DEVELOPMENT OF INDOOR CLIMATE CLASSES TO ASSESS HUMIDITY IN DWELLINGS

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ABSTRACT

The knowledge of indoor air humidity in the design phase is important to decide on the appropriate moisture control measures to prevent moisture problems in building components. Because of the uncertain nature of most of the factors affecting the indoor humidity, its accurate prediction in the design phase is not possible. To overcome this problem, the concept of 'Indoor Climate Classes' has been introduced and used in Europe since its early development in the Netherlands in the 1970's up to its recent introduction in a European Standard on the hygrothermal performance of building components. The concept allows to make a rough quantification of the indoor humidity on the basis of building type and function in order to evaluate the moisture performance of building components in the design phase. The first part of the paper gives an introduction to the concept of indoor climate classes and reviews the methodologies to define the boundaries between different classes. The second part of the paper presents a model to predict the transient indoor humidity, based on a physical analysis of the mass balance of an enclosure (vapor production, ventilation and moisture storage in building materials). The model is applied to discuss the different factors affecting the humidity in a room and to guide the classification of humidity in dwellings.

KEYWORDS

Indoor climate class, indoor humidity, vapor supply, moisture storage, physical analysis.

INTRODUCTION

The indoor humidity in a room is usually evaluated by means of a steady-state moisture balance for the indoor air, while the storage of moisture at building component surfaces and in the air volume is neglected:

$$p_i = p_e + G_v \frac{R_v T_i}{nV} \qquad (1)$$

where p_i and p_e are the partial water vapor pressures of the indoor and outside air (Pa), G_v is the vapor production in the room (kg/h), R_v is the gas constant for water vapor (462 J/kg/K), T_i is the indoor air temperature (K), n is the ventilation rate (ach/h) and V is the room volume (m^3).

According to Eqn. 1 there is a constant vapor pressure difference (also called vapor supply or excess) between inside and outside, while the variables in the second term on the right hand side are constant. Since in many building types, for instance in dwellings, the vapor production and ventilation rate strongly depend on occupants' behavior and fluctuate in time and space, it is difficult to give an accurate estimate of the indoor humidity. Nevertheless this information is crucial to design a building such that moisture problems are prevented. One way to overcome this problem of uncertainty has been to introduce highly conservative values for indoor humidity. For instance the German standard DIN 4108 on moisture protection has followed this approach by proposing a design value of 960 Pa for the vapor supply during winter, regardless of building function or design (DIN 1981).

INDOOR CLIMATE CLASSES

Physical approach

A second, more differentiated way to quantify the indoor humidity is offered by the concept of ‘Indoor Climate Classes’ (ICC), introduced in moisture control guidelines in the Netherlands and Belgium in the 1970’s (Tammes and Vos 1980, Hens 1982). Depending on the building type and function the indoor climate is assigned to one of four classes, defining the design value for the yearly mean indoor vapor pressure in the building (Table 1). The limits between the classes were based on an analysis of interstitial condensation by vapor diffusion in certain benchmark constructions (Hens 1992). For design purposes, these ‘theoretical’ classes were then assigned to building types and functions by comparison with measured data in different types of buildings. The lowest climate class (ICC 1) represents indoor climates where physically no interstitial condensation by diffusion is possible. The limit between ICC 1 and 2 coincides with the maximum indoor humidity before condensation starts in a north-facing metallic wall under mean January conditions. The upper climate class (ICC 4) represents climates where serious problems of yearly accumulating condensate in the envelope are unavoidable if no adequate vapor retarder systems are applied. The limit between ICC 3 and 4 coincides with the maximum yearly mean indoor humidity before there is a net accumulation of condensate over a year within a flat membrane roof subjected to solar radiation. The definition of the limit between ICC 2 and 3 is similar, but for the case of a north-facing metallic wall (sun-protected).

The physical definition of indoor climate classes has also been adopted for general moisture performance assessment methods within the framework of the International Energy Agency (Sanders 1996). Sanders produced contour maps of the limiting values between climate classes based on data from 93 meteorological stations in Europe and North America. As an example Figure 1 shows the contour map for the limits between ICC 2 and 3 in Europe. The figure clearly illustrates that the limits between the ICC’s resulting from this approach are not constant, but depend on the outside climate conditions. In regions with higher temperatures and more solar radiation, a higher indoor humidity and vapor supply may be allowed before problems of interstitial condensation develop in the benchmark constructions.

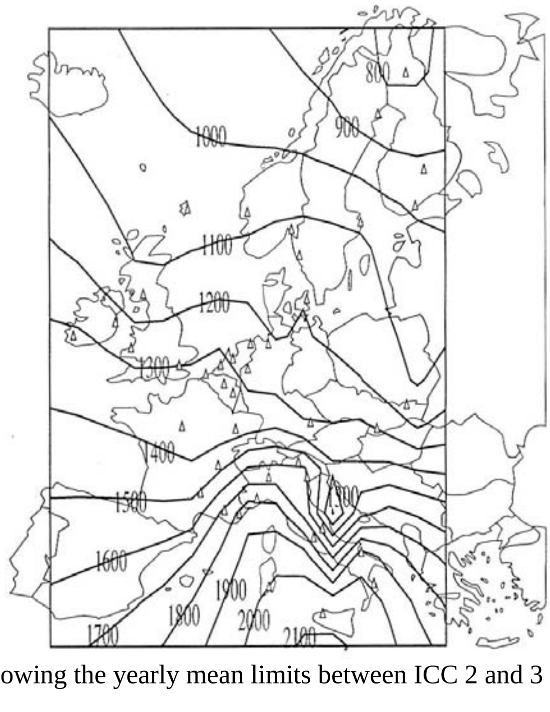

Figure 1: Contour Map showing the yearly mean limits between ICC 2 and 3 in Europe (Sanders 1996)

TABLE 1: Limits between indoor climate classes (yearly mean values)

ICC	Holland: Tammes-Vos (1980)		Belgium: Hens (1982)		BUILDING TYPE
	p_i	p_i-p_e	p_i	p_i-p_e	
1	< 1080 Pa	< 50 Pa	< 1165 Pa	< 65 Pa	storage, workshop, sports hall
2	< 1320 Pa	< 290 Pa	< 1370 Pa	< 270 Pa	large dwelling, office, shop
3	< 1430 Pa	< 400 Pa	< 1500 Pa	< 400 Pa	small dwelling, flat, school
4	> 1430 Pa	> 400 Pa	> 1500 Pa	> 400 Pa	swimming pool, laundry

Consequently the limiting values between the classes increase from Scandinavia to the Mediterranean. This is also the way these maps are to be used: as a tool to assess the risk for interstitial condensation by comparing the values on the map with the actual indoor humidity in buildings. The maps however contain no information on the statistical reality of indoor humidity in different regions. This is one of the disadvantages of the classification of indoor climates according to the physical approach: not in all climates the ‘theoretical’ classes may be as easily linked to building functions as in the original Dutch and Belgian scheme.

Statistical approach

The ICC-concept has also been used to assess other moisture problems related to indoor humidity, such as surface condensation, mould growth and interstitial condensation by air leakage. However for these purposes, a classification on the basis of short-term values of the indoor vapor supply is needed. A typical approach is to represent the boundaries between ICC’s as a function between the vapor supply in the building and the outside temperature. This allows for instance to classify existing indoor climates using short-term measurements of internal and external climate, or to select a proper value for the indoor humidity to assess the risk for surface condensation on window framing during a cold winter day.

The generation of a functional relation between the vapor supply in a building and the outside temperature has been based on a statistical analysis of measuring data. In Holland, Van der Kooi (1973) produced minimum and maximum limits for the vapor supply in dwellings, based on half-day mean measuring data of indoor and outdoor humidity and temperature. In Belgium, Hens (1992) performed a linear regression on a dataset of 355 weekly mean values of indoor vapor supply in dwellings as a function of outdoor temperature. This way three linear functions were derived from the median, and the 5- and 95-percentiles of the linear regression, to distinguish between four statistical indoor climate classes (Table 2). An advantage of this approach is that existing moisture problems may be remedied by comparing the actual measured vapor supply to the statistical mean and extremes: thus it is easily established whether the indoor humidity is higher than normal and a possible cause for moisture problems. As Figure 2 shows, both authors found that the vapor supply is not constant over a year, but a clearly decreasing function of outside temperature. The reason for this behavior is told to be inhabitants’ behavior: in warm weather there is more intensive venting (open windows) and a smaller vapor production inside (more outdoor activities).

TABLE 2: Variation of indoor climate classes with external temperature

ICC	Hens 1992 (355 weekly mean data, $r^2 = 0.25$)		CEN 2001	
	Limit p_i-p_e (Pa)	Description	Limit p_i-p_e (Pa)	Description
1	$< 159-10*\theta_e$	5% of dwellings	$< 270-13.5*\theta_e$	Storage areas
2	$< 436-22*\theta_e$	50% of dwelling s	$< 540-27.0*\theta_e$	Office, shops
3	$< 713-22*\theta_e$	95% of dwellings	$< 810-40.5*\theta_e$	Dwellings with low occupancy
4	$> 713-22*\theta_e$	5% of dwellings more humid	$< 1080-54*\theta_e$	Dwellings with high occupancy
5	-	-	$> 1080-54*\theta_e$	Special buildings

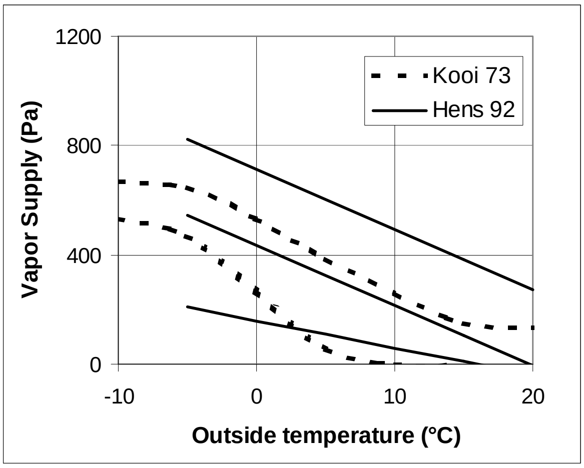

Figure 2: Variation of measured vapor supply in dwellings with external temperature

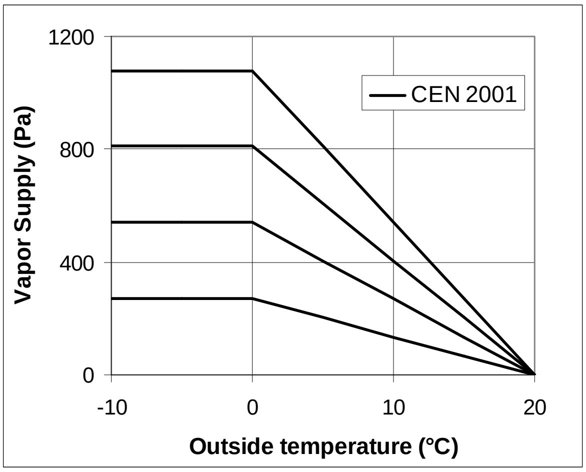

Figure 3: Variation of indoor climate classes with external temperature according to CEN (2001)

Recently, the concept of ICC has also been introduced in an informative Annex to the European Standard EN ISO 13788 on hygrothermal performance (CEN 2001). As Figure 3 and Table 2 show, the CEN-classification (5 classes) and the assessment of indoor humidity in dwellings differs substantially from those reported by Van der Kooi and Hens (4 classes). First, in the European Standard the vapor supply in dwellings is generally assessed to be higher than established in the Dutch and Belgian measurements. There is also disagreement on the trend of the evolution of indoor vapor supply with external temperature. In the CEN-graph, the vapor supply is constant at temperatures lower than 0°C and becomes zero at temperatures above 20°C for all classes. In the data by Hens on the other hand no platform was found at low temperatures, and a positive vapor supply was measured during warm weather in the more humid dwellings. Nevertheless, the knowledge of the indoor moisture load at both extremes is important for a proper assessment of moisture risks and drying potential of building components. Finally, there is the question of the validity of an ICC-classification independent of outside climate, as the publication of a single ICC-chart in a European standard suggests.

In order to guide the classification of indoor climate it is important to investigate what is the correct physical response of indoor humidity in transient conditions. Therefore the remainder of the paper discusses a model to predict the transient indoor humidity, based on a physical analysis of the mass balance of the indoor air and the vapor transport and storage from the air into the envelope. The model is applied to a single room to discuss the factors affecting the transient vapor supply in a building.

TRANSIENT NUMERICAL ANALYSIS

Model

Eqn. 2 describes the non-steady-state moisture balance for the indoor air in a room. Compared to Eqn. 1, the right hand side of Eqn. 2 also contains the terms describing the vapor storage in the air, and the convective vapor transfer from the air to the interior surfaces of the enclosure walls.

$$G_v + \frac{nV}{R_v T_i}(p_e - p_i) = 3600\left[\frac{V}{R_v T_i}\frac{dp_i}{dt} + \sum_j A_j \beta_i (p_i - p_{s,j})\right] \qquad (2)$$

In addition to the symbols explained under Eqn. 1, A_j is the area of the interior surface of wall j (m²), β_i is the convective surface film coefficient for vapor transfer (s/m) and $p_{s,j}$ is the vapor pressure at the interior surface of wall j (Pa). This latter variable couples the enclosure moisture balance to the moisture conservation equations of the walls surrounding the enclosure. Eqn. 3 describes the 1D-transfer and storage of water vapor in a wall with porous building materials:

$$\frac{\partial}{\partial x}\left[\delta(\varphi)\frac{\partial p}{\partial x}\right] = \rho\xi(\varphi)\frac{\partial \varphi}{\partial t} \tag{3}$$

where δ is the vapor permeability (s), φ is the relative humidity (-) and $\rho\xi$ is the moisture capacity in terms of relative humidity, derived from the material sorption isotherm (kg/m^3). Vapor transfer and storage properties are typically a function of ambient humidity.

The coupled set of Eqn. 2 and 3, may be solved numerically. A control volume formulation is used for discretization in space and a fully implicit scheme for discretization in time.

Application

The model is applied to a single bedroom with a volume of 40 m^3 (4mx4mx2.5m), occupied in between 9 pm and 8 am by two persons with a total vapor production of 0.14 kg/h. The envelope parts that exchange water vapor with the room air, have a total area of 52 m², and consist of brick material finished with a gypsum plaster (2 cm thick). Only half of the brick material (7 cm thick) is taken into account in the analysis, and is supposed to face an adiabatic and vapor tight boundary. The material properties for gypsum and brick are taken from Kumaran (1996). The yearly course of external boundary conditions is described in a climatic file with hourly averaged data for temperature and relative humidity. The interior temperature is supposed to be a constant 18°C, except when the exterior temperature exceeds 15°C: in this case the interior is modeled to be 3°C warmer than the exterior.

In order to show the influence of vapor production, ventilation rate, moisture capacity and exterior climate on indoor humidity, the analysis is performed for 5 different cases, with different values for these parameters (see Table 3). While the first four simulations are done for the mild and humid climate in Belgium, case 5 is for the continental East-Canadian climate with a cold and dry winter. In case 4, the standard value for convective vapor transfer at the interior surface is reduced to simulate the presence of a vapor retarding paint on the gypsum surface (μd = 0.5m). In all cases the ventilation rate is supposed to be constant in time. The interior humidity is predicted for a 3-year period, while only the results of the last year are used to produce the Figures 4 and 5, and the linear regression listed in Table 3.

From the simulation results, the following observations are made:

- The predicted vapor supplies are in the same range as the values measured by Hens and Van der Kooi (Figure 2). This suggests that humidity in dwellings is overestimated in the CEN-classification, except at higher temperatures (> 10°C), when it is underestimated.
- Even though the ventilation rate is constant in time and no inhabitants' behavior is modeled, the vapor supply is higher in winter and smaller in summer. The difference between summer and winter is significantly smaller when the ventilation rate is doubled (case 2) and when vapor transfer to the interior surface of the walls is retarded (case 4).
- The vapor supply demonstrates hysteresis over a year: in autumn the inside-outside vapor pressure difference is larger than in spring, although exterior conditions are similar. The monthly mean vapor supply in autumn may be over 300 Pa larger than in spring.

TABLE 3: Input variables and results of the numerical analysis

Case	Climate	G_p (kg/s)	n (ach/h)	β_i (s/m)	Linear fit $\Delta p(\theta_e)$ (52 weekly mean data)	r^2
1	Ukkel (B)	4E-5	0.5	18.5E-9	p_i-p_e = 574 –12.7*θ_e	0.38
2	Ukkel (B)	4E-5	1.0	18.5E-9	p_i-p_e = 270 –4.7*θ_e	0.16
3	Ukkel (B)	2E-5	0.5	18.5E-9	p_i-p_e = 315 –9.2*θ_e	0.27
4	Ukkel (B)	4E-5	0.5	0.4E-9	p_i-p_e = 543 –9.7*θ_e	0.73
5	Ottawa (Ca)	4E-5	0.5	18.5E-9	p_i-p_e = 466 –3.1*θ_e	0.11

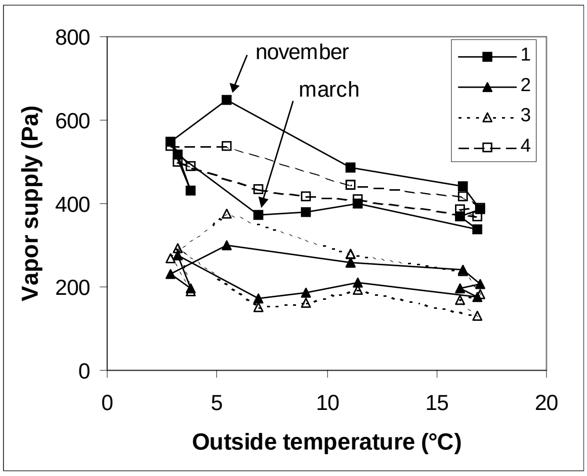

Figure 4: Variation of predicted vapor supply in bedroom with external temperature (monthly mean)

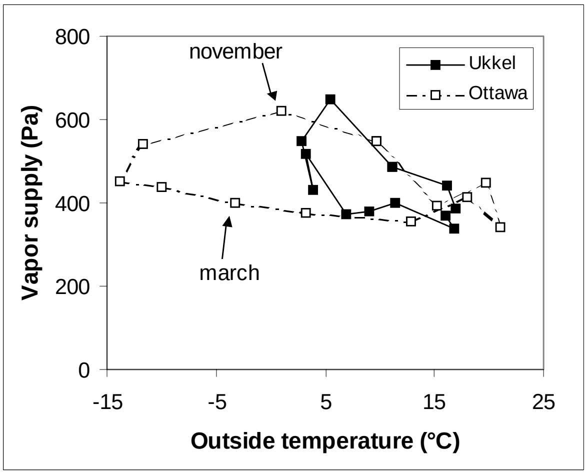

Figure 5: Variation of predicted vapor supply with external temperature for two different climates

- The transfer and storage of moisture from the air into the walls may explain both effects. During the first cold and dry months of autumn, the walls release the vapor stored during summer into the interior, hence increasing the vapor supply. After winter, the opposite takes place: the walls have dried and may absorb moisture from the air, when exterior temperature and humidity rise. The practical consequence of this is that moisture capacity may be an important factor to assess interior humidity: in interiors in contact with a large surface of porous materials, the vapor supply in winter may be higher.
- The similarity of the predicted vapor supply for two different climates (Figure 5) suggests that it may be possible to develop a generally valid classification of indoor humidity in a $\Delta p(\theta_e)$-chart independent of climate type. The trend of the evolution of the vapor supply with external temperature will be established from simulations for more climates, using an additional model to simulate air infiltration and window opening.

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