RISK OF INDOOR CONDENSATION RELATED TO THERMAL INSULATION STANDARDS

L Ponterio[&], G Rizzo[#], G Rodonò[#] and G Scaccianoce[#]
[&] Dipartimento di Ingegneria Meccanica
Università di Roma, "Tor Vergata", Roma 00133, Italy
e-mail: ponterio@uniroma2.it

[#] Dipartimento di Energetica ed Applicazioni di Fisica
Università di Palermo, Palermo 90128, Italy
fax: + 39 091 484425
e-mail: gfrizzo@ unipa.it.

ABSTRACT Condensation phenomena on internal surfaces of buildings are becoming recurrent eventualities in contemporary buildings, particularly in residential buildings. Despite the general belief, this accumulation of water on walls is not mainly due to mass migration from outdoor to indoor, but to a modification of behavioural approaches of people, especially referring to the preferred air temperature. In addition to new lifestyles of people, air changes established in buildings are strongly affected by new thermal insulation standards that call for more insulated and sealed buildings and, consequently, for less heat loss by ventilation. Both these causes generate a tendency to an increase in the air vapour concentration inside buildings: this turns into a rise of dew point temperature and, finally, in the risk of condensation on colder indoor surfaces of the envelope.

1 Introduction

In order to achieve sustainable paths in the use of energy, the building sector is world wide involved in a remarkable process of setting and adopting new technical standards, mainly focused on the improvement of the envelope thermal characteristics. This is supposed to induce a reduction in the call for fossil energy resources and, in turn, a decreasing in pollutant and greenhouse gases released in the atmosphere, allowing countries to meet huge international commitments in order to achieve a sustainable development.

The reduction of the overall transmittance of buildings does modify the thermal behaviour of confined environments, generally inducing benefits to occupants. Unfortunately, sometimes unwanted consequences are also noticed that affect the indoor quality of buildings.

One of the most frequent problems, in this sense, is the presence of condensed water vapour on internal surfaces. This could bring uncomfortable conditions to people, often frustrating thermal and environmental benefits that the insulation of wall should generate.

A significant part of the recent Italian building stock, for example, especially working class houses, is today affected by indoor moisture problems that, among other things, are caused by several contentious judgements. Despite the general thinking about the cause of these condensation phenomena (that is a lacking design or a faulty construction of dwellings), the key point of the problem should be found on the modified thermal characteristics of buildings along with the improved life style standards of people.

2 Energy saving standards and new lifestyles of people

Through this decade numerous standards devoted to energy saving in buildings have been released world wide. In Italy, for example, a national law has been passed in 1991 (GURI, 1991) that, among several prescriptions aimed at the assessment of the whole Italian energy plan, introduced remarkable constraints both in the thermal characteristics of buildings and in the energy demand for building climatisation. The related ministry regulations (GURI, 1993) essentially define a new parameter, the so-called FEN (Fattore Energetico Normalizzato, that is *Normalised Energy Demand*), for the evaluation of thermal performances of buildings.

It represents the total amount of primary energy required through the heating season (kJ/m^3 DD) for maintaining a suitable value of the indoor air temperature (say, 20°C) and assuring a given value of air changes, depending on the climatic condition of the site. The FEN, as it is defined within the Italian legislation (similarly to other thermal parameters world wide established), depends, among other things, on the transmission and ventilation properties of buildings. That is:

$$FEN = f(C_d, ach) \tag{1}$$

Where C_d is the specific overall volume transmittance of the envelope and *ach* is air changes per hour, that can be also expressed as the ventilation rate. Q_v (L/s) realised by ventilation (natural and mechanical) and air infiltration. The term C_d can be also referred to parameters that are typical of the energy estimating methods (ASHRAE, 1989*a*), that is:

$$C_d = \frac{BLC}{V_.} \tag{2}$$

where V is the volume (m^3) of the building and BLC is the building loss coefficient (W/K), that is the sum of all U-value and area products for the walls, ceilings, ground and doors (the 'envelope conductance') plus the heat transfer rate due to air change rates (the 'ventilation conductance') at standard conditions.

The main goal of these regulations is to achieve a smaller overall heat transmittance usually obtained by means of more insulated walls and more airtight windows. This indirectly generates a rise in the indoor air temperature and a reduction in the air changes per hour. Moreover, in recent years, the national building stock has shown a wider adoption of heating systems than before: this has induced people to prefer higher indoor air temperatures.

As a result of these causes, simultaneously acting on the thermal behaviour of buildings, a rise in the air temperature and in indoor relative humidity is at the same time achieved. This generates a rise of the dew point temperature on the internal surfaces and, consequently, a remarkable increase of indoor condensation risks. This is actually the true cause of the increase in complaints of people due to condensation phenomena on the internal surfaces of buildings. A simple example will easily demonstrate this occurrence. The time evolution of thermal and hygrometric conditions within a confined environment, starting from typical situations of temperature, humidity, occupation and water vapour production, has been analysed.

The room considered has a volume of 47 m^3; an air temperature of 21°C and a relative humidity of 50%. It is occupied by six people, that is typical of a living room when the family is at home. A water vapour production of 50 g/h per person has been considered, assuming a moderate activity metabolic rate (BS 5250,1975). The time dependence of the indoor air dew point has been calculated both with and without air ventilating equipment: in this last case, an extraction of 50% of the water vapour generated has been assumed.

Table 1 presents calculation results for both the examined cases, in terms of humidity ratio and dew point temperature of the room air. For the computation of dew point temperature a literature algorithm has been employed (ASHRAE 1977), while for finding the dependence of saturated vapour pressure on air temperature a non linear regression from data reported in the thermodynamics tables (ASHRAE 1989*a*) has been produced, by means of a Gauss Newton method.

Table 1 Time evolution of humidity ratio and dew point temperature for the example room

elapsed time (hours)	Humidity ratio ($g_{vapour}/kg_{of\ dry\ air}$) with ventilation equipment	Humidity ratio ($g_{vapour}/kg_{of\ dry\ air}$) without ventilation equipment	Dew point temperature (°C) with ventilation equipment	Dew point temperature (°C) without ventilation equipment
start 0.0	7.54	7.54	9.76	9.76
0.5	8.85	10.17	12.14	14.23
1.0	10.17	12.80	14.23	17.77
1.5	11.48	15.43	16.09	20.72
2.0	12.80	saturation	17.77	
2.5	14.12	saturation	19.31	
3.0	15.43	saturation	20.72	

Fig.1 graphically illustrates the same results for the dew point behaviour, T_d.

Some conclusions can be drawn from this example. First of all the tendency toward a rapid achievement of saturation conditions is obviously accelerated when a ventilation equipment is not present in the room: that is the way with which living rooms are operated during the hours of the family staying at home.

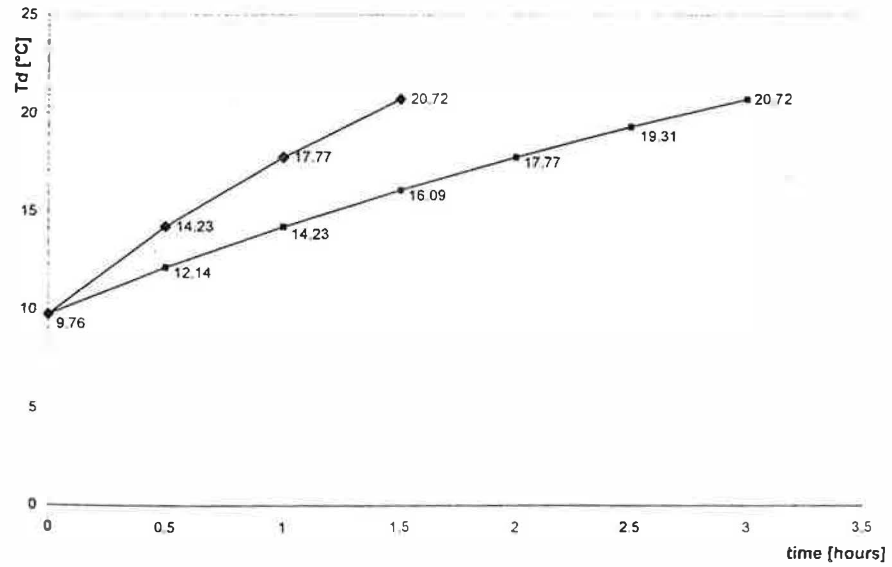

Fig.1 Evolution of the dew point temperature for the proposed example

It must also be pointed out that the saturation of the room in terms of vapour content will be faster if the starting relative humidity conditions are higher than those here assumed (ϕ = 50%). These very high values of dew point temperature indicate a noticeable risk of vapour condensation in the room, since it is quite plausible that such temperatures would be reached on some of the internal surfaces of the building envelope.

The above-described considerations call, on one hand, for corrective interventions in the ventilating management of buildings and, on the other hand, for a more accurate thermal design of the envelope. In fact, as it has been previously pointed out, suitable air changes, obtained by means of correct ventilation characteristics, can partially avoid the accumulation of water vapour indoors and, consequently, the rise of the dew point temperature. However, due to the changed behaviour of people (higher indoor temperatures preferred, mainly), a modification of the design practice is also required, with special regard to the overall thermal transmittance of the envelope.

A low value of the wall thermal transmittance, as imposed by new energy saving standards, determines in fact, during the heating season, a lesser amount of heat flow toward the outside; this causes a rising of the indoor temperature that, in turn, facilitates the accumulation of water vapour in the moist air produced by internal sources (people and household activities); the combination of higher temperatures and higher humidity content leads to higher dew point temperatures and, finally, toward bigger condensation risks.

This means that a compromise should be found between the need for energy saving (thermally sealed buildings) and the condensation risks (more ventilation allowed and lower indoor temperatures). In other words, considering heat losses of a building as a summation of the contributions through the walls and through the air changes (ventilation and windows air leakage), a low overall heat loss should be achieved by means a suitable balance: the reduction of heat losses by air changes should be limited.

It must also be pointed out that the importance of suitable ventilation in buildings is a fundamental requisite in order to bring healthy and comfortable conditions to people, as explicitly suggested by international standards (ASHRAE 1989*b*; EEC 1992). This last consideration should definitely induce designers to carefully consider the performance of a building showing too low air change values.

3 A design approach

Starting from the above-described analysis, it's easy to suggest a design approach more conscious of the hygrometric characteristics of a building. Considering in fact equation 1, suitable limits can be assessed for air changes by ventilation and infiltration (*ach*) and for the specific envelope thermal transmittance (C_d).

3.1 Building ventilation requirements

Air changes able to effectively mix indoor and outdoor air, in order to avoid saturation problems and condensation phenomena, can be easily established referring to the above cited requirements for acceptable indoor air quality (EEC, 1992). Adopting ventilation rates suggested by the European standard proposal for people's comfort and health purposes, we can assume:

$$Q_v = 10 \cdot \frac{G}{C_i - C_o} \cdot \frac{1}{\varepsilon_v} \qquad (3)$$

where G is the indoor pollution load, C_i and C_o are respectively the perceived quality levels of indoor and outdoor air and ε_v is the ventilation effectiveness.

Air changes computed by means of equation (3) are generally higher than those indicated by equation (1), Q_v can be adopted as a suitable parameter for avoiding dangerous increase of indoor humidity.

3.2 Envelope heat transmittance requirements

In addition to the aim of energy saving, the thermal characteristics of a wall can be designed keeping in mind also the condensation risk. This means that the heat transmittance should be constrained to a limit value that could avoid the condensation of water vapour on the internal surface of a wall. Such a limit is reached when the temperature of the internal surface of the building envelope equals the dew point temperature referring to indoor air conditions.

A simple design algorithm can be than derived that expresses the overall wall transmittance, U, as a function of indoor (t_i) and outdoor (t_o) air temperatures and of the indoor surface coefficient (h_i). That is:

$$U < h_i \frac{t_i - t_d}{t_i - t_o} \tag{4}$$

where t_d is the dew point temperature for indoor air at temperature t_i and relative humidity φ_i. This enables the computation of a suitable value of the thermal resistance R of the wall.

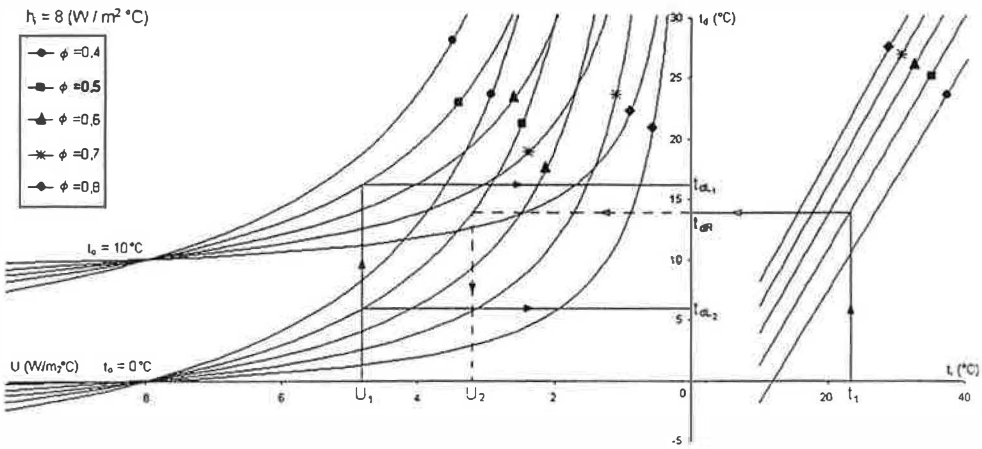

Fig.2 U values and condensation risks as a function of indoor air conditions

If s_j and λ_j are the thickness and the thermal conductivity of each layer of the given wall and h_o the outside surface coefficient, we can write:

$$R = \sum_j^n \frac{s_j}{\lambda_j} \qquad \text{and} \qquad U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o} + R}$$

Fig.2 graphically depicts the usefulness of equation 4, for the case of h_i=8 (W/m^{2}K) that is typical of building environment conditions. One can enter the graph with the assigned air temperature (for example, the desired temperature coming from analyses of thermal comfort); depending on relative air humidity, the suitable value of the overall thermal transmittance of the wall will be easily provided.

However, other uses of the graph can also be suggested, since design values of wall transmittance usually come from energy saving standards while design indoor temperature can be derived from thermal comfort standards. So, starting from assigned values of the wall transmittance U_1 and of the relative humidity φ_i, the corresponding indoor surface temperature, t_{dL}, can be found on the left side of the graph; moreover, from the preferred indoor temperature t_1 and the same previous value of relative humidity, the corresponding dew point temperature, t_{dR}, can be found on the right side of the graph. Should be $t_{dL} < t_{dR}$, a condensation phenomenon will occur on the wall, that can be avoided by decreasing the transmittance at the value U_2.It is also important to note that the value of outside temperature greatly affects the occurrence of condensation for a given wall transmittance (see Fig.2).

4 Conclusions

The role played by new energy saving standards and by new lifestyles of people in worsening the risk of condensation phenomena on indoor surfaces of building envelope has been pointed out.

An algorithm and a simple graph have been introduced that enable the evaluation of condensation risk for given indoor and outdoor air temperatures and for an assigned indoor surface coefficient.

It has been finally established that a more correct design procedure should take into account not only energy saving and people's thermal comfort requirements, but it also should refer these needs to the actual thermodynamics conditions of indoor air, with particular attention to the reaching of dew point temperature on an internal surface of the envelope.

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