Analysis of the Humidity Condition of Wall Enclosing Structures of Cooling Warehouses and Possible Ways to Improve It

Oleg Yurin, Nurmammad Mammadov, Pavlo Semko, and Nataliia Mahas

Abstract The paper deals with the wall enclosing structures of cooling warehouses, erected recently (which mainly use metal sandwich panels) and erected in the second half of the 20th century (using bricks, expanded clay and reinforced concrete panels and effective insulation). The analysis of a humidity condition of wall enclosing structures of cooling warehouses which showed their unsatisfactory condition is executed. The analysis of possible ways to improve the humidity condition of wall enclosing structures of existing cooling warehouses, such as: reducing the thickness of the outer layer from the cooled premises, increasing the resistance to vapor penetration of the vapor barrier layer, using of ventilated air layer between the inner outer and insulation. The analysis showed that it is possible to fulfill the norms of the humidity state by reducing the thickness of the inner outer layer to 5 mm or by using a ventilated air layer which ventilated by air from the cooled premises.

Keywords Humidity condition · Insulation · Enclosing walls of cooling warehouses

1 Introduction

The operations main problem of cooling warehouses' buildings is maintenance of heat-protective qualities of enclosing designs at the norm recommended level which to a large extent depend on their humidity condition.

Recently, the sandwich panels, which consist of effective insulation and metal cladding layers are mainly used in the construction of cooling warehouses. The humidity condition of such fencing structures largely depends on the quality of the joints of sandwich panels and the quality of work performed during the construction of fences. At the same time, there are a large number of cooling warehouses erected

O. Yurin · P. Semko · N. Mahas (✉)
National University "Yuri Kondratyuk Poltava Polytechnic", Poltava, Ukraine

N. Mammadov
Azerbaijan University of Architecture and Construction, Ayna Sultanova 11, Baku, Azerbaijan

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in the second half of the 20th century, in which bricks, expanded clay concrete and reinforced concrete panels with a layer of effective insulation were used as enclosing structures. As the experience of operation of such enclosing structures has shown, the humidity condition of the insulation in them and, as a consequence, the heat-protective properties are in unsatisfactory condition. During the service life of these buildings, the humidity of the insulation becomes significant. In some cases, there are formation of ice on the surfaces of the structural layers adjacent to the surface of the insulation from the cooled premises.

The humidity condition of the enclosing structures of cooling buildings is significantly different from the humidity condition of the enclosing structures of residential and public buildings. This is due to the fact that the flow of vaporous moisture in the cooling warehouses throughout the year moves in one direction—in the middle of the premises. While in the fences of residential and public buildings, this flow changes its direction during the year. In winter it moves from the premises to the outside, and in summer to the premises. That is, the period of humidity accumulation in the enclosing structures in winter changes to the period of humidity return in summer. And in protections of cooling warehouses there is a constant moisture accumulation. The fact that the structural layer in these structures is sometimes located on the inside also contributes to the accumulation of moisture. It slows down the release of moisture from the enclosing structures into the middle of the premises. The greater the density of this layer, the more humidity condenses in the enclosure. The search for ways to improve the humidity condition of enclosing structures was studied by the authors in [1–3], the thermal condition of enclosing structures improvement was also studied in [4–13]. Therefore, the study of the humidity condition of wall enclosing structures, search and analysis of possible ways to improve the moisture condition of wall enclosing structures of existing cooling warehouses is an urgent task of the study.

2 Analysis of the Humidity State of the Enclosing Wall Structures of Existing Cooling Warehouses

According to the existing standards for thermal protection and humidity [14–17] of enclosing structures for cooling warehouses, the required resistance to heat transfer of the outer walls of refrigerated premises for summer conditions for different climatic regions should be taken according to Table 1, the required resistance to vapor barrier in enclosing structures according to the Table 2.

Estimated values of temperature and relative humidity in refrigerated warehouses depend on the type of products stored in them. The values of these parameters for the most common products are given in the Table 3.

Assessment of the humidity condition of the enclosing structures was performed according to the method given in [9] for the climatic conditions of Poltava region. The humidity condition of the enclosing structures is the worst in July at the lowest

Table 1 The required heat transfer resistance depending on the air temperature in the cooled premises, m^2 °C/Watt

Average annual outdoor air temperature in the construction area, °C	−30 °C	−20 °C	−10 °C	−5 °C	0 °C	5 °C	12 °C
−2 °C and lower	4,8	3,9	3,1	2,6	2,4	2,1	1,9
Upper −2 °C and lower	5,1	4,3	3,6	2,8	2,4	2,1	1,9
7–2 °C and upper	5,4	4,8	4,3	3,7	3,3	2,8	2,2

Table 2 Necessary resistance to vapor penetration of vapor barrier depending on air temperature in the cooled premises, m^2 °C/Watt

Estimated humidity of the outside air in the construction area, gPa	−10 °C and lower	From −9 °C to 1 °C
To 14	6,6	2,7
From 14 to 18	9,3	4,6
More 18	13,3	6,6

Table 3 Temperature-humidity regime of cooled premises

Type of premises	Estimated temperature, °C	Estimated relative humidity, %
Long-term storage of ice cream, pork, poultry, fatty fish	−30	95
Storage of frozen products (meat, butter, fish)	−25	95
Storage of fats, mélange	−20	95
Long-term storage of frozen cheese	−20	85
Storage of herring and salted fish	−10	95
Short-term oil storage	−5	85
Storage of chilled eggs	−2	90
Storage of ghee	0	85
Storage of culinary products	2	80

indoor air temperature. Therefore, Table 3 adopted the calculated temperature of the indoor air $t_B = -30$ °C, and its relative humidity 95%.

According to the accepted calculation schemes (Fig. 1) for enclosing wall structures made of brick, expanded clay concrete panels and reinforced concrete panels, the characteristics of the enclosing structure layers the minimum insulation thicknesses and vapor permeability resistance of the vapor barrier layers were determined.

Calculations of humidity accumulation and humidity return were performed for all months of the year, conditional cross sections of enclosing structures with obtained

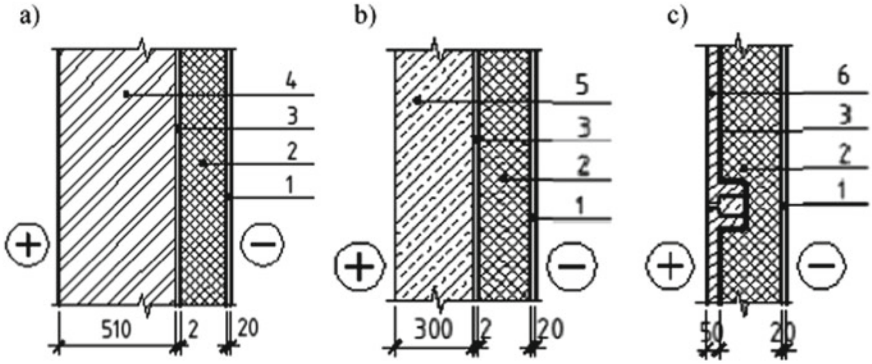

Fig. 1 Calculation scheme of the enclosing structure: **a** enclosing structure made of bricks, **b** enclosing structure made of expanded clay concrete panels, **c** enclosing structure made of reinforced concrete panels; 1—outer layer, 2—insulation, 3—vapor barrier, 4—brick, 5—expanded clay concrete panel, 6—reinforced concrete panel

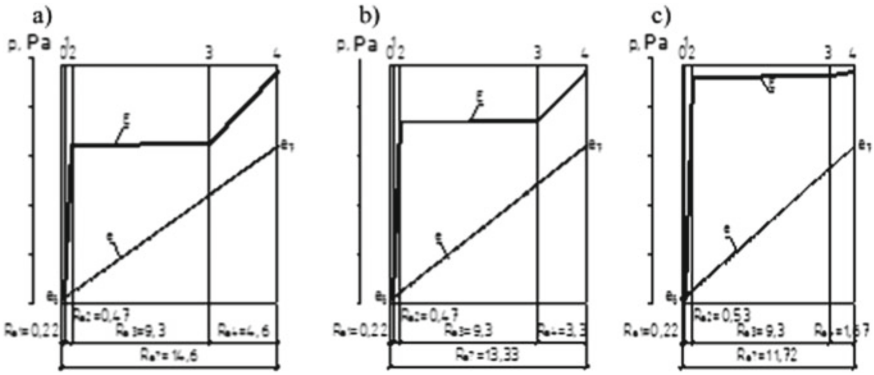

Fig. 2 Conditional section of the enclosing structure in July: **a** enclosing structure of brick, **b** enclosing structure of expanded clay concrete panels, **c** enclosing structure of reinforced concrete panels

values of saturated water vapor partial pressure in sections of enclosing structure, indoor air vapor partial pressure and outdoor air vapor tension in July are shown in Fig. 2. As the lines of partial pressure of saturated water vapor and partial pressure of water vapor of indoor air intersect, condensation of water vapor occurs in the fence.

Analysis of humidity accumulation and return during the year showed that there is a constant accumulation of humidity in enclosing structures.

Increasing the humidity of the insulation in the enclosing structures leads to the loss of their heat-protective properties. This, in turn, leads to increased heat loss through the structure, increased load on refrigeration equipment, lower internal temperature and loss of stored products quality. The greatest increase in the humidity

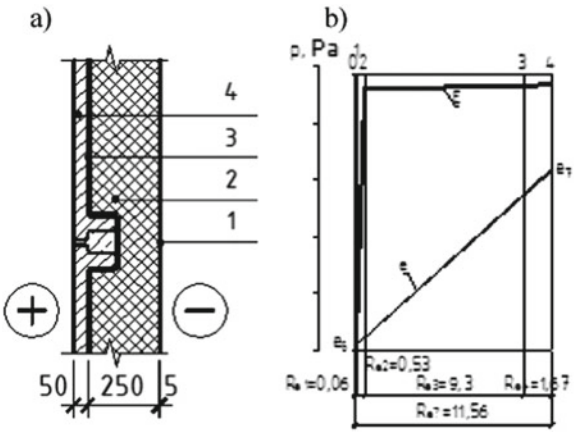

Fig. 3 **a** The design scheme of the enclosing structure of reinforced concrete panels with a reduced outer layer: 1—outer layer, 2—insulation, 3—vapor barrier, 4—reinforced concrete panel; **b** conditional cross-section of the enclosing structure made of reinforced concrete panels with a reduced outer layer in July; **c** conditional section of the enclosing structure of reinforced concrete panels with a reduced outer layer in January

of the insulation is observed in the walls with reinforced concrete panels. Therefore, this design was adopted for further research.

3 Analysis of Possible Ways to Improve the Humidity Condition of Existing Cooling Warehouses Wall Enclosing Structures

3.1 Reducing the Thickness of the Outer Layer in the Wall Structure

Vapor like moisture enters the insulation from the outside air, which has a much higher partial pressure of water vapor, due to the higher temperature than the air in the building. Moisture is removed from the insulation in the direction of the indoor air. The amount of moisture removed depends largely on the resistance to vapor penetration of the outer layer, which in turn depends on the thickness of this layer. The outer layer was usually made of lime-sand mortar with a thickness of 20 mm. Modern materials and technologies enable to reduce it to 5 mm. The calculation of humidity accumulation in the wall with an outer layer 5 mm thick was performed. The design scheme of the enclosing structure is given in Fig. 3a.

Calculations of humidity accumulation and return for all months of the year were performed, conditional sections of enclosing structures made of reinforced concrete panels with a reduced outer layer in July and January are shown in Fig. 3b, c. Analysis of humidity accumulation and return during the year showed that the enclosing structure is accumulating moisture $W_{sp} = 0{,}0186$ kg/m^2, however, more evaporates $W_{wp} = 0{,}2478$ kg/m^2.

3.2 Increasing the Resistance to Vapor Penetration of Vapor Barrier in the Wall Structure

As mentioned earlier, vapor like moisture enters the insulation from the outside air. The amount of moisture entering the insulation depends largely on the resistance to vapor penetration of the layers located between the insulation and the outside air. This is a layer of reinforced concrete panel and a layer of vapor barrier. By increasing the resistance to vapor permeability of the vapor barrier, can be reduced the amount of moisture coming from the outside air to the insulation. It is possible to determine the resistance to vapor penetration of the vapor barrier layer in the enclosing structure by both theoretical and graph-analytical methods. The graph-analytical method is simpler and clearer.

The required resistance to vapor penetration of vapor barrier in the wall structure was determined. The obtained partial pressure values of indoor airs water vapor, the average for the years water vapor partial pressure of outdoor air, the saturated water vapors partial pressure in the cross sections of the enclosing structure are plotted on the conditional section of the enclosing structure (Fig. 4). The horizontal section from the outer surface of the enclosing structure to the point of intersection of the lines is a necessary resistance to vapor penetration of the vapor barrier layer, which ensures the absence of humidity accumulation in the insulation during the year. General resistance to vapor penetration of vapor barrier $R_{e1} = 28{,}9$ (m^2 hour Pa)/mg, that is, to prevent moisture accumulation in the wall of the cooling warehouses, it is necessary to increase the resistance to vapor penetration of vapor barrier by 3 times.

Calculations of moisture accumulation and return for all months of the year were performed, conditional sections of enclosing structures made of reinforced concrete panels in July and January are shown in Fig. 5a, b. Analysis of moisture accumulation and return during the year showed that the amount of accumulated moisture in the enclosing structure $W_{sp} = 0{,}0379$ kg/m^2 equal to the amount of evaporating humidity $W_{wp} = 0{,}0379$ kg/m^2, that is, the accumulation of moisture does not occur. The vapor barrier layer with a vapor permeability resistance of at least $R_{e1} = 28{,}9$ (m^2 hour Pa)/mg can be made using the materials listed in Table 4.

It is quite difficult to perform vapor barrier with such resistance to vapor penetration, from the materials given in Table 4.

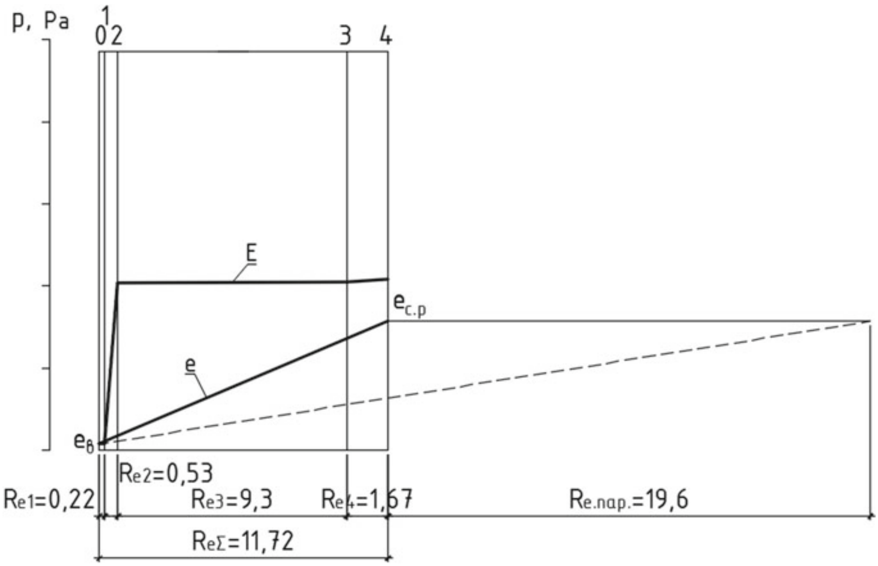

Fig. 4 Determination of resistance to vapor penetration of an additional layer of vapor barrier by graph-analytical method

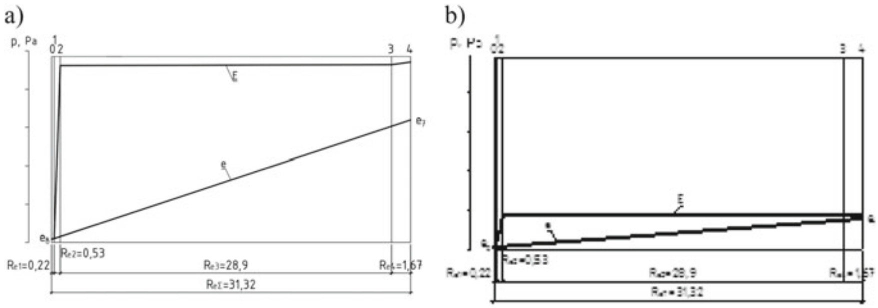

Fig. 5 Conditional section of the enclosing structure of reinforced concrete panels: **a** in July, **b** in January

3.3 The Use of a Ventilated Air Layer in the Wall Structure

Air layers, ventilated by air from the cooled rooms, located between the insulation and the inner layer, accelerate the release of humidity from the insulation. This is explained by the fact that in this case, between the insulation and the air in the cooled room there is no outer layer, which prevents the release of moisture from the insulation.

Table 4 Options for vapor barrier with resistance to vapor penetration is not less $R_{e1} = 28{,}9$ (m^2 hour Pa)/mg

Type of vapor barrier	Number of layers	General resistance to vapor penetration, (m^2 hour Pa)/mg
Painting with hot bitumen	97	29,1
Painting with enamel paint	61	29,28
Coating with insulating mastic	49	29,4
Coating with bituminous-kukersol mastic	28	29,44
Roofing glassine	88	29,04
Polyethylene film	4	29,2
Ruberoid	27	29,7

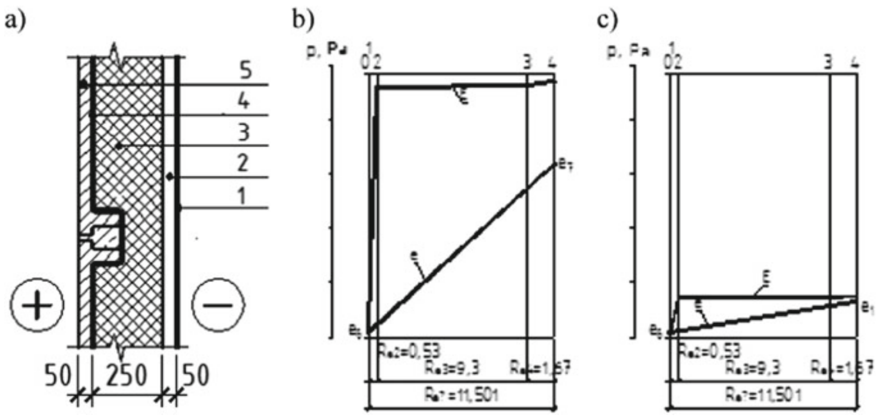

Fig. 6 **a** The calculating scheme of the enclosing structure of reinforced concrete panels with a ventilated air layer: 1—protective screen, 2—ventilated air layer, 3—insulation, 4—vapor barrier, 5—reinforced concrete panel; **b** Conditional section of the enclosing structure of reinforced concrete panels with a ventilated air layer in July; **c** Conditional section of the enclosing structure of reinforced concrete panels with a ventilated air layer in January.

The calculation of humidity accumulation in the wall with a ventilated air layer was performed, the calculation scheme of the enclosing structure of reinforced concrete panels with a ventilated air layer is shown in Fig. 6a.

Calculations of humidity accumulation and return were performed for all months of the year, conditional sections of fencing structures made of reinforced concrete panels in July and January are shown in Fig. 6b, c. Analysis of moisture accumulation and moisture removal showed that when using a ventilated air layer in the wall of moisture accumulation in the insulation during the year does not occur.

4 Conclusions

The analysis of the wall enclosing structures of recently erected cooling warehouses (mainly using metal sandwich panels) and erected in the second half of the 20th century (using bricks, expanded clay concrete and reinforced concrete panels and effective insulation) has been made. The analysis of the humidity condition of the wall enclosing structures of the cooling warehouses has been performed, and their unsatisfactory condition has been revealed. The possible ways to improve the humidity condition of the wall enclosing structures of existing cooling warehouses has been analyzed, which revealed that it is possible to meet the norms by reducing the thickness of the outer layer located on the side of the cooled room to 5 mm or using a ventilated air layer situated between inner layer and insulator which ventilated by air from cooling premises.

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