Risk Assessment of Surface Condensation in Residential Buildings

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The incidence of the phenomenon

- The surface condensation, preceded by mould, still present not only in insufficient insulated buildings, but also in buildings with high insulation level (new or rehabilitated), affects not only the appearance and the quality of finishing works, but also the comfort conditions and the occupants' health.
- The most vulnerable areas:
  - – glazing areas;
  - – areas of thermal bridges.

The appearance and development of mould on the surface of thermal bridges

The condensation risk

- ## Definition of risk

" an uncertain but possible element which appears permanently in the process of technical, human, social, political events, reflecting variations in the distribution of possible results and the probability of occurrence, having detrimental and irreversible possible effects. "

Surface condensation in residential buildings is suitable for an approach through the concept of *"risk management",* having in view the multitude of factors involved and the interaction between them.

The risk management

- The management of uncertain event in order to reduce the adverse effects and to ensure the success.
  - ✓ Identification and quantification of risk factors;
  - ✓ Assessment of response to the risk factors;
  - ✓ Optimization strategy of response to risk factors and the development of combat measures.

Identification and assessment of risk factors

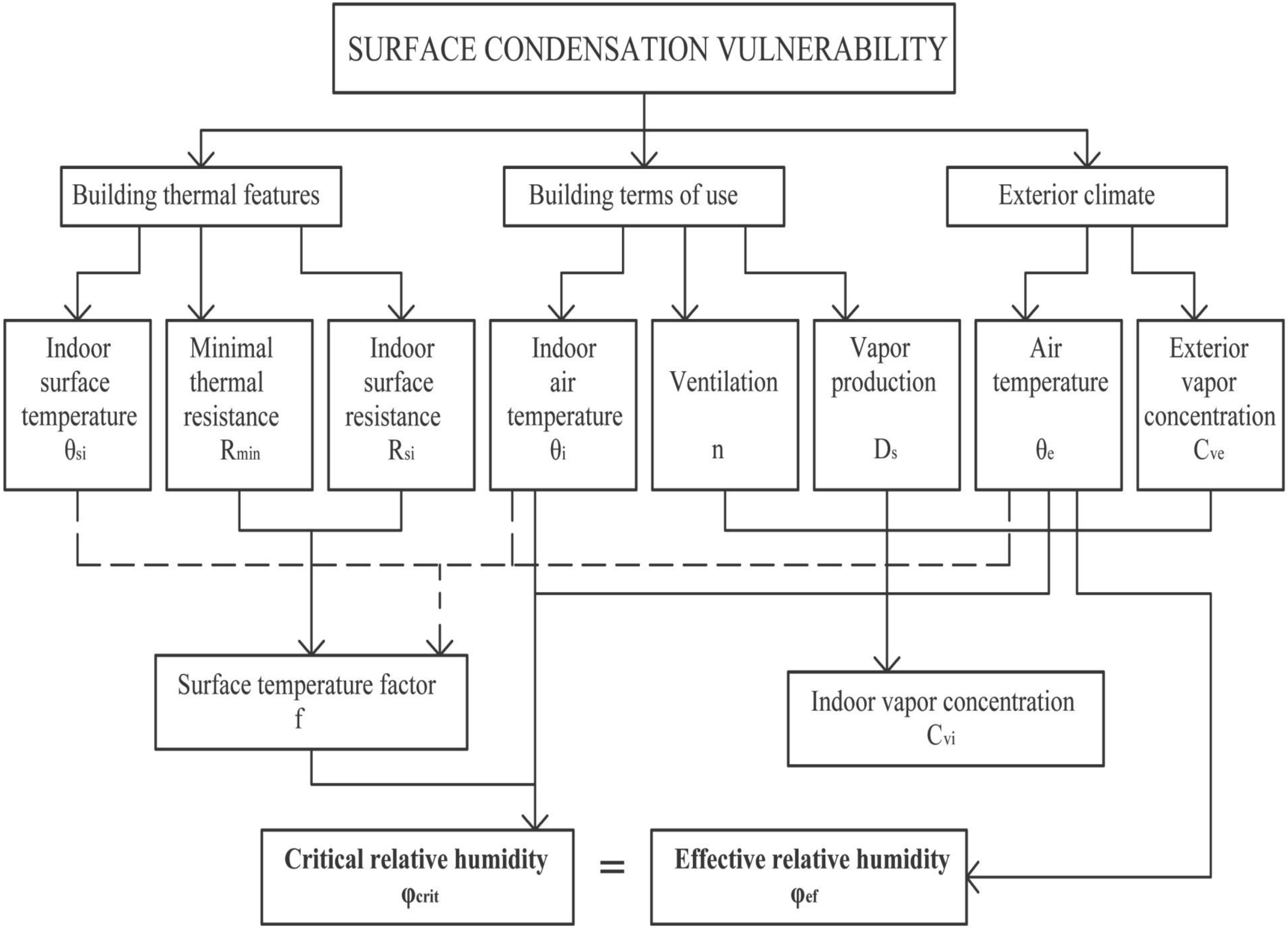
The condition to avoid the surface condensation risk is that the value of minimum surface temperature (θ_{si}) does not descend below the dew point temperature, θ_r.

$$\theta_{si, min} > \theta_r$$

or

interior relative humidity φ_i does not exceed the critical value φ_{crit}:

$$\varphi_{i,ef} < \varphi_{crit}$$



Factors that determine the vulnerability to surface condensation

Occupants' behavior

determines the concentration of vapour in air, by default the value of interior relative humidity

$$C_{vi} = C_{ve} + D_{sv} / n V$$

where:

- C_{vi} , C_{ve} is the water vapour concentration in the interior/exterior air, in g/ kg or kg/kg;
- D_{sv} is the flow rate of the vapour sources expressed in g/h sau kg/h, depending on the activity type;
- n is the ventilation rate, in air exchanges/hour in (h^{-1});
- V is the net volume in the analyzed space/room in m^3.

Effective value of relative humidity φ_{ef}

- Depends on the values of following parameters:
  - flow rate of vapor sources determined by occupancy degree and activity nature;
  - ventilation rate;
  - interior air temperature

$$\varphi_{ef} = (C_{vi}/C_{vs})100$$

- C_{vi} – effective concentration of water vapour in the indoor air at a specific temperature;
- C_{vs} – the maximum concentration of water vapour that air could hold at that temperature.

Parametric analysis with experience factorial plan method

- The plan factorial technique means to assess the influence of different parameters (or variables) on a given phenomenon, characterized by the values of some function, called response function.

Steps:

- identification of variable parameters and their range of variation;
- formulation of the response function;
- elaboration of experience factorial plan for combinations of minimum and maximum values of the variable parameters;
- determining the value of response function for the combinations from the factorial plan, by calculation or experimentally;
- establishing coefficients which highlighted the influence/impact of each variable parameter and the interaction between them, on the response function;
- analysis of the influence/impact of each parameter and their interaction on the response function.

Defining and limiting variation range of variable parameters

Parameter	Designation	Minimum value: −1	Maximum value: +1
flow rate of the vapur sources – D_{sv}	X_1	60 g/h	180 g/h
the ventilation rate– n	X_2	$0.25h^{-1}$	1.00 h−1
Indoor air temperature– θ_i	X_3	+18°C	+22°C

Encoded variables, combinations and values of response functions

No.	Flow rate of the vapour sources – D_{sv}	Ventilation rate- n	Indoor air temperature- θ_i	Water vapour concen-tration in the interior air C_{vi} (g/ kg)	Saturation concentration $C_{vs,i}$ (g/ kg)	The effective relative humidity φ_{ef}, (%)
	X_1	X_2	X_3			Y
1	-1	-1	-1	5.82	12.9	45.11
2	+1	-1	-1	15.78		122.00 (100)
3	-1	+1	-1	2.16		16.8
4	+1	+1	-1	4.13		32.00
5	-1	-1	+1	5.82	16.6	35.00
6	+1	-1	+1	15.78		95.00
7	-1	+1	+1	2.16		13.01
8	+1	+1	+1	4.13		25.00

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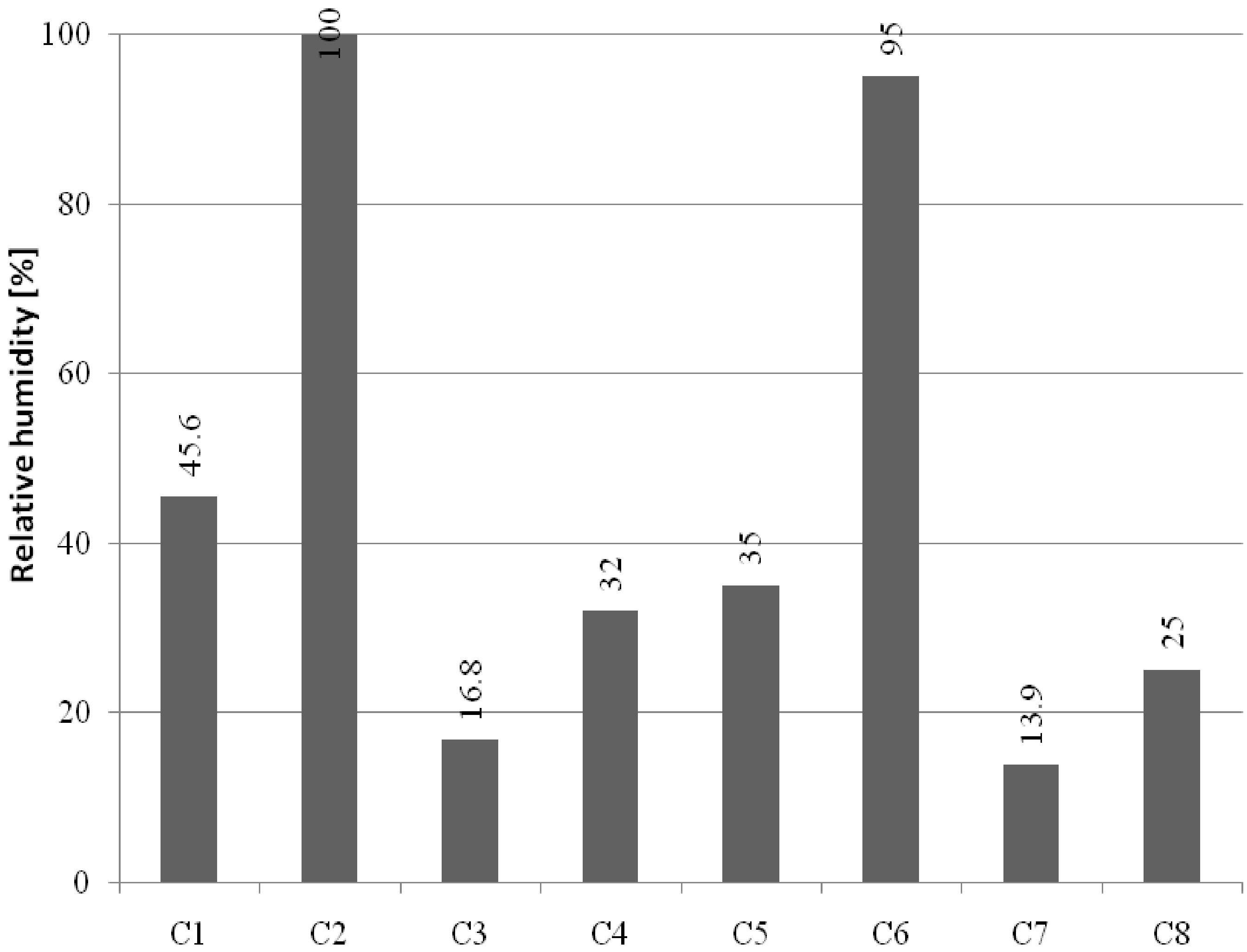


Relative humidity of indoor air for various combinations of values of variable parameters

Results analysis

Analyzing the obtained data, it can be noticed that

- the highest values of response function Y, which integrates the influence of all variable parameters were obtained for combination/ scenario 2, characterized by maximum values of vapor production and minimum values for ventilation rate and indoor air temperature.

The impact of each factor on the value of the response function

Influence of *i* parameter:

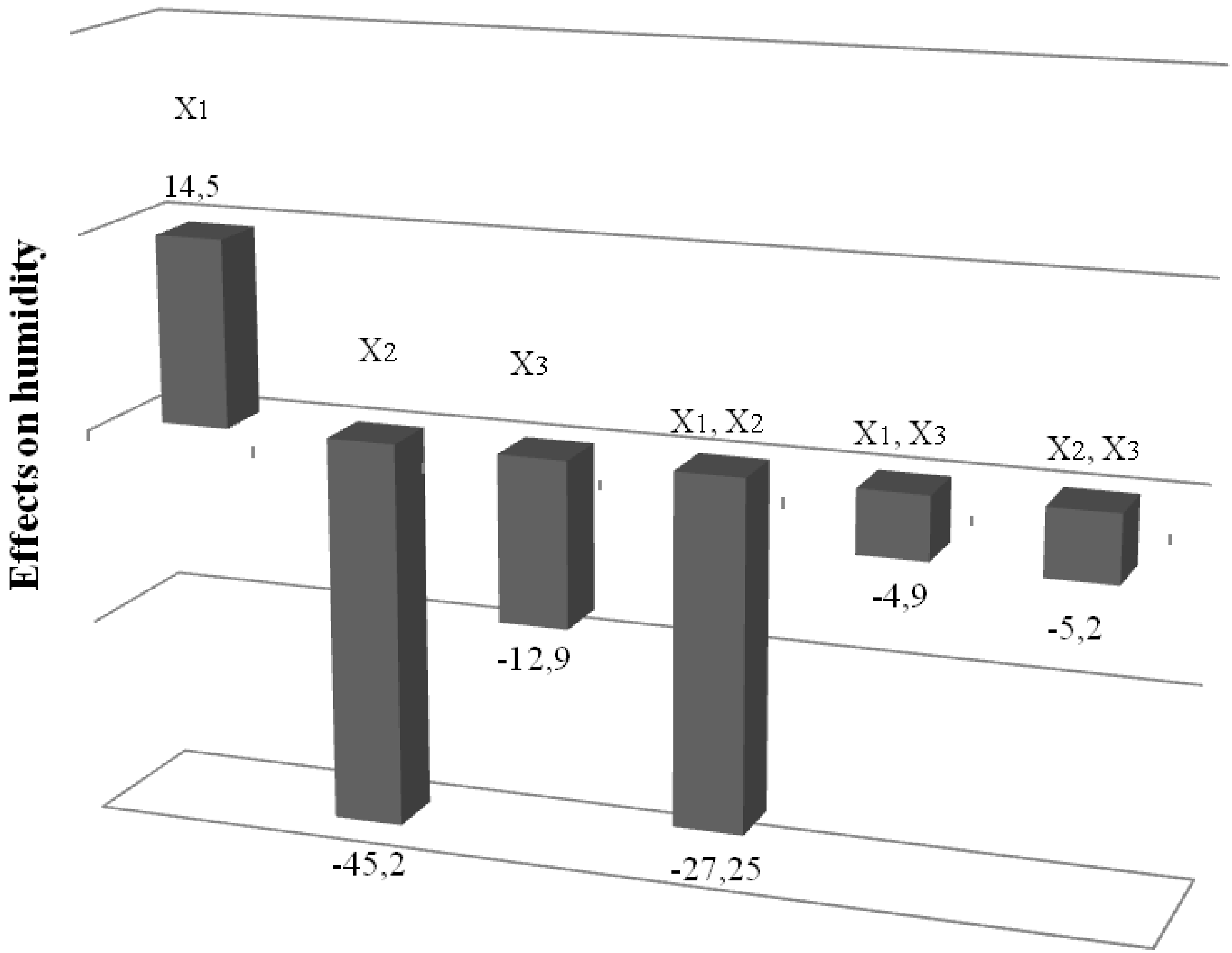
$$C_i = Y_{m+} - Y_{m-}$$

- Y_{m+} – the average of responses obtained when the variables X_i are at the maximum value (level +1)
- Y_{m-} – mean value of the response function obtained when the variables have the minimum value (level –1).

The impact of each factor on the value of the response function

- The influence of the simultaneous variation of the two parameters is measured by the difference between the average effect of the first parameter and the average effect of the second (for exemple C1,2).

- $c(1,2) = \left(\frac{y4 - y3 + y8 - y7}{4} - \frac{y2 - y1 + y6 - y5}{4}\right)/2$



The effect of each parameters and interactions

- The maximum negative impact on the response function has the ventilation rate.
- Comparably, the minimum ventilation rate, simultaneously with the maximum flow vapor sources.

Assessment of response to risk factors

At the proposal of the International Energy Agency (IEA), it was introduced a criterion that can be expressed by values of some parameters characteristic of thermal bridges, thermal resistance in the field, R, and for the thermal bridge area, R_{min}.
This is the surface temperature factor, f_{Rsi} defined by the equation:

$$fR_{si} = \frac{\theta si - \theta e}{\theta i - \theta e} = \frac{R - Rsi}{R}$$

where:
θ_e - the temperature of the exterior air;
θ_i - the temperature of the interior air;
θ_{si} - the temperature on the inside surface;
R - the thermal resistance of current field;
R_{si} - the thermal resistance at the indoor surface of the element.

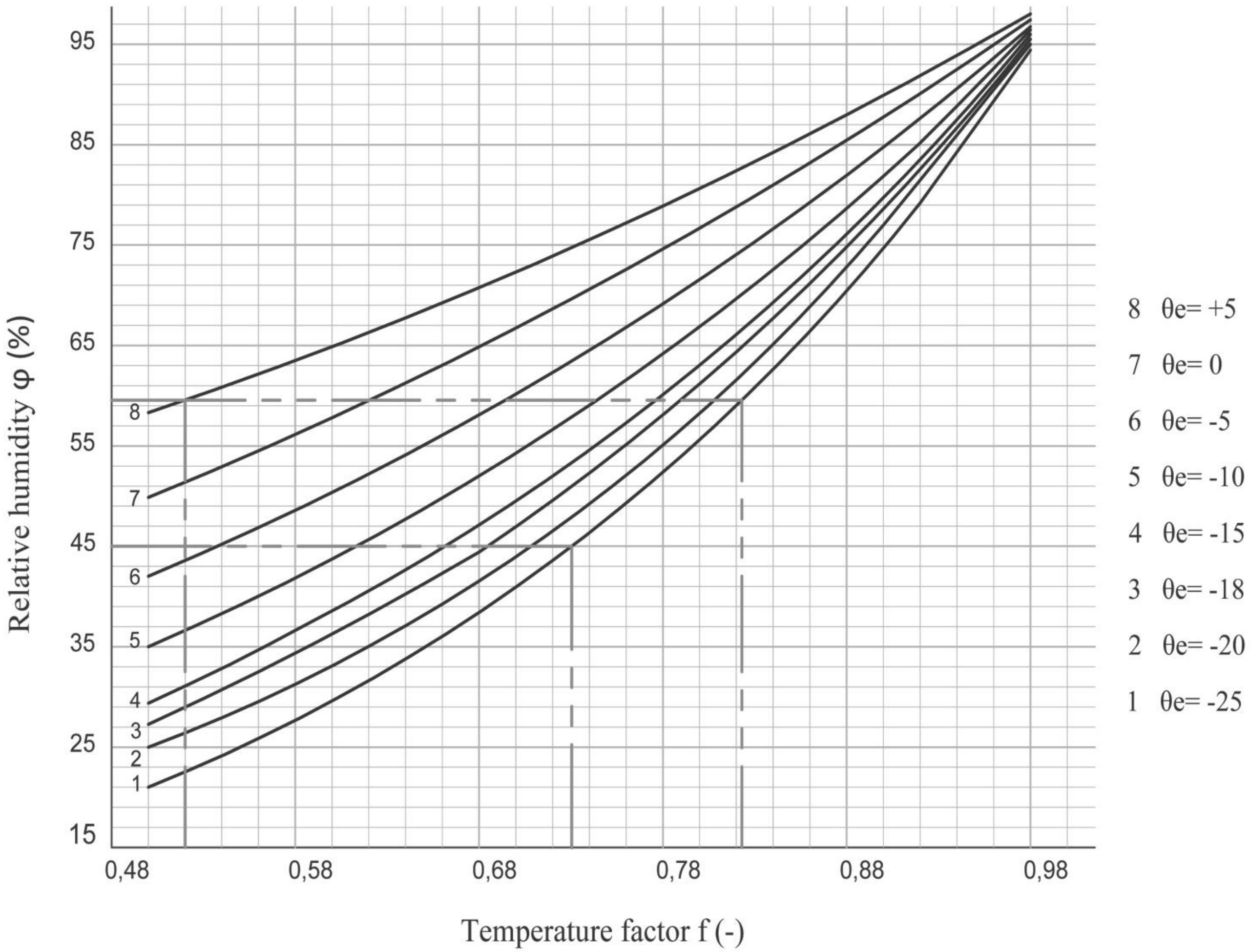
Critical value of interior relative humidity

On the basis of the temperature factor and the parameters mentioned, it may be set the critical value of the interior relative humidity which points the risk of condensation, φ_{crit} :

$$\varphi_{crit} = \left(\frac{109{,}8 + f(\theta_i - \theta_e) + \theta_e}{109.8 + \theta_i} \right)^{8.02} 100\%$$

And for mould risk:

$$\varphi_{crit,\ mould} = 0.8 \left(\frac{109{,}8 + f(\theta_i - \theta_e) + \theta_e}{109.8 + \theta_i} \right)^{8.02} 100\%$$



Risk of surface condensation for different values of relative humidity, temperature factor and exterior temperature

The risk of condensation for existing buildings or in design stage

The risk condensation for different scenarios of using and exterior temperature values:

- for low values of the relative interior humidity φ_i = 45%, areas with f_{Rsi} = 0.55, for an exterior temperature of θ_e = −5°C become vulnerable, but for f_{Rsi} = 0.70, condensation may appear only for an exterior temperature lower than θ_e = −25°C.
- for values of the relative humidity higher than φ_i = 60%, on areas with f_{Rsi} = 0.50 condensation may appear at an exterior temperature of θ_e =+5°C, and for f_{Rsi} = 0.82 at θ_e =−25°C .

Allowable minimum values of the temperature factor

Allowable minimum values of the temperature factors for:

- minimum values of average monthly temperatures characteristic for localities representative of different climatic zones;
- temperature of the interior surface – allowable minimum value to avoid the condensation risk, for θ_i =20 °C and φ_i= 60%.

12°C

- to avoid the risk of condensation and mould development:

15 °C

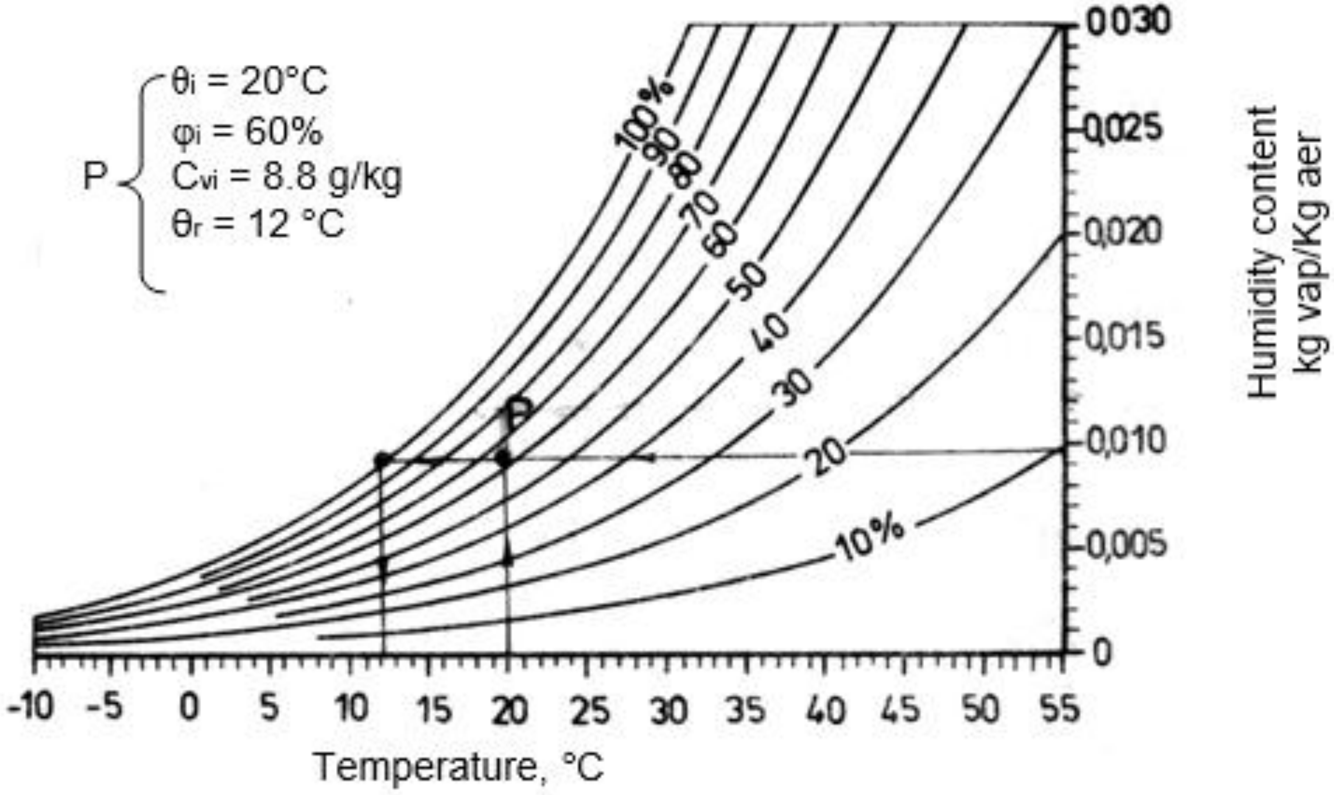


Diagram of Carrier.
The relationship between temperature, concentration and relative humidity

Minimum allowable values of temperature factor for localities in different climatic zones

No.	Locality	Minimum monthly average outdoor temperature	Minimum allowable surface temperature factor $f_{Rsi, min}$	
			For the mold avoidance	For the surface condensation avoidance
1	Constanţa	+1.4	0.677	0.569
2	Timişoara	0.0	0.70	0.60
3	Bucuresti	−1.2	0.716	0.622
4	Cluj Napoca	−1.4	0.719	0.626
5	Iaşi	−2.1	0.728	0.638
6	Suceava	−2.8	0.736	0.649
7	Braşov	−3.3	0.742	0.656
8	Miercurea Ciuc	−6.2	0.770	0.694

Critical values (minimum allowable) of the temperature factor

In Romania the minimum allowable values of the temperature factor are:

- to avoid the mould development

$$f_{Rsi} = 0.77\ (0.80),$$

- to avoid the condensation risk

$$f_{Rsi} = 0.70$$

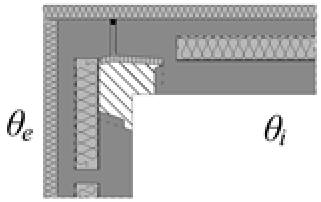
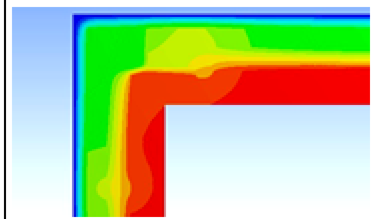
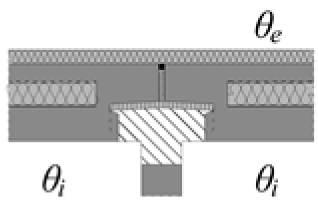
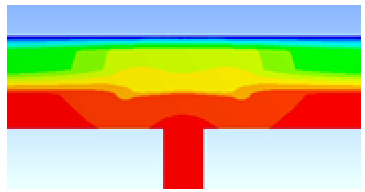
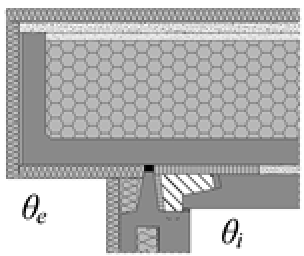
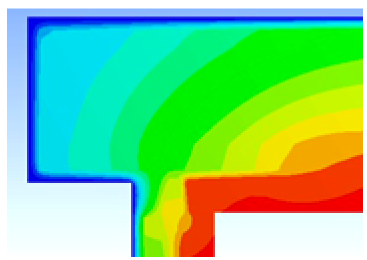
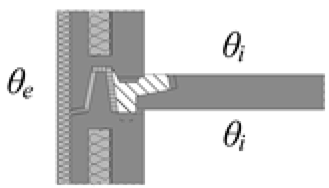
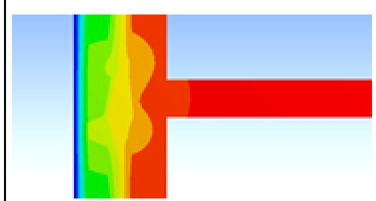
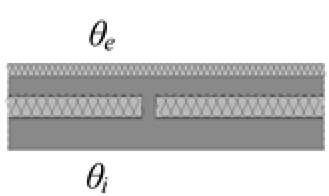
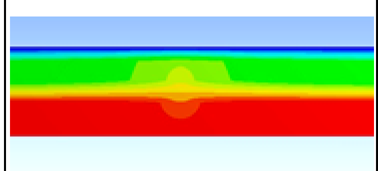
The standard values in various European countries are:

- France $f_{Rsi,crit}$=0,52 for: θ_i=18°C, θ_e=0°C, φ_i=80%
- Germany $f_{Rsi,crit}$=0.70 for: θ_i=20°C, θ_e=−5°C, φ_i=80%
- Switzerland $f_{Rsi,crit}$ >0,75
- Finland $f_{Rsi,crit}$=0.97 for floors, $f_{Rsi,crit}$=0.87 for walls.

Analysis of condensation risk on an existing building

- For the buildings made of prefabricated large panels with exterior walls of sandwich panels, the zones exposed to condensation and mould risk are those corresponding to thermal bridges.

- Normal operating conditions are considered.

a.			$d_{insulation}$ [cm]	f_{Rsi}
			0	0,627
			5	0,817
			10	0,874
			15	0,903
			20	0,920
b.			$d_{insulation}$ [cm]	f_{Rsi}
			0	0,675
			5	0,872
			10	0,916
			15	0,937
			20	0,950
c.			$d_{insulation}$ [cm]	f_{Rsi}
			0	0,589
			5	0,810
			10	0,860
			15	0,890
			20	0,909
e.			$d_{insulation}$ [cm]	f_{Rsi}
			0	0,705
			5	0,875
			10	0,917
			15	0,937
			20	0,950
f.			$d_{insulation}$ [cm]	f_{Rsi}
			0	0,724
			5	0,867
			10	0,909
			15	0,931
			20	0,944

Temperature factors corresponding to thermal bridges of a building made of prefabricated large panels

To be noticed that

- When the building is not additionally insulated, all the temperature factor values are lower than $f_{Rsi} = 0.80$, the lowest being for the thermal bridge formed at the intersection of the exterior wall with the roof terrace ($f_{Rsi} = 0.589$).
- The application of an additional thermal insulation, even of minimum thickness (5 cm) leads to an improvement, meaning the avoidance of condensation and mould risk.

Conclusions

- The risk of surface condensation is determined by a complex of factors related to structural characteristics (insulation level), outdoor climate and way of usage characterized by the production of vapor, ventilation rate and indoor temperature.

- The parametric study presented in this paper demonstrates pronounced influence of the ventilation rate to which is added the vapour production due to occupancy and way of use.

Conclusions

- The criterion for assessing the surface condensation and mould risk is the surface temperature factor f_{Rsi} that reflects the insulation level in different parts of the envelope.
- For a correct design of new buildings and of thermal rehabilitation solutions of existing ones, from this point of view, it is necessary that the value of surface temperature factor f_{Rsi} does not show values less than 0.77 (0.80) at any point of the building envelope.

Conclusions

- In the same way, it is necessary the knowledge and observance of rules for a proper operating in terms of ventilation and vapor production.
- The introduction of controlled natural ventilation systems (humidity sensitive grids) contributes essentially to ensure the indoor climatic conditions, characteristic of normal use.

Reference

- ORDIN MDRT nr. 1590/24.08.2012

  for modification of “Calculation of thermal performances of building elements – C 107/3”, C107-2005,

  Appendix K: Thermal bridges for buildings Catalog (published in the Official Monitor of Romania, Part I, nr.650bis/12.IX.2012)