THERMOHYGROMETRICAL ANALYSIS OF RESIDENTIAL BUILDINGS IN UNSTEADY -STATE CONDITIONS

C. ISETTI
Dipartimento di Energetica
Monte Luco di Rojo, I-87100 L'Aquila, Italy

E. NANNEI and G. TANDA
Dipartimento di Ingegneria Energetica
Via All'Opera Pia 15a, I-16145 Genova, Italy

1. Introduction

The occurrence of surface condensation and mould growth is at present more widespread in both new and existing buildings owing to the unbalanced introduction of energy conservation measures. These phenomena, which affect the building quality, are mainly related either to changes in human behaviour with regard to energy use (less ventilation, lower inside temperature), or to an unsatisfactory arrangement of insulation layers in the building. Air change reduction and/or lower inside temperatures cause an increase in the interior air humidity with a negative impact on the inside hygrometrical conditions.

An increased thermal insulation of the walls is usually thought to have a positive impact since it causes higher inside temperatures. This, however, is true only in steady-state conditions, while it may not be so when changes in the outside air temperature and solar radiation are considered. Therefore a correct analysis of the problem should take into account not only the mean temperature value but also the actual temperature variation occurring on the interior surface of the external wall. Such a temperature variation depends on the outside climate and on the thermophysical properties of both the external walls and the internal structures.

The aim of this paper is to analyze the hygrometrical behaviour of residential buildings in unsteady-state conditions, in order to evaluate the risk of the condensation. The model predictions are discussed in relation to a set of in situ observations.

2. Analysis of the problem

The occurrence of condensation in a room is depending upon the time-temperature variations of the interior surfaces of the peripheral walls. Such temperature variations can be calculated by solving Fourier's heat conduction equation in periodic unsteady state conditions (1,2). The lowest value of the surface temperature, reached during the

24 hours, is considered to be the dew point temperature in order to evaluate the corresponding saturation concentration c_o of the vapour in the inside air. When inside actual vapour concentration c_i is lower than c_o, no condensation can definitely occur on the surface.

The inside vapour concentration, in the absence of condensation and vapour absorption-desorption phenomena, can be derived from the following hygrometrical balance:

$$\frac{1}{n}\cdot\frac{d\,c_i(t)}{d\,t} + c_i(t) - c_e = \frac{G(t)}{n\cdot V} \qquad (1)$$

where:

$c_i(t)$	vapour concentration in the ambient	(g/m^3)
$G(t)$	vapour production	(g/h)
n	air renewals	(1/h)
c_e	external vapour concentration	(g/m^3)
V	volume	(m^3)
t	time	(h)

By assuming n and c_e constant and supposing vapour production as a step function of time so defined: $G(t) = G$ in the presence of vapour sources and $G(t) = 0$ in their absence, equation (1) can be easily solved. The analytical solution shows an exponential growth of $c_i(t)$ which exceeds 90% of the asymptotic value ($c_e + G/nV$) when the vapour sources have been working for a period longer than 2.3/n. The latter condition being verified in practical cases, a "safe choice" is to take into account a maximum c_i value defined as follows:

$$\max\left\{c_i(t)\right\} = c_e + \frac{G}{n\cdot V} \qquad (2)$$

Since c_o is the vapour concentration at which surface condensation occurs, such a phenomenon is surely avoided if $\max\left|c_i(t)\right| < c_o$ and then $G/V < n\cdot(c_o - c_e)$.

When $G/V \geq n\cdot(c_o - c_e)$ surface condensation is possible.

The function $F = n\cdot(c_o - c_e)$, known from analytical calculations, divides the plane (n , G/V) into two zones, as shown in fig. 1: zone (a), unpredicted surface condensation ($G/V < F$), and zone (b), predicted surface condensation ($G/V \geq F$).

If the air renewal n and the moisture production per unit volume G/V are known for the ambient considered, the corrispondent point clearly shows the risk of surface condensation on the walls.

Under the assumptions considered, it can be noted that this method will be "safe" because it tends to overextimate maximum inside vapour concentration $c_i(t)$ given by equation (2). In fact such a value can be reached if moisture production is continuously fully operating or when, for limited time productions, moisture absorption-desorption processes by the surfaces facing the ambient are negligible (3).

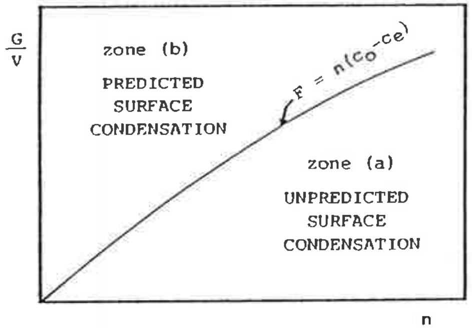


Fig.1 Zones of predicted and unpredicted surface condensation in relation to the calculated function F.

3. Results and discussion

A first series of calculations were made concerning a room (V = 37.8 m^3) with two external walls having the following characteristics:

- South-oriented external wall surface = 7.6 m^2 and window = 1.8 m^2 (window thermal transmittance = 6 W/m^2K)
- East-oriented external wall surface = 10.8 m^2 .

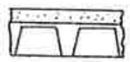
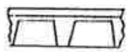
The internal structures' surfaces are the following:

- Internal partition walls = 18 m^2
- Ceiling (and floor) = 14 m^2

Two cases were studied: one with external and interior walls having high effective thermal capacity (case A) and the other with peripheral and internal walls having low thermal inertia characteristics (case B). All the thermophysical properties of the structures are given in Table 1.

Calculations were made for the climatology of an "average day" in the month of April for Genoa (44°24' lat. N.) considering c_e = 7.5 g/m^3 constant during the day (4). The "average day" is defined as a refer-

Table 1. Thermophysical properties of the materials considered in the calculation (case A and B).

DESCRIPTION	MATERIAL	THICKNESS (m)	THERMAL CONDUCTIVITY (W/mK)	THERMAL DIFFUSIVITY $(m^2/s)\times 10^7$
External walls				
outside  inside, CASE "A"	mineral wool	0.06	0.034	13.6
	concrete	0.14	2.	9.9
	gypsum panel	0.006	0.21	2.2
outside  inside, CASE "B"	concrete	0.14	2.	9.9
	mineral wool	0.06	0.034	13.6
	gypsum panel	0.006	0.21	2.2
Internal Structures				
CASE "A" 	concrete	0.08	2.	9.9
CASE "B" 	gypsum panel	0.013	0.21	2.2
	air gap	0.04	-	-
	gypsum panel	0.013	0.21	2.2
Floor  CASE "A" Ceiling	concrete	0.04	2.	9.9
	brick	0.12	0.58	4.2
Floor  CASE "B" Ceiling	moquette	0.01	0.045	4.2
	brick	0.12	0.58	4.2

ence day characterized by the hourly values of air temperature, air humidity, solar radiation and wind velocity averaged over the last twenty years (4). Outside and inside surface conductances of the peripheral walls are assumed respectively 23 and 8 W/m^2K, while, for the interior structures, surface conductance is considered equal to 5 W/m^2K. All peripheral walls are characterized by a solar absorptance equal to 0.8.

A few calculations were made for both cases A and B, varying the air renewal n in order to find the function $F = n \cdot (c_o - c_e)$. Results show in each case a quite small difference between the F function calculated for S and E oriented walls, therefore, in Fig. 2 only one F function for case A (curve A) and one for case B (curve B) are reported. As can be seen, curve B allows a smaller vapour production per unit volume owing to a lower effective heat capacity than that of case A.

As previously described, in order to estimate condensation risks, curves A and B have to be compared with moisture production G/V occurring in the room, taking into account the air renewal n. Such a value, for infiltrations due to natural ventilation, may be estimated in relation to different types of window and door frames and the wind velocity, according to the criteria provided by DIN specifications (5).

Results are shown in fig. 3, supposing $G/V = 2.25\ g/m^3h$. It is interesting to note that for metal frames with wind-shielded exposures (n = 0.2) there is a risk of condensation on the interior surfaces of walls in both the situations represented by cases A and B. For $n \geq 0.45$ (wooden frames) condensation is not predicted in either case. Finally, for n = 0.35 (metal frames, exposed site) condensation is predicted only in case B.

This simple example shows that the study of surface condensation requires an analysis in unsteady state conditions, especially for ambients bounded by low inertia structures. For said ambients, temperature variations in the 24 hours may cause considerable decreases in the limit value of vapour concentration c_o and thus favouring the occurrence of surface condensation.

This method has subsequently been applied to different dwelling rooms existing in the Ligurian area in order to verify the reliability of its predictions. The initial results of a research under way within the Piano Finalizzato Energetica-2 have been used, concerning building deteriorations of hygrometrical origin (6).

The results considered refer to a sample of 35 cases, with different exposures, construction characteristics and internal hygrometrical loads. For all the cases examined the air renewal n was evaluated by the DIN specifications (5). The vapour production per person was assumed to be equal to 50 g/h. The function $F = n \cdot (c_o - c_e)$ was evaluated analytically by means of a computer program on the basis of the walls' thermophysical and dimensional properties and by assuming air temperature, solar radiation and outside concentration c_e corresponding to the "average day" in the month of April (4). Such a month has been considered as a reference since it appears the most critical one for condensation in the Ligurian area, as shown in (3).

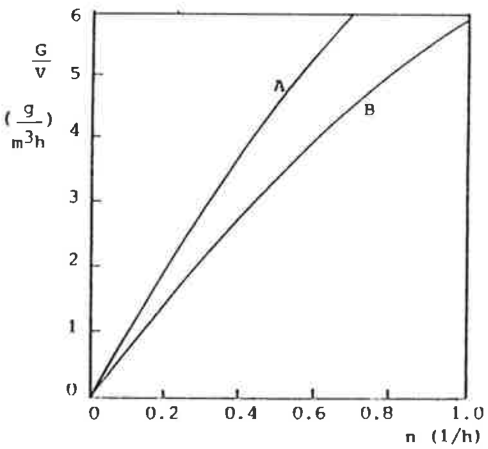


Fig. 2 Influence of high (A) and low (B) effective thermal capacity of both internal and external walls on calculated function F.

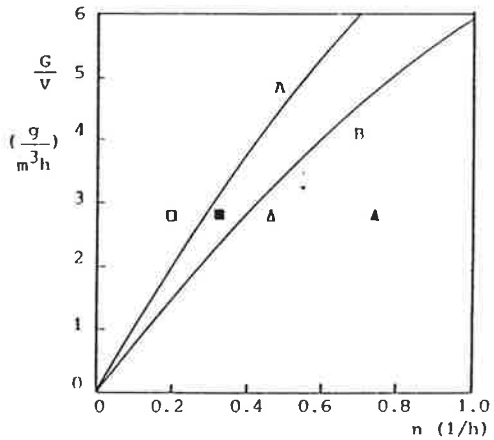


Fig. 3 Occurrence of condensation for different air renewals:

n=0.2, □ window with metal frames, wind velocity < 4 m/s
n=0.35, ■ " " " " wind velocity = 4÷6 m/s
n=0.45, Δ window with wooden frames, wind velocity < 4 m/s
n=0.75, ▲ " " " " wind velocity = 4÷6 m/s

Figure 4 shows the percentage of cases in agreement over all cases examined. It can be seen that this method, though relatively simple, allows correct predictions in 77% of the cases.

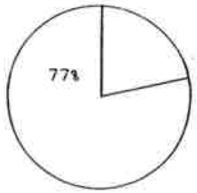


Fig. 4

Percentage of predicted cases in agreement with the results reported in (6).

Out of the 27 cases in agreement, 13 were referable to absence of damage while 14 showed clear signs of deterioration. Out of the 8 cases in disagreement, condensation was expected in 6 cases but no deterioration actually appeared. The occurrence of damages was predicted in 20 cases, but deterioration eventually occurred only in 14 cases.

The predictions of damage related to surface condensation obtained from the presented method are shown to be in a good statistical agreement with a first set of in situ observations.

4. Conclusions

The following conclusions have been reached:

- Thermal storage characteristics of both external and internal walls affect the vapour production allowed within the ambient: a thermohygrometrical analysis in steady-state conditions may be not reliable when buildings have a low effective heat capacity.

- The predictions of the theoretical model are shown statistically to agree to a large extent with a set of observations made in residential buildings.

- Further research is carried out at present through more in situ inspections.

5. References

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