

## METHOD OF ARRANGEMENT OF INTERNAL THERMAL INSULATION OF EXTERNAL PROTECTIVE STRUCTURES OF THE ROOM

<sup>1</sup>*Department Heat and Gas Supply and Ventilation,  
Lviv Polytechnic National University*

<sup>2</sup>*SSU Technical and Economic Professional College of  
Lviv Polytechnic National University  
volodymyr.y.labai@lpnu.ua*

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The paper presents the results of a study aimed at increasing energy efficiency in residential buildings, as well as an analysis of the humidity state and the possibility of condensation when using internal insulation. Numerical simulations were performed to confirm the results. The obtained results indicate that the use of mineral insulation "BETOL®" and aluminum foil used as a vapor barrier, applied from the inside, contributes to the improvement of thermal insulation of the walls and reduces the risks of condensation.

Computer modeling showed that under the formed conditions, condensation is not observed. This research has an important contribution to the development of energy-efficient solutions for the construction industry, as it allows to ensure the minimum permissible value of heat transfer resistance of external enclosures, to extend their service life.

**Keywords:** internal thermal insulation, vaporbarrier, vapor penetration, relative humidity, energy efficiency.

### Introduction

Reducing the energy consumption of existing buildings is now one of the key challenges in the construction industry. Activities carried out in the field of building modernization are mainly focused on improving the thermal insulation characteristics of facades. The energy required for heating and cooling buildings depends mainly on the thermal parameters of facades and windows and accounts for 25-30% of total energy losses in buildings (Basińska, 2021). In buildings with low energy consumption, heat loss should not exceed 5%. Thus, there is an urgent need to improve the thermal performance of external walls through thermal insulation in order to improve the energy performance of existing buildings and achieve improved energy efficiency after renovation. In modern construction, external insulation of the walls of buildings is usually used, but there are cases (architectural monuments) when this method of execution is unacceptable, then internal insulation becomes the only available solution. There are various internal insulation systems on the market that meet the high requirements of energy efficiency standards.

Recent studies show that the use of internal thermal insulation can significantly reduce the energy consumption of buildings. However, it is necessary to correctly choose the materials and technologies for arranging internal thermal insulation in order to avoid problems with condensation and an increased risk of mold formation (Krause, 2020)

For the effective use of any thermal insulation materials, it is necessary to investigate the thermal stability of the building, determine the thermal balance taking into account the temperature distribution at various points of the enclosing structures, as well as obtain the dependence of the change in thermal characteristics under the influence of external factors and their influence on the overall heat transfer coefficient of the thermal insulation shell of the building (Tsykh, 2019)

The purpose of the work is to arrange the internal heat of the insulating layer on the outer wall of the room using Betol mineral insulation. The article draws attention to the problem of condensation on the internal thermal insulation layer, which can lead to the destruction of the external wall. The authors propose a solution to this problem by arranging a multilayer structure with a vapor barrier.

### Research materials and methods

SBR V.2.6-31:2021 Thermal insulation and energy efficiency of buildings establishes requirements for thermal technical indicators of enclosing structures (thermal insulation shell) of buildings and structures and the order of their calculation with the aim of ensuring rational use of energy resources for heating, ensuring normative sanitary and hygienic parameters of the microclimate of premises, durability of enclosing structures during the operation of buildings and structures.

One of the indicators is the actual thermal resistance of heat transfer of a homogeneous opaque enclosing structure, which is calculated according to the specified DBN by the formula:

$$R_{\Sigma} = \frac{1}{\alpha_{in}} + \sum_{i=1}^n R_i + \frac{1}{\alpha_{out}} = \frac{1}{\alpha_{in}} + \sum_{i=1}^n \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{out}}, \text{ m}^2 \cdot \text{K/W}, \quad (1)$$

where  $\alpha_{in}$  i  $\alpha_{out}$  are coefficients of heat transfer of the inner and outer surfaces of the enclosing structure,  $\text{W}/(\text{m}^2 \cdot \text{K})$ , which are accepted in accordance with Appendix B of SSU B V.2.6-189:2013 Methods of selecting heat-insulating material for building insulation;  $R_i$  is thermal resistance of thermal conductivity of the  $i$ -th layer of the structure,  $\text{m}^2 \cdot \text{K/W}$ ;  $\delta_i$  – thickness of the  $i$ -th layer of the structure,  $\text{m}$ ;  $\lambda_i$  is thermal conductivity of the material of the  $i$ -th layer of the structure in the calculated operating conditions (according to Appendix A of the specified SSU B V.2.6-189:2013),  $\text{W}/(\text{m} \cdot \text{K})$ .

The actual thermal resistance of the heat transfer of the enclosing structure must satisfy the requirement:

$$R_{\Sigma} \geq R_{norm} = R_{qmin}, \text{ m}^2 \cdot \text{K/W}, \quad (2)$$

where  $R_{norm}$  is normalized value of thermal resistance of heat transfer of the enclosing structure,  $\text{m}^2 \cdot \text{K/W}$ ;  $R_{qmin}$  is the minimum permissible value of the thermal resistance of heat transfer of the enclosing structure,  $\text{m}^2 \cdot \text{K/W}$ .

During the reconstruction and overhaul of the parts of the building defined by the design documentation, including for the purpose of thermal modernization, for opaque enclosing structures, translucent enclosing structures and external doors in common areas of multi-apartment residential and public buildings, it is allowed to reduce the values of the reduced heat transfer resistance to the level of 75% in accordance  $R_{qmin}$  with table 1 SBR V 2.6-31:2021.

Old buildings, and especially buildings whose facades are of historical value, as well as high-rise buildings of the Soviet era, as a rule, do not have sufficient thermal insulation of their external walls, which could ensure at least the minimum permissible value of the thermal resistance of heat transfer of these walls. Therefore, heating such buildings during the cold period of the year requires significant energy costs, and given the constant increase in the cost of energy carriers, it will become more expensive every year. In the warm period of the year, such houses have another problem – due to the still insufficient thermal resistance of the heat transfer of the external walls, the temperature in the room is too high, which leads either to the discomfort of the residents, or to additional losses for air conditioning and air cooling in their rooms.

It is expedient from the point of view of the moisture regime of the enclosing structures to completely thermally insulate the outer walls of the entire building from the outside, but in this case it is impossible to perform such work in a building of historical construction due to the value of the facade, and in multi-story buildings it is almost impossible due to the mental and financial problems of a large number of residents these houses.

The installation of an internal thermal insulation layer on the outer wall of the room using the ideal material for this case – mineral insulation "BETOL®" makes it possible to solve the indicated problems: to preserve the original facade, to carry out individual insulation by residents of the outer walls of their apartments, to ensure rapid heating of the premises. Similar material has been solving the same problems for many years in Switzerland, Austria, Germany, Poland and other European countries.

However, in the case of installing an internal heat-insulating layer on the outer wall of the room, there is a problem of condensation in this wall during the cold season of the year, which means its destruction. In this regard, it is mandatory for an internally insulated external enclosing structure to assess its moisture condition and determine the possibility of condensation. At the same time, we have established that in order to avoid condensation during the internal thermal insulation of the outer wall of the room, it is necessary to arrange a certain multi-layer structure with a vapor barrier layer.

The condensation zone is determined by the nature of the distribution of the partial pressure of water vapor  $e(x)$  and saturated water vapor  $E(x)$  in the thickness of the layers of the enclosing structure. The partial pressure of water vapor in the thickness of the material in the section  $x$  is determined by the formula:

$$e(x) = e_{in} - \frac{e_{in} - e_{out}}{R_{e\Sigma}} \cdot R_{ex}, \text{ Pa}, \quad (3)$$

where  $e_{in}$  is the partial pressure of the water vapor of the indoor air, Pa, which is determined by the calculated value of relative humidity  $\varphi_{in0}$  depending on the purpose of the house, the value of the partial pressure of the saturated water vapor  $E_{in}$ , which depends on the temperature, according to the formula:

$$e_{in} = 0,01 \cdot \varphi_{in0} \cdot E_{in}, \text{ Pa}, \quad (4)$$

$e_{in}$  is the partial pressure of water vapor of the outside air, determined according to SSU-H B V.2.6-192:2013 Guidelines for the estimated assessment of the heat-humidity state of enclosing structures for the period of the coldest month of the year, Pa;  $R_{e\Sigma}$  – vapor penetration resistance of the enclosing structure,  $\text{m}^2 \cdot \text{h} \cdot \text{Pa} / \text{mg}$ ;  $R_{ex}$  is vapor penetration resistance of the enclosing structure at a distance  $x$  from the inner surface,  $\text{m}^2 \cdot \text{h} \cdot \text{Pa} / \text{mg}$ .

Partial pressure of saturated water vapor  $E(x)$  determined according to the dependency reference  $E(t)$  by temperature distribution  $t(x)$ , which is calculated by the formula:

$$t(x) = t_{in} - \frac{t_{in} - t_{oute}}{R_{\Sigma}} \cdot \left( \frac{1}{\alpha_{in}} + R_x \right), \text{ } ^\circ\text{C}, \quad (5)$$

where  $t_{oute}$  is calculated outdoor air temperature for the process of moisture accumulation in the structure, determined according to SSU-NB V.1.1-27:2010 Building climatology for the period of the coldest month of the year,  $^\circ\text{C}$ ;  $R_x$  is thermal resistance of the enclosing structure at a distance  $x$  from the inner surface,  $\text{m}^2 \cdot \text{K} / \text{W}$ .

The resistance to vapor penetration of the enclosing structure and its individual layers is calculated according to the formulas:

$$R_{e\Sigma} = \sum_{i=1}^n \frac{\delta_i}{\mu_i}, \text{ m}^2 \cdot \text{h} \cdot \text{Pa} / \text{mg}, \quad (6)$$

$$R_{ex} = \sum_{i=1}^m \frac{\delta_i}{\mu_i} + \frac{x - \sum_{i=1}^m \delta_i}{\mu_{m+1}}, \text{ m}^2 \cdot \text{h} \cdot \text{Pa} / \text{mg}, \quad (7)$$

where  $n$  is total number of layers in the structure;  $m$  is the number of complete layers from the inner surface to the cross-section  $x$ ;  $\mu_i$  is vapor permeability of the material of the  $i$ -th layer of the structure,  $\text{mg} / (\text{m} \cdot \text{h} \cdot \text{Pa})$ ;  $\mu_{m+1}$  is vapor permeability of the material of the construction layer,  $\text{mg} / (\text{m} \cdot \text{h} \cdot \text{Pa})$ , where the section is located  $x$ .

In case, if  $e(x) > E(x)$  in a certain thickness of the enclosing structure, moisture condensation occurs in it.

Fig. 1. Internally heat-insulated enclosing structure without a vapor barrier: 1 is ordinary solid brick masonry is outer layer:  $\rho_0 = 1800 \text{ kg/m}^3$ ;  $\delta_1 = 380 \text{ mm}$ ;

$$\lambda_{1B} = 0,81 \text{ W/(m}\cdot\text{K)}; \mu_1 = 0,11 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)};$$

2 is masonry from heat-insulating board "BETOL®" is inner layer:  $\rho_0 = 200 \text{ kg/m}^3$ ;  $\delta_2 = 100 \text{ mm}$ ;

$$\lambda_{2B} = 0,074 \text{ W/(m}\cdot\text{K)}; \mu_2 = 0,28 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)};$$

3 is plasterboard sheet:  $\rho_0 = 800 \text{ kg/m}^3$ ;  $\delta_3 = 9,5 \text{ mm}$ ;

$$\lambda_{3B} = 0,21 \text{ W/(m}\cdot\text{K)}; \mu_3 = 0,075 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)}$$

Fig. 2. Internally heat-insulated enclosing structure with a vapor barrier: 1 is ordinary solid brick masonry - outer layer:  $\rho_0 = 1800 \text{ kg/m}^3$ ;  $\delta_1 = 380 \text{ mm}$ ;

$$\lambda_{1B} = 0,81 \text{ W/(m}\cdot\text{K)}; \mu_1 = 0,11 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)};$$

2 is masonry from heat-insulating board "BETOL®" is inner layer:  $\rho_0 = 200 \text{ kg/m}^3$ ;  $\delta_2 = 100 \text{ mm}$ ;

$$\lambda_{2B} = 0,074 \text{ W/(m}\cdot\text{K)}; \mu_2 = 0,28 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)};$$

3 is plasterboard sheet:  $\rho_0 = 800 \text{ kg/m}^3$ ;  $\delta_3 = 9,5 \text{ mm}$ ;

$$\lambda_{3B} = 0,21 \text{ W/(m}\cdot\text{K)}; \mu_3 = 0,075 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)};$$

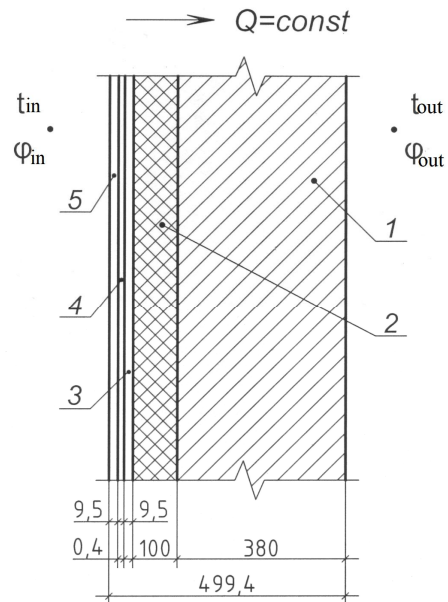
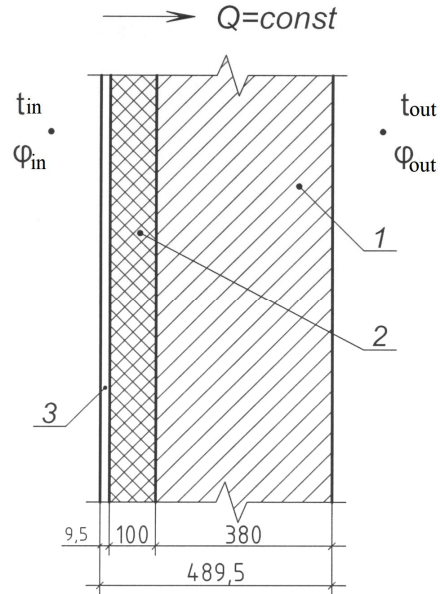
4 is aluminum foil - vapor barrier:  $\rho = 2600 \text{ kg/m}^3$ ;

$$= 0,4 \text{ mm}; \lambda_{4B} = 221 \text{ W/(m}\cdot\text{K)}; \mu_4 = 0,00001$$

$\text{mg/(m}\cdot\text{h}\cdot\text{Pa)}$ ; 5 – plasterboard sheet:  $\rho_0 = 800 \text{ kg/m}^3$ ;

$$\delta_5 = 9,5 \text{ mm}; \lambda_{5B} = 0,21 \text{ W/(m}\cdot\text{K)};$$

$$\mu_5 = 0,075 \text{ mg/(m}\cdot\text{h}\cdot\text{Pa)}$$



## Results and discussion

Consider the temperature distribution  $t(x)$ , distribution of partial pressure of saturated water vapor  $E(x)$  and its partial pressure  $e(x)$  and relative humidity distribution  $\varphi(x) = e(x)/E(x)$  in the thickness of two internally heat-insulated enclosing structures in the cold period of the year, one of which is without a vapor barrier with thermal resistance to heat transfer  $R_{\Sigma} = 2,02 \text{ m}^2\cdot\text{K/W}$  (**Fig. 1**), and the second – with our proposed vapor barrier made of aluminum foil with thermal resistance of heat transfer  $R_{\Sigma} = 2,07 \text{ m}^2\cdot\text{K/W}$  (**Fig. 2**), located in the city of Lviv, which belongs to the I temperature zone, for which  $0,75 \cdot R_{\text{norm}} = 3,0 \text{ m}^2\cdot\text{K/W}$ , and the operating conditions of the enclosing structures – Б.

From fig. 5 and 7, it can be seen that condensation occurs under the internal thermal insulation of the enclosing structures of rooms without a vapor barrier, when  $e(x) > E(x)$  i  $\varphi(x) > 100\%$ , and from fig. 6 and 8, respectively, it can be seen that the use of a vapor barrier – aluminum foil excludes the possibility of condensation during the internal thermal insulation of the enclosing structures of the premises, because  $E(x) > e(x)$  i  $\varphi(x) < 100\%$  in the entire thickness of the structure.

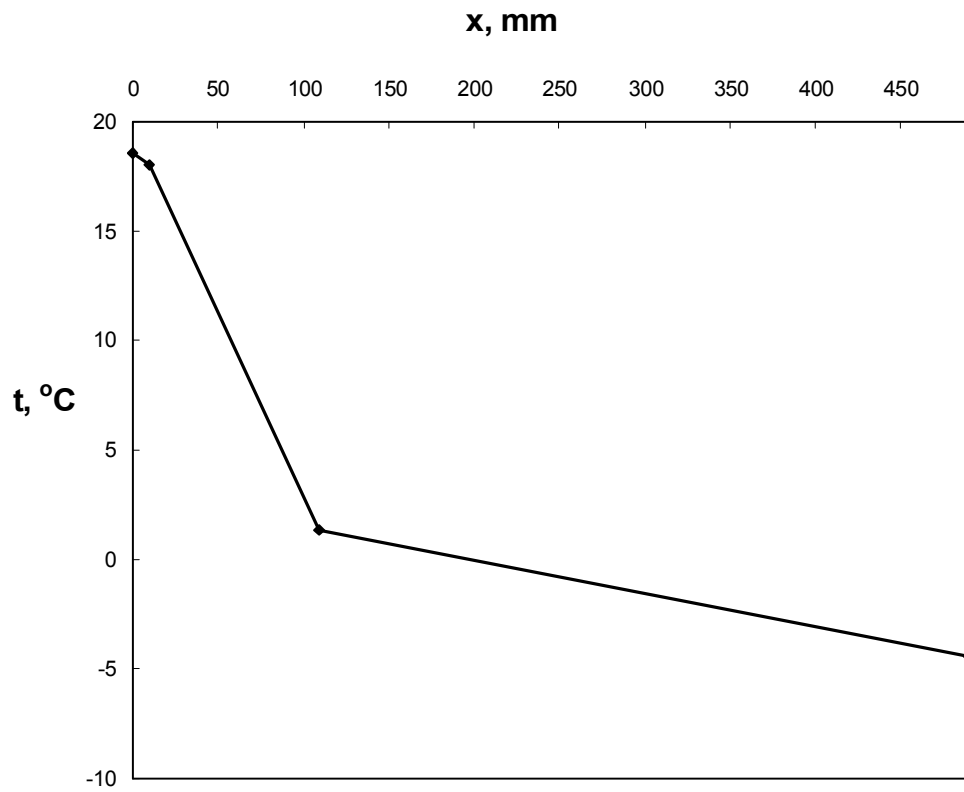


Fig. 3. Temperature distribution  $t(x)$  in the internally insulated layer an enclosing structure without a vapor barrier in the cold period of the year

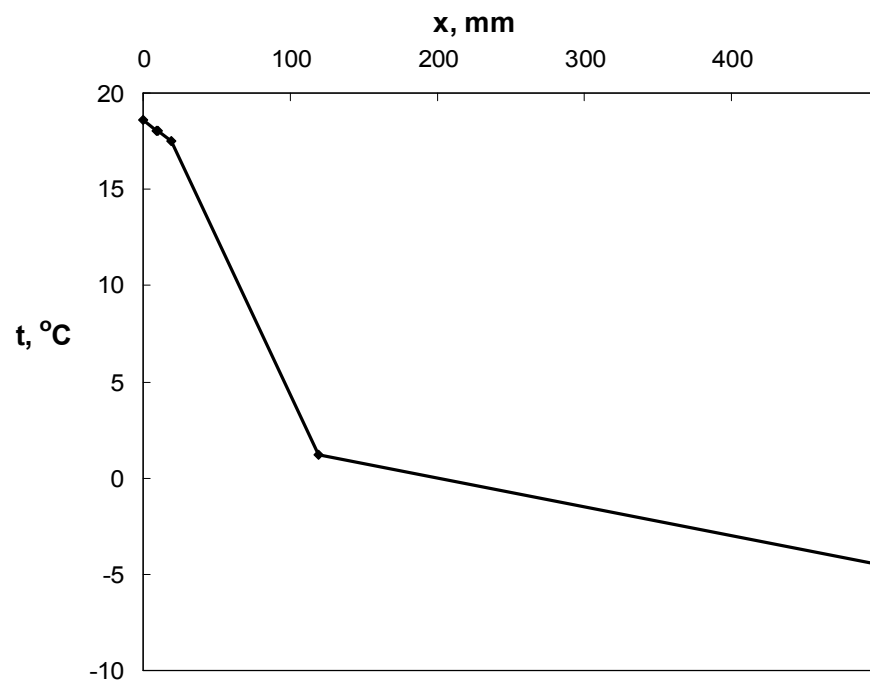


Fig. 4. Temperature distribution  $t(x)$  in the internally insulated layer of an enclosing structure with a vapor barrier in the cold period of the year

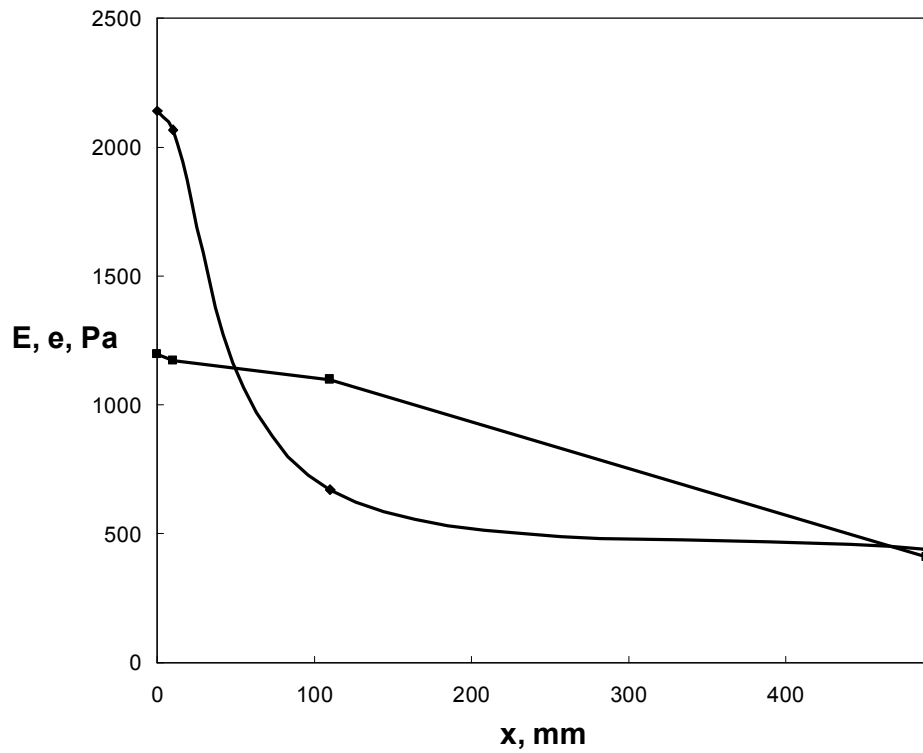


Fig. 5. Distribution of the partial pressure of saturated water vapor  $E(x)$  and its partial pressure  $e(x)$  in the thickness of an internally heat-insulated enclosing structure without a vapor barrier in the cold period of the year:  $\blacklozenge - E(x)$ ;  $\blacksquare - e(x)$

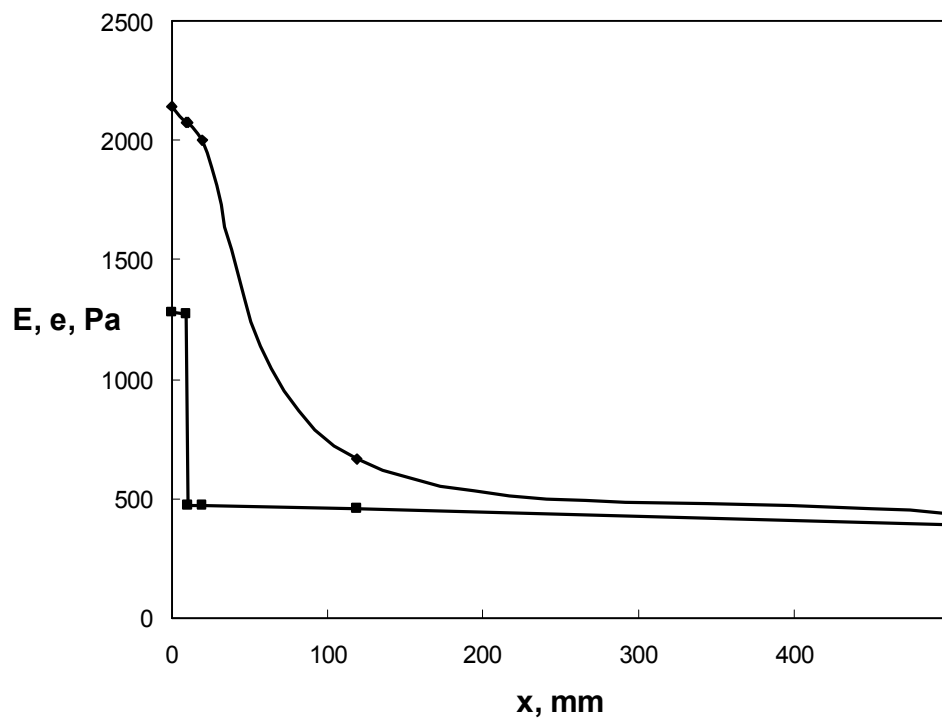


Fig. 6. Distribution of the partial pressure of saturated water vapor  $E(x)$  and its partial pressure  $e(x)$  in the thickness of an internally heat-insulated enclosing structure with a vapor barrier in the cold period of the year:  $\blacklozenge - E(x)$ ;  $\blacksquare - e(x)$

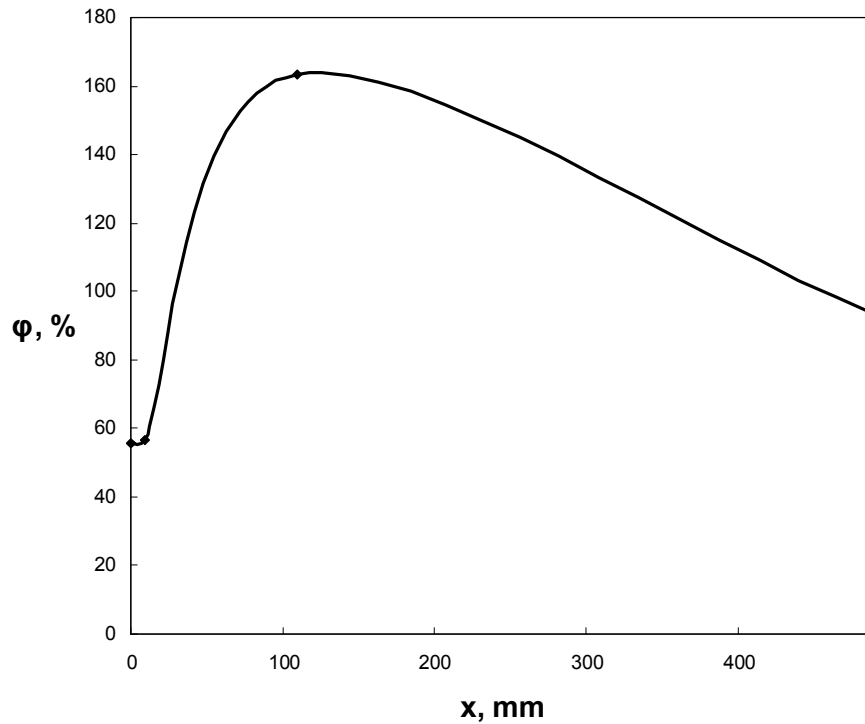


Fig. 7. Distribution of relative humidity  $\varphi(x) = e(x) \cdot 100/E(x)$ , %  
in the thickness of an internally heat-insulated enclosing structure without a vapor barrier  
in the cold period of the year

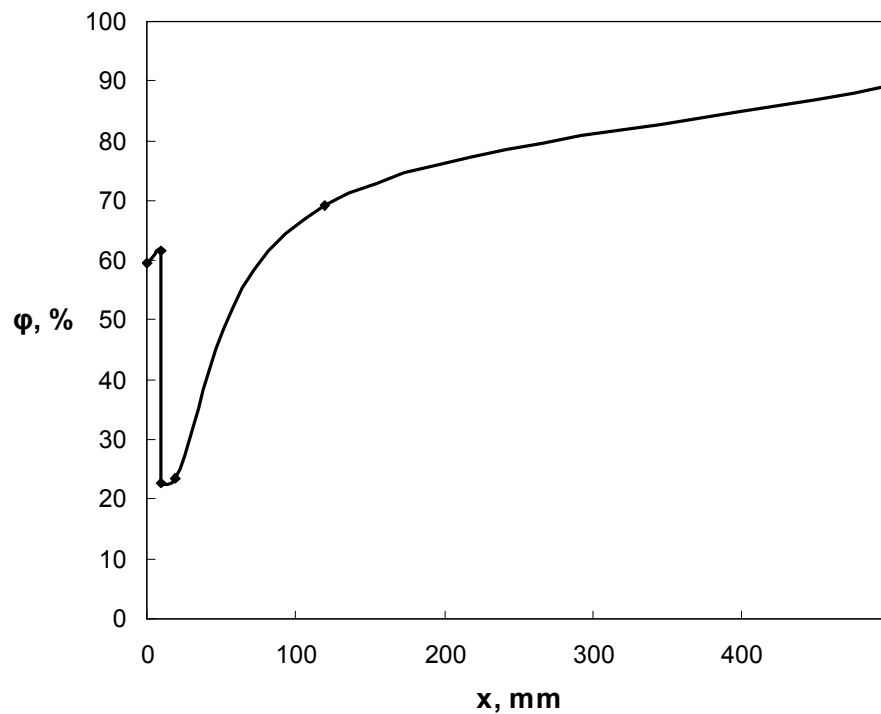


Рис. 8. Distribution of relative humidity  $\varphi(x) = e(x) \cdot 100/E(x)$ , %  
in the thickness of the internally heat-insulated enclosing structure with a vapor barrier  
in the cold period of the year

## Conclusions

During the installation of internal thermal insulation of the enclosing structures of the premises, it is necessary to perform not only an assessment of the thermal, but also the moisture condition of the structure.

Internal thermal insulation of the enclosing structures of the premises with the use of mineral insulation "BETOL®" is possible with the use of a vapor barrier – aluminum foil.

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**В.Й. Лабай<sup>1</sup>, Г.І. Верещинська<sup>2</sup>**

<sup>1</sup> Кафедра теплогазопостачання і вентиляції,  
Національний університет "Львівська політехніка"

<sup>2</sup> ВСП Техніко-економічний фаховий коледж  
Національного університету "Львівська політехніка"

## **СПОСІБ УЛАШТУВАННЯ ВНУТРІШНЬОЇ ТЕПЛОВОЇ ІЗОЛЯЦІЇ ЗОВНІШНІХ ЗАХИСНИХ КОНСТРУКЦІЙ ПРИМІЩЕННЯ**

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Зменшення енергоспоживання існуючих будівель зараз є однією з ключових проблем у будівельній галузі. У будівлях з низьким енергоспоживанням втрати тепла не повинні перевищувати 5 %. Отже, існує нагальна потреба покращити теплові характеристики зовнішніх стін шляхом теплоізоляції. В сучасному будівництві, зазвичай, застосовують зовнішнє утеплення стін будинків, проте трапляються випадки, (пам'ятки архітектури) коли такий спосіб виконання є неприпустимим, тоді внутрішня ізоляція стає єдиним доступним рішенням.

Ця стаття має на меті обговорити екстремальні умови, за яких можна уникнути конденсації, тим самим уникнути руйнування огорожувальної конструкції. В роботі представлено дослідження енергозберігаючої конструкції фасаду житлового будинку, в якому використовуються ізоляційні матеріали, які придатні для цілей внутрішньої ізоляції історичних будівель.

Проведений аналіз вітчизняних та європейських літературних джерел, що стосуються підвищення рівня теплового захисту будівель та енергозбереження, свідчить про те, що підвищення енергоефективності є важливим для забезпечення сталої, доступної та безпечної енергетичної системи.

У роботі представлені результати дослідження, спрямованого на підвищення енергоефективності в житлових будинках, а також аналіз вологісного стану та можливості утворення конденсату при застосуванні внутрішнього утеплення. Для підтвердження результатів було проведено чисельне моделювання. Отримані результати свідчать про те, що використання мінерального утеплювача "БЕТОЛЬ®" та алюмінієвої фольги використаної в ролі паробар'єру, накладених зсередини, сприяє покращенню теплоізоляції стін і знижує ризики утворення конденсату.

Комп'ютерне моделювання продемонструвало, що за розглянутих умов конденсація не виникає. Це дослідження вносить важливий внесок у розвиток енергоефективних рішень для будівельної галузі так, як дозволить забезпечити мінімально допустиме значення опору теплопередачі зовнішніх огорожень, подовжити їх термін експлуатації.

**Ключові слова:** внутрішня тепла ізоляція, паробар'єр, паропроникнення, відносна вологість, енергоефективність, енергозбереження.