Modified Glaser's Condensation Model

T. Ficker, Z. Podešvová

Glaser's condensation scheme with incorporated non-isothermal diffusion is presented and its consequences are studied.

Keywords: non-isothermal diffusion, partial pressure profile, condensation in building structures, Glaser's condensation scheme.

1 Introduction

It is well-known that Glaser's model [1]–[7], a combined graphical and numerical method to assess the condensation of water vapor in building structures [8]–[9], suffers from some drawbacks which make the model rather debatable. For example, the model includes neither hygroscopic nor liquid transports and also omits the transition from the liquid into the solid phase. In addition, the numerical part of the model is based on isothermal diffusion. However, real building envelopes, especially in the winter season, are considerably non-isothermal. These inconsistencies raise the question: What will happen with the model if fully non-isothermal conditions are incorporated into its scheme. This paper aims to implement non-isothermal diffusion into Glaser's model and discusses some features of the modified scheme.

2 Non-isothermal steady-state diffusion

In our previous paper [10] we developed two basic models for describing non-isothermal steady-state diffusion of water vapor through porous building materials, namely the DIAL and DRAL models.

The DIAL model (Diffusion through an Immobilized Air Layer) led to the following basic relations (1)–(4) that hold for a non-isothermal structure (wall) of thickness d, which is embedded into an air environment. Dry air is supposed to have a constant concentration c_a on both sides of the wall. The wall shows, however, different temperatures T_1, T_2 and concentrations c_{1w}, c_{2w} of water vapour on its two sides (internal and external). The concentration profile $y^*(x)$ and diffusion flux q_w^*, expressed within the DIAL non-isothermal model, read

$$y^*(x) = \frac{c_w(x)}{c_w(x) + c_a}, \qquad c(x) = c_w(x) + c_a, \tag{1}$$

$$y_w^*(x) = \left\{ 1 - (1 - y_{1w}) \cdot \left[\frac{1 - y_{2w}}{1 - y_{1w}}\right]^{\frac{T_1^{0.19} - \left(T_1 - \frac{T_1 - T_2}{d} x\right)^{0.19}}{T_1^{0.19} - T_2^{0.19}}} \right\}, \tag{2}$$

$$y_{1w} = \frac{c_{1w}}{c_{1w} + c_a}, \quad y_{2w} = \frac{c_{2w}}{c_{2w} + c_a},$$

$$q_w^* = \frac{\ln\left[\frac{1 - y_{2w}}{1 - y_{1w}}\right]}{R_{\text{eff}}^*} \approx \frac{y_{1w} - y_{2w}}{R_{\text{eff}}^*}, \tag{3}$$

$$R_{\text{eff}}^* = \frac{d}{D_{\text{eff}}^*} \quad [\text{kg}^{-1} \cdot \text{m}^2 \cdot \text{s}],$$

$$D_{\text{eff}}^* = \frac{0.19\, k p_a}{\mu R_a} \cdot \frac{T_1 - T_2}{T_1^{2-n} - T_2^{2-n}} = \frac{5.629 \cdot 10^{-8}}{\mu} \cdot \frac{T_1 - T_2}{T_1^{0.19} - T_2^{0.19}} \quad [\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}]. \tag{4}$$

The symbols μ and R_{eff}^* are the diffusion resistance factor and diffusion resistance of the structure, respectively, while p_a stands for the pressure of dry air. More details concerning the derivation of (1)–(4) can be found in [10].

The DRAL model (Diffusion through a 'Rigid' Air Layer) is based [10] on the following relations

$$q_w = \frac{c_{1w} - c_{2w}}{R_{\text{eff}}} \quad [\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}],$$

$$R_{\text{eff}} = \frac{d}{D_{\text{eff}}} \quad [\text{m}^{-1} \cdot \text{s}], \tag{5}$$

$$D_{\text{eff}} = \frac{0.81 k (T_1 - T_2)}{\mu \left(T_2^{1-n} - T_1^{1-n}\right)} \quad [\text{m}^2 \cdot \text{s}^{-1}],$$

$$c_{1w} = \frac{p_{1w}}{R_w T_1} \quad [\text{kg} \cdot \text{m}^{-3}], \quad c_{2w} = \frac{p_{2w}}{R_w T_2} \quad [\text{kg} \cdot \text{m}^{-3}], \tag{6}$$

$$k = 8.9718 \cdot 10^{-10} \quad [\text{m}^2 \cdot \text{s}^{-1} \cdot \text{K}^{-1.81}],$$

where p_{1w}, p_{2w} are the partial pressures of water vapour on the two sides of the structure and $R_w = 462\ \text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ is the gas constant of water vapour. For more details see [10].

The computational part of Glaser's *standard* model is based on the isothermal approximation [10]

$$q_d = \frac{p_{1w} - p_{2w}}{R_d}, \quad R_d = \frac{\mu d}{\delta}, \quad \delta = 1.881 \cdot 10^{-10}\,\text{s}, \tag{7}$$

$$p(x) = p_{1w} - \frac{p_{1w} - p_{2w}}{d} x. \tag{8}$$

3 Glaser's condensation schemes

Glaser's graphical method [7] for finding the condensation region inside a building structure enables us to incorporate straightforwardly not only *isothermal diffusion* (coordinate system (R_d, p)), as initially introduced by Glaser (*standard* model), but also *non-isothermal diffusion* within the models of

Table 1: Condensation region according to Glaser's method

x [m]	T [K]	Glaser's standard model			DIAL model			DRAL model		
		$R_d \cdot 10^{-9}$ $[\mathrm{m \cdot s^{-1}}]$	p_w [Pa]	$p_w^{(\mathrm{satur.})}$ [Pa]	$R^*_{\mathrm{eff}} \cdot 10^{-4}$ $[\mathrm{kg \cdot m^{-1} \cdot s^{-1}}]$	$y_w \cdot 10^3$	$y_w^{(\mathrm{satur.})} \cdot 10^3$	$R_{\mathrm{eff}} \cdot 10^{-4}$ $[\mathrm{m^{-1} \cdot s}]$	$c_w \cdot 10^3$ $[\mathrm{kg \cdot m^{-3}}]$	$c_w^{(\mathrm{satur.})} \cdot 10^3$ $[\mathrm{kg \cdot m^{-3}}]$
0	293.15	0	1402	2337	0	9.108	15.09	0	10.35	17.25
0.0733	286.82	3.60	1186	1564	2.255	7.770	10.15	2.568	8.930	11.80
0.1467	280.48	7.20	969.8	1025	4.554	6.405	6.674	5.245	7.452	7.910
0.2200	274.15	10.81	753.6	657	6.892	5.018	4.288	8.029	5.915	5.187
0.2933	267.81	14.41	537.4	390	9.278	3.600	2.524	10.937	4.310	3.150
0.3667	261.48	18.01	321.2	224	11.706	2.156	1.466	13.967	2.637	1.850
0.4400	255.15	21.61	105	125	14.183	0.688	0.8187	17.133	0.895	1.060
		$\Delta q_{AB} = 4.21 \cdot 10^{-8}$ $[\mathrm{kg \cdot m^{-2} \cdot s^{-1}}]$ (from Fig. 1)			$\Delta q_{AB} = 4.4 \cdot 10^{-8}$ $[\mathrm{kg \cdot m^{-2} \cdot s^{-1}}]$ (from Fig. 2)			$\Delta q_{AB} = 3.5 \cdot 10^{-8}$ $[\mathrm{kg \cdot m^{-2} \cdot s^{-1}}]$ (from Fig. 3)		

DIAL (coordinate system $(R^*_{\mathrm{eff}}, y_w)$) and DRAL (coordinate system (R_{eff}, c_w)).

Let us have, for example, a building envelope realized by a plain brick wall (without plaster, $\mu = 9$) of thickness $d = 44$ cm. The wall separates a heated room of a usual environment (*surface* temperature and relative humidity: $T_1 = 293.15$ K, $\varphi_1 = 60$ % RH) from an outdoor space ($T_1 = 293.15$ K, $\varphi_1 = 60$ % RH). Table 1 and Figs. 1, 2, 3 show the results of Glaser's schemes based on isothermal and non-isothermal diffusions and applied to the structure given above. Since the structure is only 'weakly' non-isothermal ($T_1 - T_2 < 40$K), large differences in results cannot be expected (see the discussion in [10]).

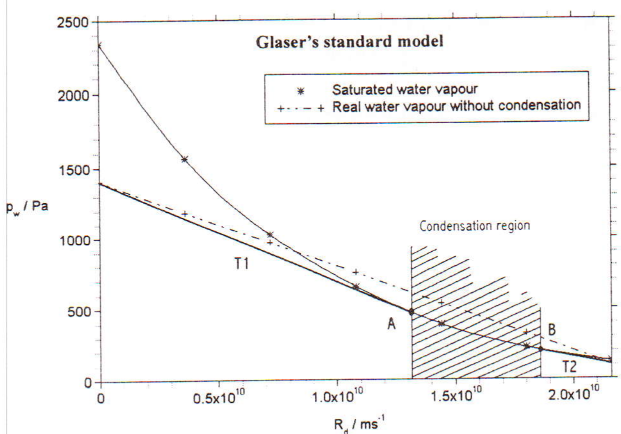

Fig. 1: Glaser's standard condensation scheme

The amount of condensate Δq_{AB} extracted from an area of 1 m² per second is calculated as the difference between the diffusion flux q_A entering the condensation region at point A (see Figs. 1, 2, 3) and leaving the region (q_B) at point B

$$\Delta q_{AB} = q_A - q_B \,. \tag{9}$$

The corresponding amounts of condensate Δq_{AB} (Table 1) determined by means of the three investigated models

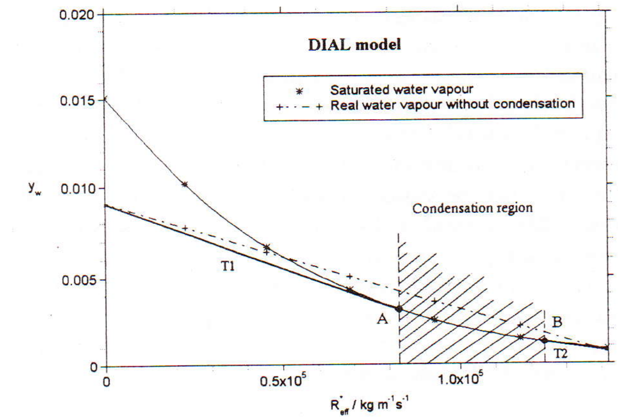

Fig. 2: Glaser's condensation scheme with DIAL approximation

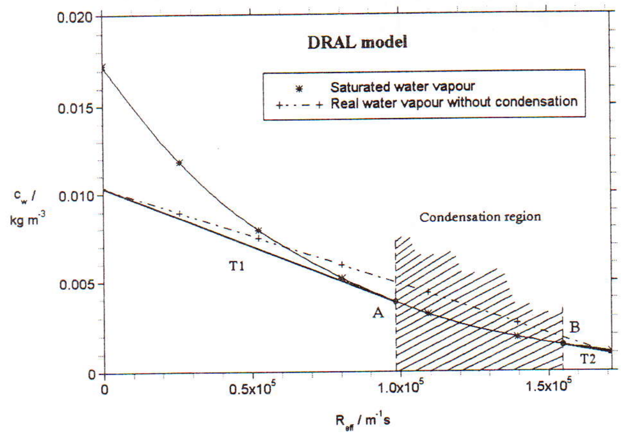

Fig. 3: Glaser's condensation scheme with DRAL approximation

(Glaser's *standard* model: $4.4 \cdot 10^{-8}$ $\mathrm{kg \cdot m^{-2} \cdot s^{-1}}$; DIAL: $4.21 \cdot 10^{-8}$ $\mathrm{kg \cdot m^{-2} \cdot s^{-1}}$; DRAL: $3.5 \cdot 10^{-8}$ $\mathrm{kg \cdot m^{-2} \cdot s^{-1}}$) show certain differences. The largest amount of condensate is yielded by Glaser's *standard* model, while the smallest amount of condensate is forecasted the DRAL model. As was mentioned earlier [10], the applicability of the DRAL model is restricted especially to materials possessing closed pores, which is not our case, so this result does not represent a relevant condensation prognosis. On the other hand, the DIAL model has been developed [10] especially for building materials having mutually interconnected open pores. Thus only the comparison between the standard and DIAL values is meaningful. This comparison shows that the standard value ($4.4 \cdot 10^{-8}$ $kg \cdot m^{-2} \cdot s^{-1}$) is larger than that of the DIAL model ($4.21 \cdot 10^{-8}$ $kg \cdot m^{-2} \cdot s^{-1}$) by about four percent, which is a negligibly small difference in this field. Nevertheless, in extreme climatic regions ($T_1 - T_2 > 40$ K) the difference may be significantly larger [10], and in such cases the DIAL model will yield a more realistic prognosis as compared with the standard model, which overestimates the amount of condensate occurring in building structures. However, thanks to the ability to overestimate the condensate, Glaser's standard model yields prognoses that are on the 'safe side', though not always on the 'economical side'.

4 Conclusion

It has been illustrated that Glaser's standard condensation model can be modified to include fully non-isothermal calculations of water condensate appearing in building structures. Such calculations do not lead to very different results in normal Central European climatic regions ($\Delta T < 40$ K). However, in extreme climatic regions ($\Delta T > 40$ K) essential differences can be expected and in such events the DIAL model offers a good tool for a more realistic assessment of condensation problems. In conclusion, it should be stressed that Glaser's standard condensation scheme provides an assessment that is on the safe side, but especially in extreme non-isothermal cases it will not lead to an economically optimal design of building structures.

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Assoc. Prof. RNDr. Tomáš Ficker, DrSc.
phone: + 420 541 147 661
e-mail: fyfic@fce.vutbr.cz

Department of Physics

Ing. Zdenka Podešvová

Department of Building Structures

University of Technology
Faculty of Civil Engineering
Žižkova 17
662 37 Brno, Czech Republic