CONTRIBUTIONS TO THE TRANSFER OF HEAT AND MASS INTO BRICK WALLS WITH VERTICAL HOLES

Madalina - Xenia CALBUREANU - POPESCU¹, Marin BICA¹, Diana - Mara CALBUREANU - POPESCU¹*, Dragos TUTUNEA¹

¹University of Craiova, Faculty of Mechanics, Craiova, Romania
*Corresponding author; E-mail: diana.calbureanu@gmail.com

Abstract: The paper presents the analysis of heat and mass transfer in brick walls with vertical holes, type of envelope widely used in the construction of residential dwellings in Romania. Moving towards the concept of passive house leads to the sealing of the envelope as much as possible, leading to complex mass transfer phenomena. The analysis of winter mass transfer phenomena for buildings in climate areas II, III for such a type of envelope leads to conclusions that can be used for solutions that lead to high energy efficiency in conditions of interior comfort and fulfillment of parameters leading to the occupants' health.

Key words: mass transfer, vertical hole bricks, comfort parameters

1. Introduction

Under the conditions of reducing energy consumption for new buildings, increasing the efficiency of thermal insulation becomes of major importance. The efficient combination of the type of material used in thermal insulation with the reduction of thermal bridges would be a solution to solve this aspect. It should be taken into account that the low temperatures that can cause the dew point occur especially around the windows, in the material layers of the walls that have not been chosen properly for each situation (climate zone, shelter, etc.). In the existing buildings and which have not been given from the beginning of this area of elimination of condensation in coats must be avoided higher humidity level, a sufficient flow range and thermal points reduced in relation to if higher surface temperatures. [1-4]

Due to the basic concepts of heat transfer and mass for thermally insulated walls, the following mass flows of material appear:
- A heat flow from the temperature difference;
- A flow of moisture as water vapor given by the difference between partial water vapor pressures in wet air on both sides of the walls. [5-7]

The insulating properties of the building materials of the walls are severely affected by the appearance of condensation in the layers. The effect is amplified by the freezing of condensed water. This phenomenon is most likely when temperatures become negative during the cold season. Therefore, it is necessary to check the condensation phenomenon in layers and actions to eliminate it. [8]

Condensing checking inside insulation layer is realized in several phases as follows:
- Is used the concept that the temperature inside the plain wall varies linearly in all the layers of the building material. So, the \( p'' \) graphic variation of the water vapor saturation pressure inside the layers is determined in dependence of the temperature modification;
- The second step is to determine the graphic of \( p' \), the water vapor partial pressure inside the layers of the cladding;
- The third step is to make the difference between these two graphic curves. Can be identified two different possibilities:
  a) Those two graphics have no points in common and \( p'' > p' \), then there is no conditions of occurring condensation inside of any layer of the wall;
  b) Those two graphics have points in common, i.e. Fig.1 and there are zones where \( p'' < p' \). That zones are named the condensation zones. In these areas the moisture and all its negative influence will occur. [9-11].

Fig. 1 The variations of temperature, of the moisture vapor saturation pressure \( p'' \) and of their partial pressure \( p' \) inside a wall provided with thermal insulation.

The dew point occurring temperature is characterized as the temperature at which the air becomes saturated with water vapor - the air is chilled by removing sensible heat. This state is quite significant because it is related to the amount of water vapor in the air and it can be used to calculate variables such as the relative humidity, the vapor pressure and even the wet bulb temperature and vapor pressure deficit. [12]

In existing constructions there are various issues at present because of the high level of humidity in correlation to moisture accumulating quantity, air change rate and the severity of thermal bridges. These issues could be avoided if the surface temperature was higher. In order to highlight the maintenance, health, comfort, next issues are important:
- The repercussions of condensation phenomenon on the surfaces are that it requires more maintenance and the treatment for the surface should be applied more often.
- Condensation can also cause the risk of mold growth which can lead to health problems for the occupants and allergies.
- Thermal bridges can lead to thermal comfort problems. Cold draughts can be caused by poorly insulated areas of the walls, uninsulated walls and can lead to cold surfaces during winter. Cold draughts can also be caused by leakages in the building envelope leading to low floor temperatures. The low floor temperatures and cold draughts contribute to thermal comfort problems. [13]

The phenomenon of the dew-point occurring in the brick walls is in general in the internal layers of the cladding. This is increasing the possibility of the accumulating the moisture within the cladding. This phenomenon leads to freezing and causing mechanical resistance of the building materials damage. Bad insulation with EPS around windows is the cause of thermal bridges formation. [14]

When executing the construction of a house, five to ten percent of the cost is caused by polystyrene insulation materials which are quite expensive. Over the structure’s lifetime, the homeowner will easily save money on heating and cooling due to good insulation.[15] Beside the polystyrene insulation, benefits are offered by the concrete grid that also contributes to the thermal comfort. These materials prevent pests contamination such as termites that appear usually in wood frame home if left unchecked. With a thermal resistance value of usually over 3 m²K/W during its lifetime, EPS is a recyclable product that lasts a long time. The downsides of this product are that it can be deteriorated by exposure to the sun, solvents and solvent based materials can attack it irreversibly and high temperatures (over 74°C or 165°F) can melt it. A very discussed topic is the incompatibility of EPS with some thermoplastics and its inflammability.

2. Modelling Heat and Mass Transfer in Insulated Walls

As physical model for finite element analysis there were used the common composition as layers for the wall of a residential house from climatic zone II and III, Romania, Fig. 2, a, b, c.

In the heat transfer analysis performed were included as input parameters the thermotechnical characteristics of building wall execution. There were considered as follows: the internal temperature 20[°C] assuming a residential room, the external temperature –15[°C] for zone II (Bucharest), and –18 [°C] for the Iasi city, the interior convection coefficient \( \alpha_i = 7 [Wm^{-2}K^{-1}] \), the exterior convection coefficient \( \alpha_e = 17 [Wm^{-2}K^{-1}] \).

Tab. 1 presents the thickness and the material properties for the layers. The component layers of the wall are: external plaster including decorative paint, expanded polystyrene, Porotherm brick and interior plaster including paint.
Fig. 2 The Romanian climatic zonation – the map of the winter external temperature (a); the medium annual temperature (b) and the summer external temperature (c).

**Tab. 1** Dimensions and material properties for layers

| No. | Materials                  | Thickness [m] | Thermal conductivity $[\text{Wm}^{-1}\text{K}^{-1}]$ | The vapor permeability resistance factor [-] | Mass Density $[\text{kgm}^{-3}]$ | Specific heat $[\text{Jkg}^{-1}\text{K}^{-1}]$ |
|-----|----------------------------|---------------|-----------------------------------|---------------------------------------------|-------------------------------|----------------------------------|
| 1   | Plaster exterior           | 0.010         | 0.870                             | 8.50                                        | 1800                          | 840                              |
| 2   | Expanded Polystyrene EPS 15| 0.150         | 0.044                             | 30                                          | 30                            | 1460                             |
| 3   | Portherm Brick             | 0.350         | 0.580                             | 4.50                                        | 1250                          | 870                              |
| 4   | Plaster interior           | 0.010         | 0.700                             | 5.30                                        | 1800                          | 840                              |

The H2O vapor diffusion analysis, condensation accumulation and dew point analysis are done using a proprietary program (Excel spreadsheets). Fig. 3 shows the characteristic elements of the heat and mass transfer at the level of a brick building element.

Fig. 3 Brick model with vertical holes used in mass transfer study. Longitudinal Vapor Transfer Direction (a); transversal vapor transfer directives (b).
The analysis of the water vapor diffusion in the longitudinal direction of the building element through the porosities of the material and the interior vertical holes, Fig. 4, considering the gravitational effect, leads to the obtaining of the isothermal space distribution fields of Fig. 5.

Fig. 4. The isometric view of isobar surfaces of water vapors into the brick

![Isobar Surfaces](image1)

Fig. 5. The left view of isodensity surfaces into the brick

Determination of isothermal surfaces inside the body of the brick element on water vapor diffusion allows the determination of the position and spatial shape of the surface on which the condensation of these vapors is made inside the brick.

Fig. 6. The relative humidity [%] map into the brick block

![Relative Humidity](image2)
The study of spatial field distribution when the diffusion direction is transverse and the analysis of water vapor diffusion in the transverse direction – the relative humidity map is presented in Fig. 6. [16-17]

3. Results and Discussions

3.1 Results for climatic zone II

Using input data corresponding to the climate zone II for a residential building as in Tab. 2, a condensation temperature of \(-10,15°C\) is obtained under relative humidity of 85% outside air (Tab. 3).

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature     | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m²°C |

| External climatic parameters |  |
|-----------------------------|--|
| Average annual outdoor air temperature | 9.50 °C |
| Relative humidity of outdoor air | 80 % |
| Heat transfer coefficient at outer surface | 24.00 W/m²°C |

**Tab. 2**

**Determination of condensation temperature**

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature     | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m²°C |

| Outdoor climatic parameters |  |
|-----------------------------|--|
| The outside air temperature at which condensation occurs | -10,15 °C |
| Relative humidity of outdoor air | 85 % |
| Coefficient of thermal transfer to the outer surface | 24 W/m²°C |

In Tab. 4 the indoor and outdoor climatic parameters are shown for determining the quantity of condensed water, and in Tab. 5 is determined the amount of water accumulated by condensation. It is noticed that the temperature of the outside air during condensation is \(-15.15°C\), and the amount of condensed water is 0.0115 kg/m².

**Tab. 4**

**The amount of water eliminated by evaporation during the hot season**

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature     | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m²°C |

| Outdoor climatic parameters |  |
|-----------------------------|--|
| Outdoor air temperature during evaporation | 8.00 °C |
| Relative humidity of outdoor air | 70 % |
| Coefficient of thermal transfer to the outer surface | 24 W/m²°C |
In Tab. 6, the input parameters for determining the quantities of water eliminated by evaporation during the warm season are shown, and in Tab. 7 we have the excess humidity checking module. We have outside air temperature 8°C during evaporation and 70% relative humidity outside. The results center and the pressure variation chart are given in the Tab. 8 and Fig. 7.
It is noticed that we have a quantity of evaporated water over the hot season than that accumulated by condensation in the cold season, so the composition of the wall is the correct one.

### 3.2 Results for Climatic Zone III

Using input data corresponding to the climate zone III for a residential building as in Tab. 9, a condensation temperature of $-16.15^\circ$C (Tab. 10) is obtained under 85% relative humidity relative humidity.

### Tab. 9

| Indoor climatic parameters | 20 °C |
|---------------------------|-------|
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer on the inner surface | 8 W/m²°C |

| Outdoor climatic parameters | 7.50 °C |
|-----------------------------|-------|
| Relative humidity of outdoor air | 80 % |
| Coefficient of thermal transfer on the outer surface | 24.00 W/m²°C |
Tab. 10

**The amount of condensed water in the cold season**

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature    | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m²°C |

| Outdoor climatic parameters |  |
|-----------------------------|--|
| External air temperature during condensation | -16.15 °C |
| Relative humidity of outdoor air | 85 % |
| Coefficient of thermal transfer to the outer surface | 24 W/m²°C |

In Tab. 11 the indoor and outdoor climatic parameters for determining the quantity of condensed water are shown, and in Tab. 12 is the amount of water accumulated by condensation. It is noticed that the outside air temperature during condensation is –16.15°C and the amount of condensed water is 0.0279 kg/m².

Tab. 11

**The amount of condensed water in the cold season**

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature    | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m²°C |

| Outdoor climatic parameters |  |
|-----------------------------|--|
| External air temperature during condensation | -16.15 °C |
| Relative humidity of outdoor air | 85 % |
| Coefficient of thermal transfer to the outer surface | 24 W/m²°C |

Tab. 12

**Parameters for calculating the amount of condensed water**

| Parameters for calculating the amount of condensed water         |  |
|------------------------------------------------------------------|--|
| Saturation pressure at the first point of tangency               | 402.9 Pa |
| Saturation pressure at the second point of tangency              | 241.2 Pa |
| Vapor permeability resistance \( R'_{v}/10^9 \)                   | 241.8 m/s |
| Vapor permeability resistance \( R''_{v}/10^8 \)                  | 45.1 m/s |
| The duration of the condensation process                         | 492.5 ore |
| **The amount of water accumulated by condensation**               | **0.0279 kg/m²** |

Tab. 13

**The amount of water accumulated by evaporation during the warm season**

| Indoor climatic parameters |  |
|---------------------------|--|
| Indoor air temperature    | 20 °C |
| Relative humidity of indoor air | 60 % |
| Coefficient of thermal transfer to the inner surface | 8 W/m³°C |

| Outdoor climatic parameters |  |
|-----------------------------|--|
| Outdoor air temperature during evaporation | 7.00 °C |
| Relative humidity of outdoor air | 70 % |
| Coefficient of thermal transfer to the outer surface | 24 W/m³°C |
In Tab. 13 the input parameters for determining the quantity of water eliminated by evaporation during the hot season are shown. The results center and the pressure variation chart are given in the Tab. 14 and Fig. 8.

![Fig. 8 The pressure variation graph inside the wall](image)

### Tab. 14 Results centralization

| Results centralizer                  |          |
|-------------------------------------|----------|
| 1 Average annual outdoor air temperature ($T_{ann}$) | 7.50 °C  |
| 2 The outside air temperature at which condensation occurs ($T_{c}$) | -10.15 °C |
| 3 Average outside air temperature during condensation ($T_{ann}$) | -16.15 °C |
| 4 Average outside air temperature during evaporation ($T_{ev}$) | 7.00 °C  |
| 5 The amount of condensed water accumulated in the cold season ($m_{c}$) | 0.0279 Kg/m² |
| 6 The amount of water eliminated by evaporation during the hot season ($m_{e}$) | 2.0659 Kg/m² |
| 7 Increased humidity at the end of the condensation period ($\Delta W$) | 2.04 %    |
| 8 Maximum admissible increase in mass humidity ($\Delta W_{max}$) | 15.00 %   |

It is noted that we have a quantity of evaporated water over the hot season higher than that accumulated by condensation in the cold season, so the wall composition is correct.

### Conclusions

The research study took into consideration the analysis for cold season of Southern East Europe. There are two climatic zones used in this study: Bucharest – climatic zone II (where the medium temperature is −10°C) and Iasi – climatic zone III (where the medium temperature is −15°C). In Romania, generally, the bad (negative) influence of the dew-point occurring in the brick wall is maintained for 4 months annually. It was observed that even using very good quality of the binding materials e. g. the high quality of the Porotherm brick as humidity resistance, the negative effects of the condensing phenomena will appear in time. In order to avoid condensation in buildings walls with severe thermal bridges, it is mandatory to ensure that relative humidity in the room is sufficiently low. This is possible to achieve by assuring that the quantity of the moisture is minimum and there is a enough large rate of air change. In the low recommended case of supplementary insulation on the interior wall
side, there may also be a higher risk of moisture occurring that the air change rate has to be increased. Raising the exchange air rate in the rooms can lead to increased energy consumption. It is noticed that the wall-making solution is the right one for the conditions of a residential building. If the indoor air humidity increases (crèches, hospitals, elderly homes), using results similar to those presented in this paper, appropriate thicknesses of the insulation can be determined to prevent the negative effects of condensation in layers, possibly using vapor barriers that bring dew point positioning away from building elements in masonry.

Nomenclature

- $c_p$ – specific heat, $[\text{Jkg}^{-1}\text{K}^{-1}]$;
- $h$ – heat transfer coefficient, $[\text{Wm}^{-2}\text{K}^{-1}]$;
- $h_m$ – mass transfer coefficient, $[\text{ms}^{-1}]$;
- $k$ – thermal conductivity, $[\text{Wm}^{-1}\text{K}^{-1}]$;
- $L$ – distance between first and second cylinder, $[\text{m}]$;
- $M$ – moisture distribution, $[\text{kgkg}^{-1}]$;
- $\text{Nu}$ – Nusselt number, $=hDk^{-1}$, $[-]$;
- $T$ – temperature, $[\text{K}]$;
- Greek symbols $\mu$ – dynamic viscosity, $[\text{kgs}^{-1}\text{m}^{-1}]$;
- $\rho$ – density, $[\text{kgm}^{-3}]$;
- $\infty$ – environment.

References

[1] Mohelníková, J., Mišák, O., Energy Rating Concept and Retrofit of Building Envelopes in Proceedings of the 5th WSEAS International Conference on Environment, Ecosystems and Development, Venice, Italy, November 20-22, 2006 pp148-152.
[2] Bukarica, V., Tomsic, Z., Energy efficiency in Croatian residence and service sector – analysis of potentials, barriers and policy instruments, 3rd IASME/WSEAS Int. Conf. on Energy & Environment, University of Cambridge, UK, February 23-25, 2008, pp 61-66.
[3] Duffie, J., Beckmann, W. A., Solar Engineering of Thermal Processes, John Wiley & Sons, New York, USA, 1991.
[4] Incropera, F. P., Witt, D.P., Fundamentals of Heat and Mass Transfer, John Willey & Sons, New York, USA, 1996.
[5] OPET CR - Thermal bridges in residential buildings in Denmark, Brno, 2002
[6] Mohelníková, J., Mišák, O., Energy Rating Concept and Retrofit of Building Envelopes in Proceedings of the 5th WSEAS International Conference on Environment, Ecosystems and Development, Venice, Italy, November 20-22, 2006 pp148-152.
[7] Bukarica, V., Tomsic, Z., Energy efficiency in croatian residence and service sector – analysis of potentials, barriers and policy instruments, 3rd IASME/WSEAS Int. Conf. on Energy & Environment, University of Cambridge, UK, February 23-25, 2008, pp 61-66.
[8] Duffie, J., Beckmann, W. A., Solar Engineering of Thermal Processes, John Wiley & Sons, New York, USA, 1991.
[9] Incropera, F.P., Witt, D. P., Fundamentals of Heat and Mass Transfer, John Willey & Sons, New York, USA, 1996.
[10] OPET CR - Thermal bridges in residential buildings in Denmark, Brno, 2002
[11] Oztop, H. F., Akpinar, E. K., Numerical and Experimental Analysis of Moisture Transfer for Convective Drying of Some Products, International Communications in Heat and Mass Transfer, 35 (2008), 2, pp. 169-177
[12] Kadem, S., et al. Computational Analysis of Heat and Mass Transfer during Microwave Drying of Timber, Thermal Science, 20 (2016), 5, pp. 1447-1455
[13] Dorfman, A. S., *Conjugate Problems in Convective Heat Transfer*, Taylor & Francis, New York, USA, 2010, pp. 21-29
[14] Winkler, C. M., et al., *Film Condensation of Saturated and Superheated Vapors along Isothermal Vertical Surfaces in Mixed Convection*, Numer. Heat Transfer, 36 (1999), 2, pp. 375-393
[15] Zhang, B. Q., Liu, X. F., *Effects of Fractal Trajectory on Gas Diffusion in Porous Media*, *AIChE Journal*, 44 (2003), 12, pp. 3037-3047
[16] Calbureanu, M. X., et al., Contributions above the dew-point problem in civil building EPS insulated walls modeling with finite element the convective heat transfer, *INTERNATIONAL JOURNAL OF MECHANICS Issue 3, Volume 4*, 2010, pp. 53-62
[17] Calbureanu, M. X., et al., The finite element analysis of water vapor diffusion in a brick with vertical holes, pag. 57-62, *International Conference on Mathematical Models for Engineering Science (MMES ’10)*, ISBN: 978-960-474-252-3, ISSN: 1792-6734, Puerto De La Cruz, Tenerife, November 30-December 2, 2010