it played a major role in the problems encountered with condensation against the sheathing as main deficiency. The recommendations he made for walls included adding a vapour barrier at the warm side of the insulation and for attics, caring for ventilation [2]. The theoretical explanation looked simple: draw the temperature curve in the wall, situate the dew point indoors on the ordinate and see if a horizontal across cuts the temperature curve in the insulation. If so, expect condensation against the outside sheathing (Fig. 1).

Rogers [3] was the first to draw vapour pressure curves, their shape being defined by the vapour permeances of the materials used, though a comparison with the vapour saturation curve was not considered necessary (Fig. 2).

The one that joined both and definitely advanced diffusion through porous materials as ‘the theory’ was Rowley [4,5]. Attractive to the calculations was that diffusion resembled steady state heat conduction (Fig. 3).

Intersection meant condensation, presumably against the sheathing. As the condensate was deposited in the wall, the name ‘interstitial condensation’ looked logic. Rowley also advanced air convection as driving force for vapour transfer but did not explore the consequences and its impact on the amounts deposited.

After World War 2, Rowley's work found application in Europe [6,7]. Many practitioners however assumed condensate was deposited everywhere between both intersections with the vapour saturation line, giving birth to the conviction that in cold and temperate climates insulation definitely went wet in walls where the curves crossed. The vapour barrier at the warm side of the insulation had to be tight enough to eliminate intersection, a conviction giving rise to a vapour barrier phobia. Every assembly with some insulation layer included needed one. Nobody criticised the boundary conditions assumed, steady state which for dwellings, schools, offices, etc. unrealistic values: outdoors the design temperature for heating in combination with high relative humidity, indoors the comfort temperature and 60% relative humidity.

End of the 1950-ties, H. Glaser published four papers on interstitial condensation in cold store walls [8–11]. Because the intersection approach clearly negated conservation of mass, he forwarded the correct tangent solution, which was easily transposable into a graphic tool using vapour diffusion thickness as abscissa, see Fig. 4.

In the USA and Canada, the Glaser method went on being called “the dew point method” [12]. Although developed for cold stores

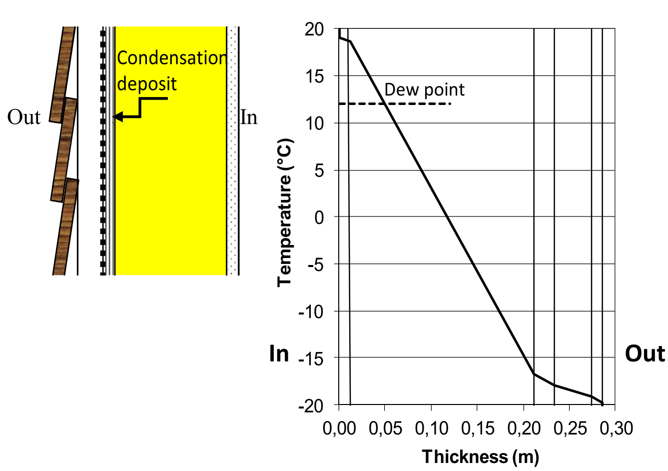

Fig. 1. Timber framed wall, dew point indoors/temperature curve combination [16].

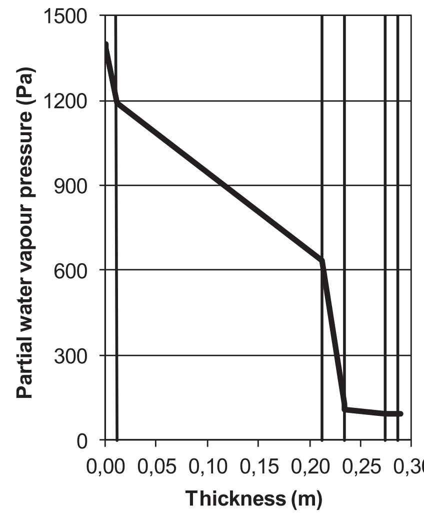

Fig. 2. Same wall as in Fig. 1, partial water vapour pressure curve in the wall [17].

where claddings and the insulation are hardly hygroscopic, where the ice, interstitial condensation forms, piles up without moving and where the ambient conditions are close to steady state, the method became popular as tool for evaluating the humidity response of building assemblies, overlooking the fact many building materials are hygroscopic and capillary. Take Karl Seiffert's book ‘Wasserdampf diffusion im Bauwesen’ (Water vapour diffusion in buildings) of 1967 [13]. In it, ambient conditions remain unrealistic, acceptability still sounds ‘interstitial condensation not allowed’ and vapour barriers go-on being ‘the only measure’. The advent of the indoor climate class concept, first introduced in the Netherlands [14], then in Belgium [15,16] and now part of the standard EN ISO 13788 [17] (Fig. 5) initiated the change. At the same time the twelve monthly means of a reference year replaced the fixed conditions outdoors (Fig. 6). That winter condensation alters with summer drying became obvious so, which refined acceptability to ‘no annually accumulating interstitial condensate and deposit in winter restricted to a material dependent maximum’. In a next upgrade a monthly mean equivalent temperature for condensation that accounted for solar gains, under-cooling and non-linearity between temperature and vapour saturation pressure replaced

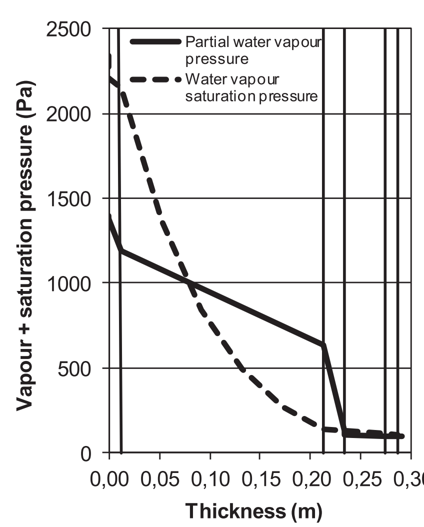

Fig. 3. Same wall as in Fig. 1, combining the partial water vapour curve with the vapour saturation curve, Intersection means interstitial condensation [18].