Interstitial Condensation Risk at Thermal Rehabilitated Buildings

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Abstract. The increasing thermal insulation degree of existing residential buildings, aiming to reduce the energy requirements for ensuring the indoor comfort, has as expected effect the elimination of condensation risk. However, in some cases this phenomenon occurs, both on the inner surface of the closing element and also in its structure. The surface condensation causes can be identified and can be easily removed. Instead, the causes and even the presence of interstitial condensation are more difficult to be observed. But the moistening of the insulation materials and the reduction of thermal insulation capacity or even its total degradation, contravene into a large extent or totally to the main purpose of the additional thermal protection. To avoid such situations, it is necessary to respect some principles concerning the structure, resulted from the knowledge of the water vapour diffusion behaviour of various materials. It is known that condensation vulnerability is higher for the additional thermal protection solutions by disposing the insulating material on the inside surface of the closing element. But practice has shown that the condensation phenomenon is not totally excluded neither in the case of outside thermal insulation – which is the current solution applied to the rehabilitation works - if the principles mentioned above are not known and respected. In this paper two models are compared on which the risk of interstitial condensation can be checked. The analysis made on two structures of exterior walls with thermal insulation demonstrates the need for additional verifications before proposing a solution for thermal rehabilitation of the envelope elements.

1. The interstitial condensation mechanism and the verification of the condensation developing risk
The condensation of the water vapour can take place in the mass of building elements that separate the environments with different temperatures and vapour concentrations, as a result of diffusion of water in the gaseous form that is produced from the interior heated space to the outside - in winter conditions - and from the outside in summer conditions, in the case of basements or other rooms with low temperatures [1].

Basically, in order that interstitial condensation phenomena to not affect the normal operation of a building, there must be a balance between the amount of vapour that accumulates in the structure of the element in the cold season, and that which could be eliminated by drying during the hot weather.
In case when this balance is not achieved, there is a gradual accumulation of water that usually is stationing in the pores of the insulating material, which, by wetting, considerably diminishes the thermal insulation capacity.

The favouring factors which determine the interstitial condensation phenomenon and influence its intensity are:
- characteristics of indoor climate, respectively vapour flow sources, ventilation rate and temperature;
- characteristics of the outdoor climate, respectively air temperature and humidity;
- characteristics of the materials that make up the element, respectively porosity, hygroscopicity and the vapour permeability;
- degree of exposure to aggressive climatic factors, rain, wind, solar radiation;
- the existence of other sources of moisture with synergistic effect on the phenomenon of diffusion (external water seepage caused, for example, by malfunctioning of devices for rainwater drainage).

In a graphical interpretation of the phenomenon of vapour diffusion, the condition that the condensation should not meet is that the partial pressures diagram does not have a common point with the saturation pressure diagram. There are three possible distinct situations:
- the partial pressures diagram has no common point with that of pressures of saturation, respectively, in any section of the element, the following condition is fulfilled: \( p_v < p_{vs} \). The condensation does not appear;
- the partial pressures diagram is tangential to the saturation pressure diagram – a surface condensation appears;
- the partial pressures chart diagram intersects the saturation pressure - a condensation zone appears (Figure 1).

![Condensation Diagram](Figure 1)

**Figure 1.** Verification of condensation risk of in the mass of closing elements; graphical representation.

In reality, the phenomenon is more complex, in most cases, to the diffusion transport of water is added the water transport in liquid form by capillary action - that modifies the properties of materials - and the surface diffusion that occurs as an intermediate stage between the liquid and gas ones. These aspects can be considered if we use complex computer programs capable of simultaneous simulation of moisture transfer by diffusion and capillary action and the action of external climatic factors such as rainfall and solar action [2].
2. Methods for assessing the risk of interstitial condensation
An accurate assessment of the interstitial condensation risk in the stage of projects development for new buildings or for rehabilitation works is very important not only to avoid the adverse effects of moisture on building materials, but also for the assurance of indoor environmental quality.

The verification way of the risk of interstitial condensation is regulated by SR EN ISO 13788:2013 - Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods [3].

The verification is based on analysis of moisture annual balance sheet by comparing the total amount of water accumulated through condensation and the one that can be removed by drying, on the base of monthly vapour flow calculation. For this is considered the mean monthly air temperature and humidity specific for the building site. It is considered exclusively the moisture transfer by diffusion and the analysis is based on Glaser method that simplifies the phenomenon of heat and mass transfer by accepting the following assumptions:
- the condensation occurs only at the interface between layers of different materials and remains at that interface;
- the thermal conductivity is independent of the moisture content of the material;
- the transfer of moisture in a liquid state and the migration by capillary action do not occur in the closing element;
- there is no transfer by convection inside the structure;
- the boundary conditions are the values of mean monthly temperature and humidity;
- the transfer of heat and humidity is unidirectional;
- the effect of rain and solar radiation are neglected.

The complexity of the phenomenon is reflected with much more accuracy in the method that is based on the calculation program WUFI 2D, which takes into account the transitional regime concerning the boundary conditions and more data on their characteristics, such as:
- dependence on moisture of the vapour resistance factor;
- dependence on moisture of the thermal conductivity coefficient of materials;
- coefficient of transport and redistribution of liquid water;
- moisture storage function defined for hygroscopic porous materials.

The boundary conditions variable in time are defined by the following parameters:
- indoor and outdoor air temperature;
- humidity inside and outside;
- impact of rain on the exterior wall;
- incidence of solar radiation on the exterior wall surface.

3. Interstitial condensation risk analysis on the basis of two models; results, discussion.
The risk was analysed for two solutions of thermal rehabilitation of the exterior walls, which are estimated to have a greater vulnerability to interstitial condensation. There were considered the climatic conditions of outside air (temperature and humidity), specific for the area of Iasi and the characteristics of the indoor climate, specific for a normal use of dwellings, respectively the indoor air temperature $T_i = 20 \, ^\circ C$ and a relative humidity $\varphi_i = 60\%$.

a. Walls of brick masonry of 37.5 cm thickness, with thermal insulation of 10 cm expanded polystyrene disposed to the inner surface.

The geometric and physical characteristics are presented in Table 1.
### Table 1. Geometric and physical characteristics of the external wall

| Layer | Material                        | Layer Thickness d [m] | Resistance factor to water vapour permeability μ [-] | Thermal conductivity λ [W/(m·K)] | Resistance to thermal transfer R [m²·K/W] | Equivalent thickness sₜ=d=μ d [m] |
|-------|---------------------------------|-----------------------|-----------------------------------------------------|----------------------------------|-----------------------------------------|-----------------------------------|
| 1     | Reinforced lime cement plaster  | 0.005                 | 100                                                 | 0.93                             | 0.005                                   | 0.500                              |
| 2     | Expanded polystyrene           | 0.100                 | 30                                                  | 0.04                             | 2.500                                   | 3.000                              |
| 3     | Brick masonry                   | 0.375                 | 6.1                                                 | 0.80                             | 0.469                                   | 2.287                              |
| 4     | Cement plaster                  | 0.025                 | 7                                                   | 0.87                             | 0.029                                   | 0.175                              |
|       | TOTAL                           |                       |                                                     |                                  | 3.003                                   |                                    |

The verification of the interstitial condensation risk according to SR EN ISO 13788:2013 consists in assessing the moisture balance by evaluating the monthly flow of water accumulation from condensation (Table 2).

### Table 2. The flow of condensation and accumulation in the wall

| Month   | Interface 2 | Condensation flowrate gₜ [kg/m²] | Accumulated moisture content Mₜ [kg/m²] |
|---------|-------------|----------------------------------|----------------------------------------|
| November| 0           | 0                                | 0                                      |
| December| 0.05900500  | 0.5900500                        |                                        |
| January | 0.06596900  | 0.1249740                        |                                        |
| February| 0.03650500  | 0.1614790                        |                                        |
| March   | -0.00791460 | 0.1535644                        |                                        |
| April   | -0.13040352 | 0.0231608                        |                                        |
| May     | -0.40223550 | 0                                |                                        |

It is found that the accumulation of water condensation begins in January, and the drying process begins in March. In May the eliminated water flow is higher than the accumulated one.

The section in which the condensation occurs is that of contact between the interior thermal insulation and the existing wall (warm face of the insulation).

The element behaviour in transient regime was analysed using minimum, maximum and average values of the relative humidity in characteristic sections of the element, figure 2, obtained by using WUFI 2D software.
Figure 2. Mean values of relative humidity in characteristic sections of masonry wall, additionally insulated with polystyrene at the interior

The results of the analysis in transient regime show that:
- the relative humidity values in characteristic sections reach a peak of 70% in the section separating the polystyrene insulation and the brickwork, confirming the results of the calculation according to SR EN ISO 13788:2013 regarding the absence of the risk of progressive accumulation of condensation water and the section where condensation appears;
- higher values of relative humidity, close to 90% occur on the external surface, as a result of the action of rain, taken into account by the program.

b. External wall made of masonry of autoclaved aerated concrete blocks with 30 cm thickness and a thermal insulation of 10 cm expanded polystyrene thermal insulation disposed at the outer surface.

The geometric and physical characteristics are presented in Table 3.

Table 3. Geometric and physical characteristics of the external wall

| Layer | Material                     | Layer Thickness d [m] | Resistance factor to water vapour permeability μ [-] | Thermal conductivity λ [W/(m·K)] | Resistance to thermal transfer R [m²·K/W] | Equivalent thickness sₐ=μ d [m] |
|-------|------------------------------|-----------------------|------------------------------------------------------|----------------------------------|------------------------------------------|--------------------------------|
| 1     | Reinforced lime cement plaster | 0.020                 | 7                                                    | 0.87                             | 0.023                                    | 0.14                           |
| 2     | Autoclaved aerated concrete masonry | 0.300              | 3.9                                                  | 0.30                             | 1.00                                     | 1.17                           |
| 3     | Expanded polystyrene         | 0.100                 | 30                                                   | 0.04                             | 2.50                                     | 3.00                           |
| 4     | Cement plaster               | 0.005                 | 100                                                  | 0.93                             | 0.005                                    | 0.50                           |
| TOTAL |                              |                       |                                                      |                                  |                                          | 3.528                          |
The results of the risk assessing of interstitial condensation according to SR EN ISO 13788:2013 by evaluating the monthly flow of water accumulation through condensation are shown in Table 4.

**Table 4. The flow of condensation and accumulation in the wall**

| Month  | Interface 3 | Condensation flowrate $g_c$ [kg/m²] | Accumulated moisture content $M_a$ [kg/m²] |
|--------|-------------|-------------------------------------|------------------------------------------|
| November | 0           | 0                                   | 0                                        |
| December | 0.000179    | 0.000179                            | 0.009767                                 |
| January  | 0.009588    | 0.055109                            | -0.020987                                |
| February | -0.055109   | -0.045342                           | 0                                         |
| March    | -0.209878   |                                     | 0                                         |

It can be noticed that the accumulation of condensation water begins in December and the drying process begins in February, the month in which the eliminated water flow is higher than that of the accumulated one.

The section in which condensation occurs is at the contact between the exterior thermal insulation and the existing wall.

The element behaviour in transient regime was analysed using minimum, maximum and average values of the relative humidity in characteristic sections of the element, figure 3, obtained by using WUFI 2D software.

![Figure 3. Mean values of relative humidity in characteristic sections of masonry wall made of autoclaved aerated concrete blocks additionally insulated with polystyrene at the exterior side](image)

The results of the analysis in transient regime show that:
- the relative humidity values in characteristic sections reach a peak of 70% in the section that separates the inner plaster from the masonry autoclaved concrete blocks, unconfirming the calculation results made according to SR EN ISO 13788:2013 concerning the section where is present the most pronounced risk of condensation;
- higher values of relative humidity, about 80%, occur on the external surface, as a result of the action of rain, which is taken into account by the program.
Discussions on the results of the analysis can be done on two distinct aspects. One concerning the accuracy and concordance of results obtained for the two models and the other on the composition principles of layered elements from the point of view of behaviour to the interstitial condensation.

In general, the two models - based on steady state, respectively transient regime, give similar results in assessing the risk of interstitial condensation. It should be noted, however, that taking into account the effects of rain and sunlight is very important, highlighting the need for a waterproofing layer (but permeable for vapours) on the outside surface of the wall. In addition, in practice are met situations when the swinging rain effect, especially on North façade, is manifested by the intensification of the interstitial condensation, which is becoming visible on the inside surface of the wall.

Studies reported in the research area, reflected in recommendations concerning the avoiding of condensation risk in layered structure, emphasize the main factors involved in the appearance and development of this phenomenon:
- the arrangement of layers of different materials from the inside to the outside in order to increase the vapour permeability;
- the use of vapour barriers on the warm face of the thermal insulating material;
- the use of outside protection systems which include a ventilated air layer.

The second structure, that was the subject of the analysis, does not comply with the first recommendation regarding the composition of the layered structures, the outside layer of thermal insulation, the expanded polystyrene, being much less permeable than the existing structure made of autoclaved concrete. However, there is no risk of gradual water accumulation through condensation, the behaviour being even better than the first structure, correctly made. The explanation can be found only in the different thermal resistance of the two structures, the second having a thermal resistance $R = 3.695 \text{ m}^2\text{K} / \text{W}> R = 3.17 \text{ m}^2\text{K} / \text{W}$.

Obviously, firm conclusions may not be drawn only on the basis of two situations. But a thorough study concerning the weight of different factors involved in the production of interstitial condensation seems to be necessary. This study would determine to what level of thermal protection the order of arrangement of layers or the presence of vapour barrier is no longer so important.

In all circumstances, a correct and economic solution of additional thermal protection involves a risk analysis of interstitial condensation, preferably using a model for conducting of the transfer phenomena in transient regime, taking into account the action of rain and solar radiation.

3. Conclusions

The condensation verification according to SR EN ISO 13788:2013, having as model the stationary transfer phenomena, provides realistic information concerning the risk of interstitial condensation. The significant amount of calculation made by hand and the use of the graphical method can easily generate errors that may distort the results of an analysis.

Computer programs based on the transient regime, able to take into account the variability with moisture of the materials characteristics, as well as the complex action of climatic factors, provide more information even more truthful, useful in developing some optimal solutions of additional thermal protection. The results of a systematic research program and using numerical modelling could be summarized in a catalogue of building closing solutions with interstitial condensation risk.

References
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