Assessment of the Effect of Energy Saving and Heat Loss Through External Enclosure Structures with Low Resistance to Air Penetration

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Abstract. The features of heat and mass transfer through external enclosure structures with capillary-porous material, which are not taken into account in the norms of thermal protection of buildings, are considered. Such features more often occur in buildings with a long service life because of the increasing heat loss, caused by the violation of the terms of repair for a long time. For structures, located in the lower part of the building and having little resistance to air penetration, a calculation model is considered to determine the value of the economizer effect and the saving of thermal energy in conditions of cold air infiltration. The developed model clearly demonstrates, that for two- and twelve-story houses the saving of thermal energy, as a result of the economizer effect, is about 3% and 10% respectively. A computational model of exfiltration of warm air through similar structures, located in the upper part of the building, is proposed. An additional value of heat loss during exfiltration of the warm air from the rooms is determined, using an example of old building with a wooden floor of a cold attic and bulk insulation in the absence of layers with high resistance to air penetration. This value is 3.5 times higher, then that determined by the standard method, which does not take into account the redistribution of cold and warm air densities along the height of the building. This leads to a deterioration of the indoor climate and an increase in heat loss. By calculation, the dependence of the value of heat losses on the total thermal resistance of the attic floor and on the number of floors was established. A number of measures, aimed at improving the energy efficiency of existing residential buildings, are proposed, such as laying a vapor barrier layer and an additional layer of effective thermal insulation on top of the bulk insulation as part of the attic floor and installing a cement-sand screed for this insulation.

1. Introduction

A common method of heat loss calculation through the thickness of the external enclosure structures of buildings does not fully take into account the features of heat exchange in capillary-porous structure of the material. The process of infiltration of cold air is considered as an unfavorable factor, causing the cooling of the structure mass and increasing of heat loss. However, such heat exchange under certain conditions is the cause of the economizer effect, which provides partial utilization of heat leaving the room air. This method also provides an underestimated amount of heat loss during air exfiltration in the form of heat flow through relatively air-permeable external enclosure structures.

2. Analysis of computational model for air infiltration and energy saving effect

As mentioned, the standard method [1] is not taken into account the economizer effect in the external enclosure structures. The volume of infiltrated air through capillary-porous material of the enclosure...
structures provides a reduction of the necessary volume of ventilation air \( w_v \), and therefore a reduction of thermal energy \( Q_v \), spent on its heating.

The result is the effect of energy saving, when considering economizer effect:

\[
Q_v = 0.28 \cdot w_v \cdot \gamma_{ext} \cdot c_{int} \cdot (t_{int} - t_{ext})
\]  

(1)

The values of the temperature \( \tau_{int} \) and heat flux \( q_{int} \) on the inner surface of the external wall during infiltration were determined by formulas:

\[
\tau_{int} = t_{ext} + \left( t_{int} - t_{ext} \right) \cdot \frac{e^{c_{int} \cdot w \cdot R} - 1}{e^{c_{int} \cdot w \cdot R_0} - 1}
\]  

(2)

\[
q_{int} = \frac{c_{int} \cdot W \cdot e^{c_{int} \cdot w \cdot R}}{e^{c_{int} \cdot w \cdot R_0} - 1} \cdot \left( t_{int} - t_{ext} \right)
\]  

(3)

where: \( w = \Delta P / \Sigma R_{inf} \); 
\( \Sigma R_{inf} \) - the total resistance to air permeability of structural layers.

In [2] the approximate economizer effect was evaluated on the example of room area 12 m\(^2\), located on the ground floor of 2- and 12-storey residential buildings under following conditions: the temperature of the indoor and outdoor air is 20 °C and -29 °C; the wind speed is 5.6 m/s; the main array of the outer wall area 8.8 m\(^2\) is made of macroporous lightweight aggregate concrete density 900 kg/m\(^3\).

Calculation of the developed model has shown, that thermal energy savings as a result of the economizer effect under these conditions will be slightly more than 3% and 10% for 2-storey and 12-storey buildings respectively.

3. The increase of heat loss through capillary - porous material of external enclosure structures
3.1. The increase of heat loss during air exfiltration

In the buildings with a long service life the most rapid deterioration of functional properties is subject to structural layers and elements intended for thermal protection of buildings (insulation, vapor-waterproofing).

The results of field surveys of the old residential buildings, carried out by various specialists, indicate, that along with the process of physical and moral aging of the buildings, a progressive deterioration in the microclimate and an increase in heat loss are observed. Especially low levels of thermal protection have old low-rise buildings with a cold attic.

In order to clarify the causes of large heat loss and the deterioration of the thermal conditions of the rooms, field surveys of the state of their thermal protection were performed [3]. Obtained results indicated significant heat loss through the attic floors, which included a strongly deformed both bulk insulation and an airtight layer. This state of the protective layers was the reason for the large heat fluxes, entering the airspace of the attic and the intense accumulation of snow and ice massif on the roofs of buildings.

The decrease in the thermal efficiency of such buildings was mainly influenced by the violation of the terms for current and major repairs for a long time.

3.2. Analysis of computational model for air exfiltration

To estimate the value of heat loss through the roof structures of the surveyed buildings, the features of structural solutions of attic floors were considered, taking into account the difference in air pressure \( \Delta p \), Pa, on both sides of the structure:

\[
\Delta p = 0.55H \cdot (\gamma_n - \gamma_a) + 0.03\gamma_n \cdot v^2
\]  

(4)

where \( H \) - is the height of the building (from the floor level of the first floor to the attic vents), m; 
\( \gamma_n, \gamma_a \) - is the specific weight respectively of the outer and inner air in N/m\(^3\); 
\( v \) - is the maximum of the average wind speeds in rumba for January.
In the absence of wind, the mechanism of air infiltration through the external enclosure structures of the lower floor and its exfiltration on the upper floor will act due to the redistribution of the densities of cold and warm air along the height of the building, i.e., due to the heat pressure.

Based on the obtained results of instrumental measurements, the air velocity over the surface of the attic floor insulation was extremely small and amounted to only a few cm / s. Therefore, in determining $\Delta p$, the second term of equation (4) was not taken into account.

According to [1], the amount of heat loss through the attic floor, which includes an airtight layer, is determined by the formula:

$$ q = \frac{(t_{in} - t_{ext})}{R_0}, \text{W/m}^2 $$

(5)

However, if that layer has defects or is absent, as was noted during field surveys, through the attic floor will be exfiltration of air in the form of heat flow, the value of which was determined by the formula:

$$ q_{ext} = \frac{c_i \cdot \omega \cdot e^{c_i \cdot \omega \cdot R_u}}{e^{c_i \cdot \omega \cdot R_u} - 1} \cdot (t_{in} - t_{ext}) $$

(6)

where $t_i$, $t_e$ - are the internal and external air temperatures on both sides of the attic floor, °C;

$c_i$ - specific heat of air, J / kg·°C;

$\omega$ - the amount of exfiltrated air, kg / m$^2$·h

$$ \omega = \frac{\Delta p}{R_u} $$

$R_u$ - resistance to air permeability of the multilayer structure of the attic floor, (m$^2$·h·Pa) / kg ;

$R$ - is the heat transfer resistance of the attic floor at the boundary near the inner surface, m$^2$·°C / W;

$R_0$ - total resistance to heat transfer of the attic floor, m$^2$·°C / W.

In accordance with the calculation model there was determined the value of heat loss $q_u$ through the examined and some other attic floors of a 2-story building, provided that $\Delta p = 1.54$ Pa (table 1).

| №  | Constructive schemes                          | $\omega$, kg / m$^2$·h | $R_u$, (m$^2$·h·Pa) / kg | $R_0$, m$^2$·°C/W | $R$, m$^2$·°C/W | $q_u$, W/m$^2$ | $q_{req}$, W/m$^2$ |
|----|-----------------------------------------------|------------------------|--------------------------|-----------------|----------------|---------------|----------------|
| 1  | slag filling boards on beams                  | 6,16                   | 0,25                     | 2,4             | 2,29           | 68,23         | 19,6           |
|    | Surveyed design                               |                        |                          |                 |                |               |
| 2  | cement-sand screed                            | 0,089                  | 17,25                    | 2,5             | 2,39           | 15,51         | 18,8           |
|    | slag filling boards on beams                  |                        |                          |                 |                |               |
| 3  | mineral wool plate                            | 0,68                   | 2,25                     | 5,13            | 5,02           | 14,07         | 9,2            |
|    | slag filling boards on beams                  |                        |                          |                 |                |               |

Table 1. Thermophysical indicators of attic floor structures.

The following values of density, kg/m$^3$, and thickness, cm, were adopted for the structural layers: slag filling - 900 and 18, boards - 700 and 2.5, mineral wool plate - 150 and 15, cement-sand screed - 1700 and 2.
Values of \( q_{\text{req}} \), W/m\(^2\), are found by formula (5). With an increase in the number of storeys of the building the value of heat loss \( q_u \), W/m\(^2\), through the upper enclosure structures will also increase, due to the increase in heat pressure (table 2).

**Table 2.** The values of \( q_u \) for the design to scheme 1.

| Number of floors | 1    | 2    | 3    | 4    | 5    |
|------------------|------|------|------|------|------|
| \( q_u \), W/m\(^2\) | 40,4 | 68,2 | 92,2 | 122,5| 149,7 |

The dependence of the value of heat loss \( q_u \) on the total thermal resistance \( R_0 \) of the attic floors is shown in figure 1.

**Figure 1.** The dependence of the value of heat loss \( q_u \) on the total thermal resistance \( R_0 \)

According to the data in table 1, through the surveyed attic floor structure (scheme 1), the heat loss is 3.5 times greater, than that, determined by the standard method in the absence of exfiltration (according to Equation 5). This is confirmed by measurements of the air temperature in the rooms of the upper floor of the surveyed buildings, which during the period of cold snap was within +14-15 °C.

In the practice of thermal modernization of such roofs they sometimes use an additional layer of effective thermal insulation from a material with little resistance to air permeation, for example, a mineral wool slabs, on top of bulk insulation. The results of calculation of indicators for the design of the scheme 3 show, that such “energy-saving” measure also does not solve the problem of increasing heat loss.

The installation of cement-sand screed on bulk or loose slab insulation (scheme 2) provides a heat loss value lower than normative indicator.

And although this energy-saving measure belongs to well-known and uncomplicated structural solutions, however, in some buildings with a long service life it has not been implemented since construction. This was the reason that over the decades of operation, such houses suffered very large total heat loss.

4. Results and discussions

A computational model of exfiltration of warm air through structures, located in the upper part of the building, is proposed. An additional value of heat loss during exfiltration of the warm air from the rooms is determined, using an example of old building with a wooden floor of a cold attic and bulk
insulation in the absence of layers with high resistance to air penetration. By calculation the
dependence of the value of heat loss on the total thermal resistance of the attic floor and on the number
of floors was established. A number of measures, aimed at improving the energy efficiency of existing
residential buildings, are proposed, such as laying a vapor barrier layer and an additional layer of
effective thermal insulation on top of the bulk insulation as part of the attic floor and installing a
cement-sand screed for this insulation.

5. Conclusions
Thus, when determining heat loss through the external enclosure structures with a relatively small
resistance to air penetration and calculating the energy performance certificate of the building, it is
necessary to take into account: the possibility of an economizer effect in the enclosure structures,
which provides an energy saving effect; the additional heat loss during the exfiltration of warm air
through the upper sections of these structures.

References
[1] SP 50.13330.2012. Thermal protection of buildings. Actualized edition of SNiP 23-02-2003.-
M.: NIISF RAASN, 2012. - 95 p.
[2] Beregovoy A.M., Beregovoy V.A. Energy Saving Effect in Conditions of Air Infiltration
through External Wall Made of Air-Permeable Materials. (WOS). 2019 IOP
Conf.Ser.:Mater.Sci.Eng. 471 052015 https://doi.org/10.1088/1757-899X/471/5/052015.
[3] Beregovoy A.M. Energy savings in the residential buildings with big service–life /Text/ A.M.
Beregovoy, V. A. Beregovoy. A.V. Maltsev. M. A. Petryanina// News of higher educational
institutions. Construction.— 2011.– №5.– P. 59 – 64.
[4] Beregovoy A.M. Evaluation of heat losses during exfiltration of air through the porous
structure of the material of the enclosure structure [Text]/A. M. Beregovoy, M. A. Derina, B.
A. Beregovoy, A.V. Maltsev // Regional architecture and engineering.—2014.—No.2.— P. 79–
83.