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Moisture regime of enclosure structures with insulation layer in educational buildings

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ABSTRACT

An assessment of the moisture regime of the external enclosing structures of the building with a layer of insulation on the outer and inner sides was carried out, considering the thermophysical characteristics of all materials of the outer wall of the building. It is shown that brickwork without insulation to preserve the estimated term of its optimal operation, requires taking measures to bring its thermal resistance to heat transfer to a standardized value or to arrange more intensive air exchange in the premises of the building. It has been proven that when designing residential and public buildings, the results of assessing the moisture regime of external enclosing structures and the building's energy indicators for compliance with current requirements are a very important criterion.

KEYWORDS

enclosure structure, humidity regime, dew point, partial pressure, water vapor

1. INTRODUCTION

The implementation and operation of buildings in the European Union accounts for about 40% of total energy consumption. Ensuring the necessary microclimate in the premises of educational institutions is an important problem, since they occupy a significant share of the total energy consumption. Comfortable conditions in the room require constant adjustment, paying attention to the condition of the people who are in it. Many authors were engaged in microclimate research, which indicates the relevance of this topic [1]. The articles [2, 3] investigated a higher educational institution in which the air quality during education was determined. An assessment of air quality was carried out based on the measured parameters and the results of the questionnaire in the selected class.

One of the elements of the rationalization of energy consumption in buildings is the thermal modernization of buildings. Mistakes in the implementation of the energy efficiency program led to the phenomenon of the syndrome of sick buildings. The articles [4, 5] present the results of research conducted in several educational buildings before and after thermal modernization.

One of the important measures, which is used along with the insulation of the external walls of buildings, is the modernization of thermal points. These measures are relevant for Ukraine and Europe, which is described in [6–8]. Heating systems also play an important role in the energy consumption of public buildings [9–14].

An important point in energy saving is the study of annual energy consumption and annual final energy consumption for heating educational buildings [15]. The article [16] proved the direct influence of the quality of construction work on annual heat consumption.

This proves the relevance of energy saving measures, in particular the importance of thermal renovation of buildings.

During the reconstruction of existing buildings, as well as the construction of new buildings, great attention is paid to increasing their thermal stability and reducing air tightness. The moisture content of the materials of the enclosing structure determines its durability, the suitability of the structure for operation, the level of heat flows in the heating period of the year and, accordingly, the characteristics of energy efficiency and thermal efficiency [17–19]. Therefore, already at the stage of designing external fences, it is necessary to take measures to prevent the possibility of wetting of the materials of the fence structure, to exclude the possibility of condensation of water vapor both on the inner surface and in the thickness of the fence [20, 21]. All this testifies to the exceptional importance of design calculations of the wet regime of enclosing structures. This is important for maintaining a satisfactory microclimate in the premises of educational institutions [22–24].

When designing the thermal insulation shell of existing buildings based on multilayer structures, during their thermal modernization and implementation of energy-saving measures or major repairs, there is a need to choose the optimal insulation thickness and its location (from the inside or outside of the building's external wall) [25, 26].

Modeling of the porous material, which is the thermal insulation material of the external walls of the building, was carried out [27–29]. The proposed model of the studied material allows solving complex problems of heat and mass transfer through external protection.

According to [30, 31] layers of thermal insulation materials should be laid on the outside of the load-bearing part of the wall, using external wall designs with facade insulation. It is not recommended to use structural solutions with layers of heat-insulating materials on the inside of the structure due to the possible excessive accumulation of moisture in the heat-insulating layer, which leads to an unsatisfactory heat-humidity condition of the structure and the room, as well as to a decrease in the thermal reliability of the enclosing structures. This article will be devoted to the study of the thermal reliability of enclosing structures when using thermal insulation materials.

2. PREVIOUS RESEARCH AND PROBLEM STATEMENT

Various methods of studying thermal processes in the room were analyzed: theoretical, experimental and numerical modeling [32–34] methods. At the same time, various mathematical models [35–36] were taken into account. Considering the special status of the issue, the Scientific Research Institute of Building Structures has developed an automated calculation program for assessing the moisture regime of external fences. The program is called “Moisture mode of enclosing structures” and is intended for applied

calculations by design engineers of the moisture mode. When developing the program, the positive experience of similar development was taken into account—the computer version of the program for calculating the Energy Passport of the house.

However, today, for the majority of typical structures, there are no publicly available graphical representations of the distribution of its temperature and humidity indicators over the thickness of the structure, which indicates the need to perform calculations each time to assess the moisture regime of external fences. These studies and calculations are aimed at choosing the optimal location of the insulation, from the point of view of construction physics.

3. THE PURPOSE OF THE ARTICLE

The purpose of the article is to study the distribution of temperature-humidity indicators of the external enclosing structures of the educational building of the National University of Life and Environmental Sciences (NULES) of Ukraine with different locations of the insulation layer.

4. MATERIALS AND METHODS

For conducting research, the starting conditions were the following characteristics of the external walls of the building of educational building of NULES of Ukraine: from masonry of ceramic full-bodied brick, thickness 510 mm, are insulated with mineral wool plates ($\lambda = 0.045 \text{ W/(m}\cdot\text{K)}$), $\gamma = 135 \text{ kg/m}^3$), thickness 150 mm (0.15 m), on the adhesive solution Ceresit, thickness 5 mm (0.005 m), exterior decoration (the adhesive solution Ceresit, thickness 2 mm (0.002 m), and decorative plaster, thickness 2.5 mm (0.0025 m) and internal cement-sand plaster ($\delta = 20 \text{ mm}$ (0.02 m)).

Below the temperature field of the node of the corner connection of the walls is shown (Fig. 1).

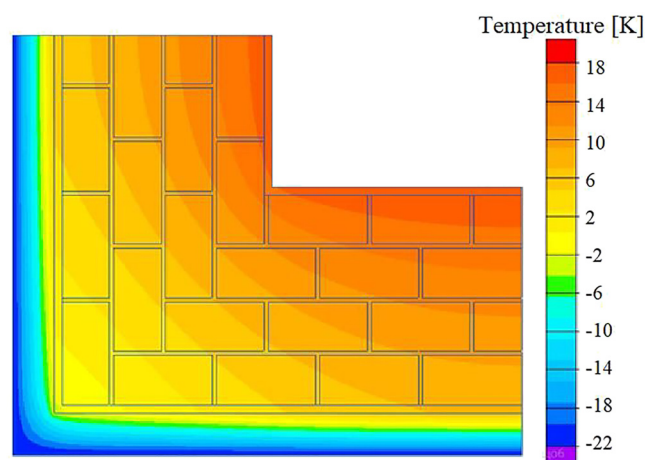


Fig. 1. Temperature field of the node of the corner connection of the walls

To calculate the “dew point”, a diagram of the heat-humidity state of the enclosing structure using was built (Fig. 2). Using the diagram in Fig. 2, the “dew point” temperature at $t_{in} = 20\text{ }^{\circ}\text{C}$ and $\varphi_{in} = 55\%$ for a brick wall and get for the outer wall of the building $\tau_{dp} - \tau_p = 10.4\text{ }^{\circ}\text{C}$ was found. Humidity 55% was taken as the average value according to the normative of 40–70% for public buildings.

Condensate on the plane of the inner surface of the wall will form if $\tau_{in} \leq \tau_{dp}$. Since $18.7\text{ }^{\circ}\text{C} > 10.4\text{ }^{\circ}\text{C}$, then there will be no condensation and the design of the outer wall meets the requirements of current standards of Ukraine.

The temperature of the outer surface of the wall depends on the heat transfer coefficient, which is affected by the wind speed. The higher the wind speed, the higher the heat transfer coefficient and the lower the thermal resistance.

In order to achieve universality, it is necessary to analyze the options with other insulation, since it is characterized by different parameters, primarily thermal conductivity coefficients and cost.

In this regard, it is advisable to construct 2 graphs: 1 is a graph of the dependence of the dimensionless thickness of the insulation δ on the dimensionless thermal conductivity coefficient $\bar{\lambda}$; 2 is a graph of the dimensionless value C of the insulation against the dimensionless coefficient of thermal conductivity $\bar{\lambda}$ (Fig. 3).

All dimensionless quantities δ , C and $\bar{\lambda}$ represent the ratio of the current value to the maximum value, for example, the dimensionless thermal conductivity coefficient is the ratio of the current thermal conductivity λ [W/(m·K)] to the maximum λ_{max} [W/(m·K)]. The representation of values in a dimensionless form is universal and allows performing the necessary mathematical operations.

When Fig. 3 is constructing, the following assumptions and simplifications were adopted:

- since the schedule must be universal, it is endowed with qualitative parameters, that is, it is made schematically without taking into account the scale (quantitative indicators should not be displayed);

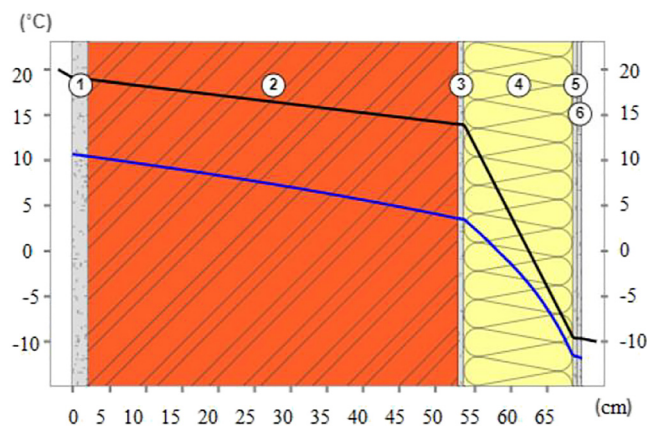


Fig. 2. Diagram of the heat-humidity state of the enclosing structure, 1) Cement-sand solution; 2) Brickwork; 3) Adhesive mixture (Ceresit CT 190); 4) Mineral wool insulation; 5) Adhesive mixture (Ceresit CT 190); 6) External plaster

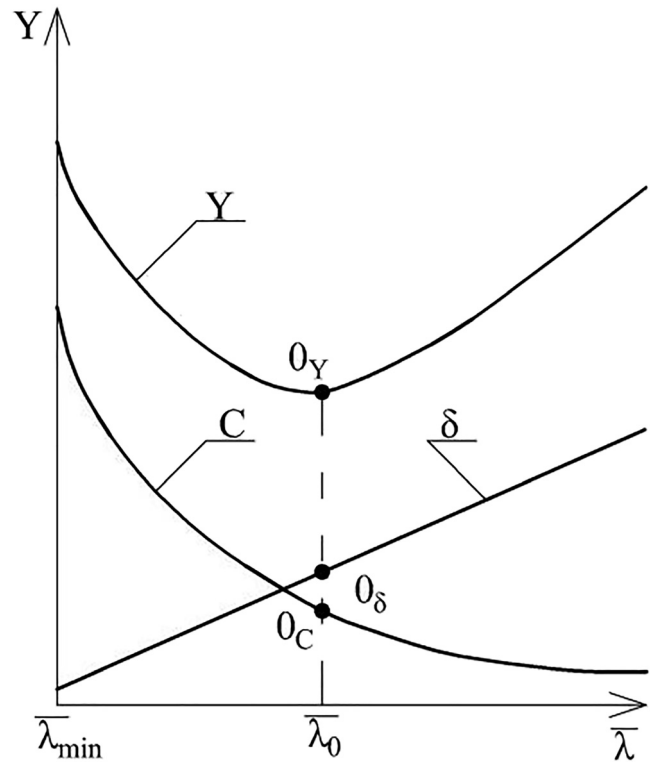


Fig. 3. Graphs of the dependence of the dimensionless thickness of the insulation δ (line δ) and the dimensionless cost of the insulation C (line C) on the dimensionless thermal conductivity coefficient $\bar{\lambda}$

- a non-linear mathematical model is adopted.

These graphs make it possible to draw a conclusion about the optimal coefficient of thermal conductivity of the heat-insulating material based on the cost and thickness of the insulation, subject to the required thermal resistance. As it can be seen from Fig. 3, this will be the minimum point of the dimensionless function Y , which is the sum of the dimensionless values δ and C . Due to Fig. 3, it is possible to expand the list of heat-insulating materials, since under these conditions, intermediate values $\bar{\lambda}$ from a continuous interval according to the initial data are considered.

Let us determine the minimum point of function $Y(\bar{\lambda})$ due to analytical method. This function $Y(\bar{\lambda})$ is size less, therefore it can be presented as sum of 2 size less functions $\delta(\bar{\lambda})$ (straight line) and $C(\bar{\lambda})$ (hyperbolic one) as Eq. (1):

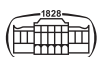
$$Y = \delta_0 + k\bar{\lambda} + \frac{a}{\bar{\lambda}}, \quad (1)$$

where a and δ_0 are constant unitless coefficients; k is the angular unitless coefficient of the straight line.

After differentiation of Eq. (1) it is obtained as minimum point $\bar{\lambda}_0$:

$$\bar{\lambda}_0 = \sqrt{\frac{a}{k}}. \quad (2)$$

Due to Eq. (2) the a value can be determined with very high accuracy, because analytical method is more accurate,



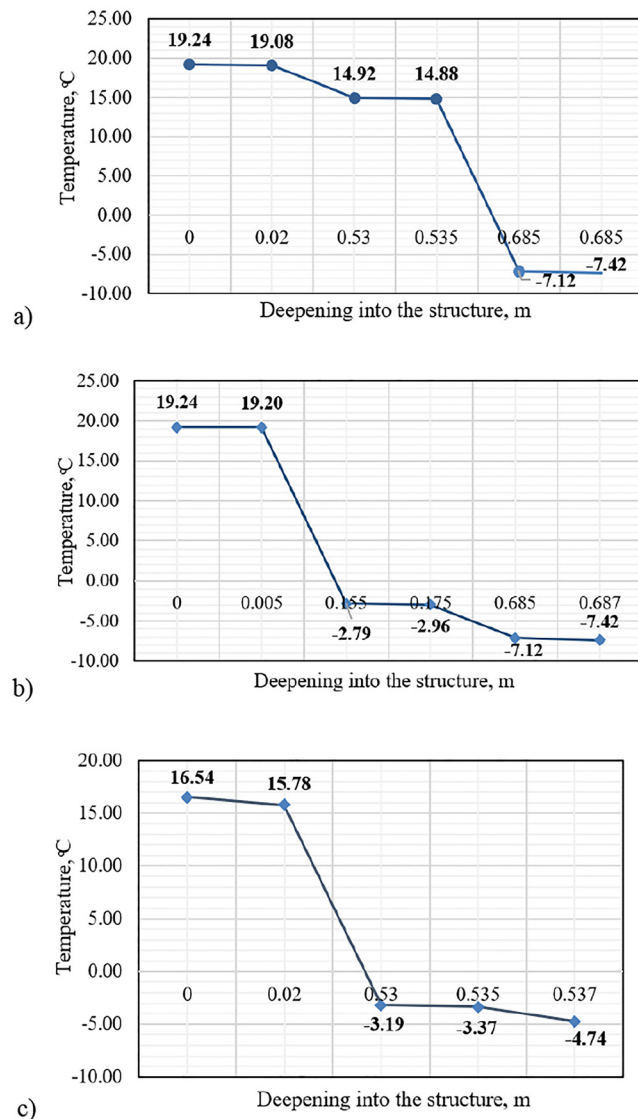


Fig. 4. Temperature distribution in the thickness of the thickness of a brick wall with insulation

than graphical one. An increase in the relative coefficient of thermal conductivity of the insulation leads to an increase in its thickness and a decrease in its relative cost, and therefore to the need to determine its optimal value. The ratio of coefficients a and k , that is, the relative cost of the insulation to its thermal resistance, is decisive. This factor should be considered when choosing a heat-insulating material. The right choice provides a solution to the problem in both technical and economic aspects.

The proposed method can be used for buildings of various purposes in any climatic zone, i.e., in all European countries.

5. RESEARCH RESULTS AND DISCUSSION

The assessment of the moisture regime of the enclosing structures was carried out for closed areas of the main field

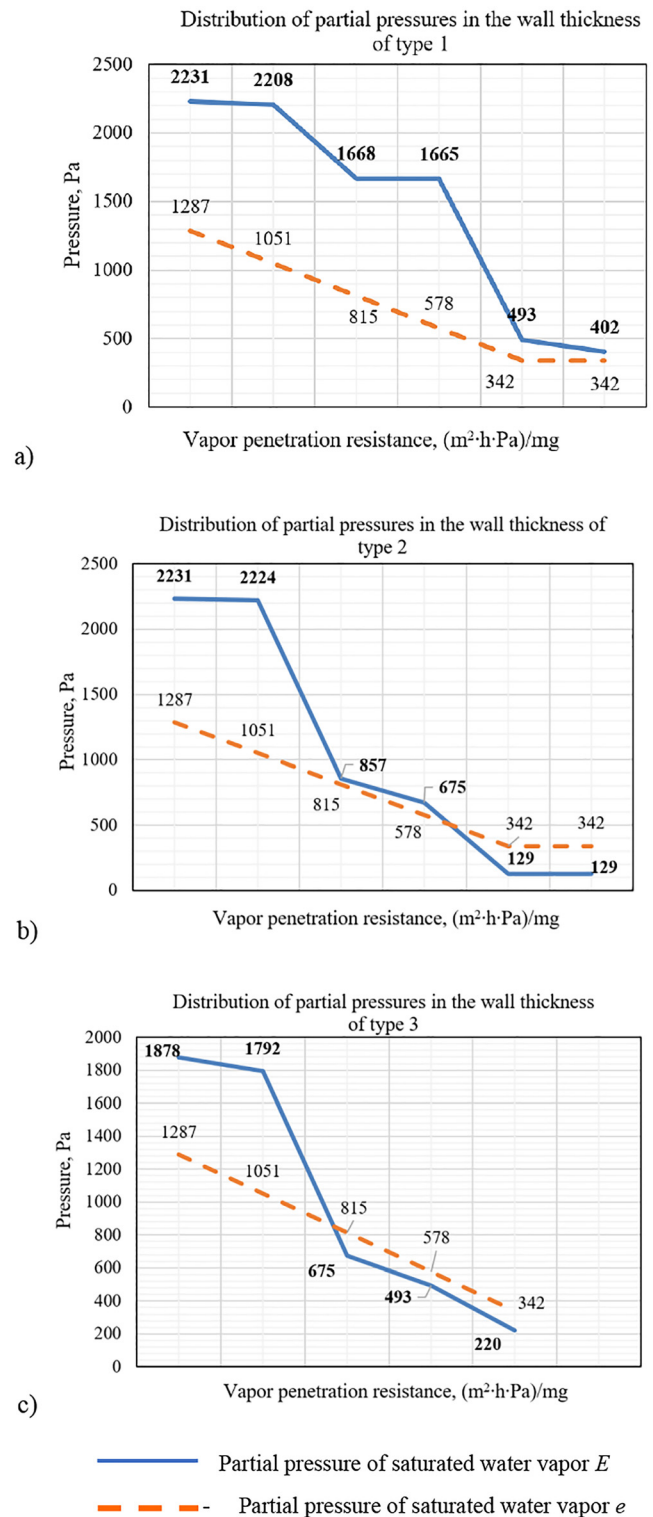


Fig. 5. Distribution of partial pressures in the thickness of a brick wall with insulation

of external walls. First, the results of the study of the construction of the external wall made of ceramic solid brick masonry with insulation from the outside (type 1), then - from the inside (type 2) and without insulation (type 3), which is characteristic of educational building of NULES of Ukraine (the building belongs to an architectural monument

of local importance), which makes it impossible to insulate it from the outside.

The images in Fig. 4 show the calculation of the heat-humidity condition of brickwork made of ceramic solid bricks and mineral wool insulation from the outside (Fig. 4a) without installing a ventilated air layer, then from the inside (Fig. 4b) and without insulation (Fig. 4c).

On the scale of resistance to vapor penetration, the dependence of the partial pressure of saturated water vapor and the partial pressure of water vapor was built: brickwork made of ceramic solid bricks and mineral wool insulation from the outside (Fig. 5a) without installing a ventilated air layer, from inside (Fig. 5b) and without insulation (Fig. 5c).

Since lines E and e in Fig. 5a do not intersect, this indicates that the process of condensation of water vapor in the thickness of the enclosing structure does not occur. A completely different situation in Fig. 5b and c, where the lines intersect, which negatively affects the heat-humidity condition of the enclosing structures and indicates the inexpediency of insulating brickwork made of ceramic solid bricks with mineral wool insulation from the inside. In addition, brickwork without insulation, in order to preserve the estimated term of its optimal operation, also requires measures to bring its thermal resistance to heat transfer to a standardized value or arrange more intensive air exchange in the premises of the building. However, the latter can cause additional energy costs. The feasibility of one or another approach should be considered in more detail from the point of view of comparing operating costs and energy losses of the building.

Adequacy of the theory of the experiment is confirmed by the Student, Cochran and Fisher criteria with a confidence probability of 95%.

As future research, it is planned to study the humidity regime of the room under the action of radiant heating using infrared heaters.

5. CONCLUSIONS

The obtained research results allow to clearly determine the constructive solution of external fences already at the stage of development of project documentation. For each specific design solution, the optimal location of the insulation is established, based on the condition of non-accumulation of moisture in the thickness of the structure under study. So, with a correct assessment of the humidity regime, structures with internal insulation cannot be used. As can be seen, for this type of design, condensation of moisture occurs in the thickness of the insulation, which is unacceptable.

It is shown that brickwork without insulation, in order to preserve the estimated term of its optimal operation also needs to take measures to bring its thermal resistance to heat transfer to a standardized value or arrange more intensive air exchange in the premises of the building. However, the latter can cause additional energy costs. The feasibility of one or another approach should be considered in more

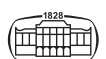
detail from the point of view of comparing operating costs and energy losses of the building.

It has been proven that when designing residential and public buildings, the results of assessing the moisture regime of external enclosing structures and the building's energy indicators for compliance with current requirements are very important criterion when choosing a supplier of building materials from a large assortment on the market, which can be decisive in making a specific design decision.

When choosing a heat-insulating material, one should consider its thermal conductivity coefficient and cost, which combines its heat-technical properties and economic characteristics. The method of determining the optimal isolation material, concerning its costs and the thermal resistance are presented.

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