

Factors of quality reduction of exploitation of pitched roofs with a cold attic in conditions of dense urban development

Marina Dement'eva^{1*}

¹ Moscow State University of Civil Engineering , Yaroslavskoe shosse, 26, Moscow, 129337, Russia

Abstract. The paper presents the results of a survey of cold attic of a residential building with a pitched roof. The aim of the work was in the conformity assessment of the actual operating conditions of the cold attic regulatory requirements. Measuring data of temperature and air velocity, mathematical processing of results are presented. Method of calculating the area of the ventilation holes was analysed, recommendations to prevent the formation of icings and condensation were made.

1 Introduction

Considerable part of infrastructure of urban economy includes low-rise houses. According to [1] in the housing stock in Moscow, exploit more than 20 thousand houses up to five floors, which is about 35% of buildings with pitched roof and a cold attic. Such constructive solution of a roof has merits and demerits analyzed in numerous researches [2-5]. A well-known problem of exploitation as icing eaves and drainpipes.

Change of the constructive solution of sloped roofs on flat roofs can be cardinal version of the solution of this problem. But the urban policy of Russia is directed to preservation of historical appearance of the cities. Therefore reconstruction with change of the constructive solution of a roof often isn't allowed. Today as the main way of elimination of ice and snow serves mechanical cleaning after which the roof is often damaged and there are leakages. Active methods of protection against formation of ice are much less often used: artificial heating or processing by anti-icing components of an eaves part of a roof. As a result on fight against icicles, icings and leakages are spent considerable financial means, but not all of them become applicable because of complexity of execution, small efficiency or a contradiction to policy of energy saving [7-12]. Another side of the problem is the formation of condensate on the inside surfaces of the roof.

The mechanism of these processes is caused by the presence of a constant heat of natural and technogenic origin. In the first case the process begins with the melting of the upper layer of snow. It is caused by atmospheric heat at a temperature of external air above zero, or solar radiation even at negative temperatures, up to $-5\text{ }^{\circ}\text{C}$ [8]. In the second case on process of melting the bottom layer of snow affect additional heat gain from the attic.

Heat gain of technogenic origin can be divided into two integrated groups. The first is

*Corresponding author: 7dem@mail.ru

caused by insufficient thermal insulation of overlappings of an attic, of engineering communications, of air ducts. The second is connected with the increased breathability of constructions in places of pass of air ducts, of channels, of hatches. Consequently, the more the thermal stream, the is lower range of temperatures of external air where can occur process of formation of condensate and ice. Therefore the research of factors of deterioration in operational qualities is necessary that proves relevance of work.

The equation of the heat balance of the attic can be represented as follows, where the left part indicated heat coming into attic, and in the right part of the outgoing heat from the attic:

$$Q_{ir}^g + Q_h^g + Q_{inf}^g + Q_s^g = Q_r^l + Q_w^l + Q_v^l \quad (1)$$

where: Q_{ir}^g —heat gain through the overlapping of the attic;

Q_h^g —heat input from pipes of heating and hot water supply;

Q_{inf}^g —heat input across air ducts, channels, hatches;

Q_s^g —heat gain from solar radiation and temperatures above zero;

Q_r^l —heat loss through the roof;

Q_w^l —heat loss through the walls;

Q_v^l —heat loss due to ventilation.

The formula of thermal balance is expressed by system of the equations:

$$\left\{ \begin{array}{l} Q_{ir}^g = \alpha \cdot (t_{int} - t_s) \cdot F_{at} \\ Q_h^g = \frac{2\pi \cdot K \cdot (T_r - T_u) \cdot L}{\ln \frac{D}{d}} \\ Q_{inf}^g = 0,28 \cdot c \cdot G^g \cdot \rho^g \cdot (t_{inf} - t_{int}) \\ Q_s^g = \frac{\rho \cdot I \cdot F_r}{\alpha \cdot R_{0r}} \end{array} \right\} = \left\{ \begin{array}{l} Q_r^l = \frac{(t_{int} - t_{ex}) \cdot F_r}{R_{0r}} \\ Q_w^l = \frac{(t_{int} - t_{ex}) \cdot F_w}{R_{0w}} \\ Q_v^l = 0,28 \cdot c \cdot G^l \cdot \rho^l \cdot (t_{ex} - t_{int}) \end{array} \right\} \quad (2)$$

where: α – heat transfer coefficient of the outer surface the overlapping of the attic;

t_{int} , t_s , t_{inf} , t_{ex} – respectively, air temperature on an attic, average temperature of the outer surface the overlapping of the attic, air temperature arriving on an attic from warm rooms, outside air temperature;

F_{at} , F_r , F_w – respectively, surface area of the overlapping of the attic, surface area of the roof, area of the walls of the attic;

L , D , d – respectively, pipe length, outer diameter of a pipe with isolation, outer diameter of a pipe without isolation;

K – coefficient of heat conductivity of isolation of a pipe;

T_r , T_u – respectively, water temperature in pipe, surface temperature of the pipe insulation;

c – specific heat of air;

G^g , G^l , ρ^g , ρ^l – respectively, volume and density of supply air and exhaust air;

ρ , I – respectively, coefficient of absorption of solar radiation roof surface, density of a thermal stream of solar radiation;

R_{0r} , R_{0w} – respectively, heat transfer resistance the overlapping of the attic and of the roof.

Excess heat from the attic should be allocated by means of ventilation with outside air. To do this is necessary arrange dormers, the vents under the cornice and along the roof ridge, if necessary, is arrange vent pipes, which provides cross-ventilation of the attic. The area of vents F is determined by the functional dependence $F=f(q; \Delta P)$. According to [13]

air exchange is carried out by pressure of heat ΔP_T and of wind ΔP_V :

$$\Delta P = \Delta P_T + \Delta P_V = h \cdot (\gamma_{ex} - \gamma_{int}) + \frac{(k_1 - k_2) \cdot v^2 \cdot \gamma_{ex}}{2g} \quad (3)$$

where: h – the distance between the centers of holes for supply and exhaust ventilation in height;

$\gamma_{ex}, \gamma_{int}$ – respectively, density of the internal and external air;

k_1, k_2 – respectively, aerodynamic coefficient supply and exhaust openings;

g – free fall acceleration;

v – air velocity in the sectional points.

In the normative documentation specified conditions of temperature in the attic, in which there shouldn't be no thawing of snow, icing and condensation:

$$\Delta t = (t_{ex} - t_{int}) \leq 4^\circ C \quad (4)$$

Let's take this indicator as criterion of quality of exploitation of pitched roofs with a cold attic to bring multi-criteria optimization problem of the temperature regime of the cold attic in one-criterion [14]. Let's call its in further temperature gradient ∇t which shows a vector of the direction of change of temperature in attic space on axes x, y, z :

$$\nabla t = \left(\frac{\partial t}{\partial x}, \frac{\partial t}{\partial y}, \frac{\partial t}{\partial z} \right) \quad (5)$$

Then the results of the analysis of formulas (1-3) can be represented as a model:

$$\Delta t = f\left(\sum Q^g - \sum Q^l\right) = f(\{\beta_i\}; \{\mu_l\}; \{\omega_i\}) \xrightarrow{t_{ex} \leq 0} 0 \quad (6)$$

where: $\{\beta_i\}$ – set of parameters that are managed and controlled in the course of building life cycle (for example, the thermal conductivity of insulation);

$\{\mu_l\}$ – set of conditionally operated parameters which are specified in the project (for example, the size of the building);

$\{\omega_i\}$ – set of uncontrolled parameters which size can be randomly (for example, the wind speed).

Of interest is the study of changes in temperature of the attic from climatic conditions, in particular outside air temperature and from the wind mode, as well as the study of the distribution of the function Δt as a vector in the space on arguments x, y, z .

For this purpose the following tasks were solved:

- have assessed the technical state of structural and roofing made of sheet steel;
- temperature and air velocity measurements at different points in the attic was performed;
- mathematical processing and analysis of measurement results was carried out,
- it was concluded about an peculiarities of the distribution of the temperature gradient in the attic.

2 Experimental section

Measurements of air temperature in the attic performed in vertical sections. Step sections is equal to the distance between the rafters (fig. 1).

Temperature measurements were performed daily for 2 months – January and February 2016, out before sunrise and after sunset to avoid the influence of ambient heat and solar radiation on heat gain. Measurements of temperatures were performed by an electronic

thermometer with range of work from $-50\text{ }^{\circ}\text{C}$ to $+200\text{ }^{\circ}\text{C}$ with measurement accuracy $\pm 0.1\text{ }^{\circ}\text{C}$.

Measurements were carried out along slopes of the roof, on the central support, out on surface of overlapping near external, internal walls and in the center of span, out on the surface of the heating pipes, hot water supply, sewage pipes and ventilation ducts (fig. 2).

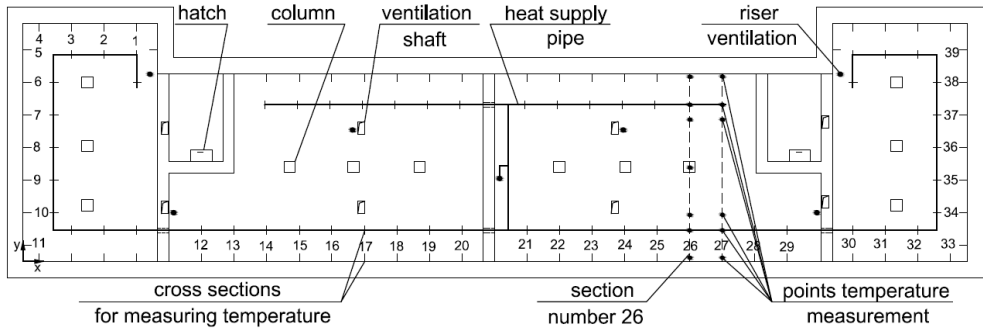


Fig. 1. The scheme of measurements of temperature on an attic.

The measurements of air velocity in the attic performed in the cornice and the roof ridge and dormers (Fig. 2) by an anemometer with range of work from 0.2-40 m/s with measurement accuracy $\pm 0.01\text{ m/s}$. The actual values of wind speed were determined according to [15].

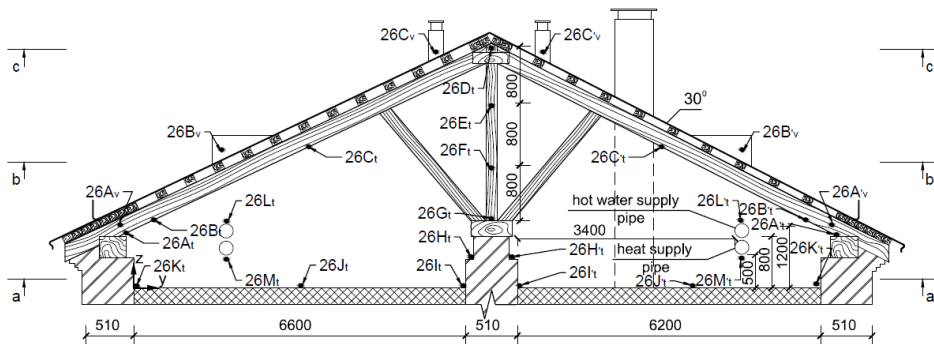


Fig. 2. Temperature measurement point in the cross section (A_t-L_t) and horizontal sections (a-c), measurement points of air velocity in cross section (A_v-C_v).

Ventilation is carried out in the attic through 6 dormer, of air holes in the cornice and of the roof ridge (Fig. 3). Their area of little more than the calculated value is 1.55 m^2 , and therefore ventilation should remove excess heat, but this does not happen. Studies have shown that in the attic there are areas where not ventilation and warm air accumulates and warms areas of the roof.

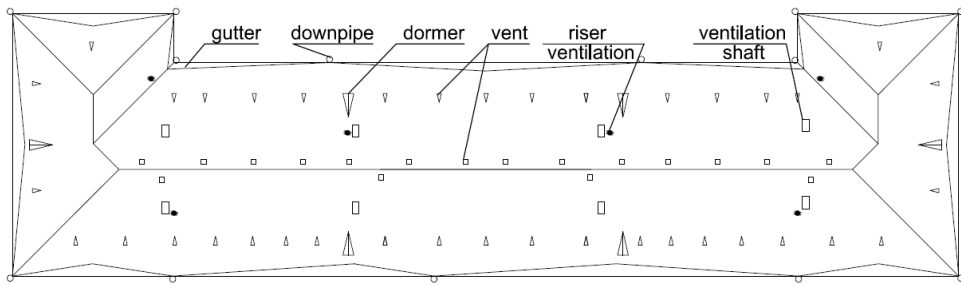


Fig. 3. Roof plan with ventilation devices.

3 Results section

Processing of measurement results performed by the standard method of determining the mathematical expectation, standard deviation and coefficient of variation. The calculation was made on by eligibility criterion of quality of exploitation of pitched roofs with a cold attic – Δt .

Mathematical treatment was performed by ranges of external temperatures with a step of 5° C in vertical and horizontal section at the corresponding points (for example, at the points 26A_t и 26A'_t) and on set of the corresponding points of different sections (for example, {At}={1A_t, 1A'_t, ..., 5A_t, 5A'_t,...}). Additional heat input have been taken into account in some sections, for example, due to uninsulated pipe equipment and the availability of the channel. Example results of processing in one of the intervals (from – 20 °C or lower) is shown in Table 1.

Table 1. The results of mathematical processing Δt values at a plurality of points of sections when the outdoor temperature is below –20 °C.

Distribution parameters	{A _t }	{B _t }	{C _t }	{D _t }	{E _t }	{F _t }	{G _t }	{H _t }	{I _t }	{J _t }	{K _t }
Expected value, °C	11.3	13.1	16.0	19.3	16.3	16.3	14.3	13.0	19.9	17.4	17.9
Dispersion	1.9	2.1	1.7	1.6	2.9	2.3	0.9	0.7	1.8	1.7	2.1
Standard deviation, °C	1.39	1.46	1,31	1.26	1.71	1.50	0.96	0.82	1.36	1.30	1.46
Variation factor, %	12.3	11.1	8.2	6.5	10.5	9.2	6.7	6.3	6.8	7.5	8.2

Variation factor confirms that the results are uniform. Therefore, average values can be regarded as significant, characterizing the totality of the values obtained. Results of processing executed measurements are shown in Fig. 4.

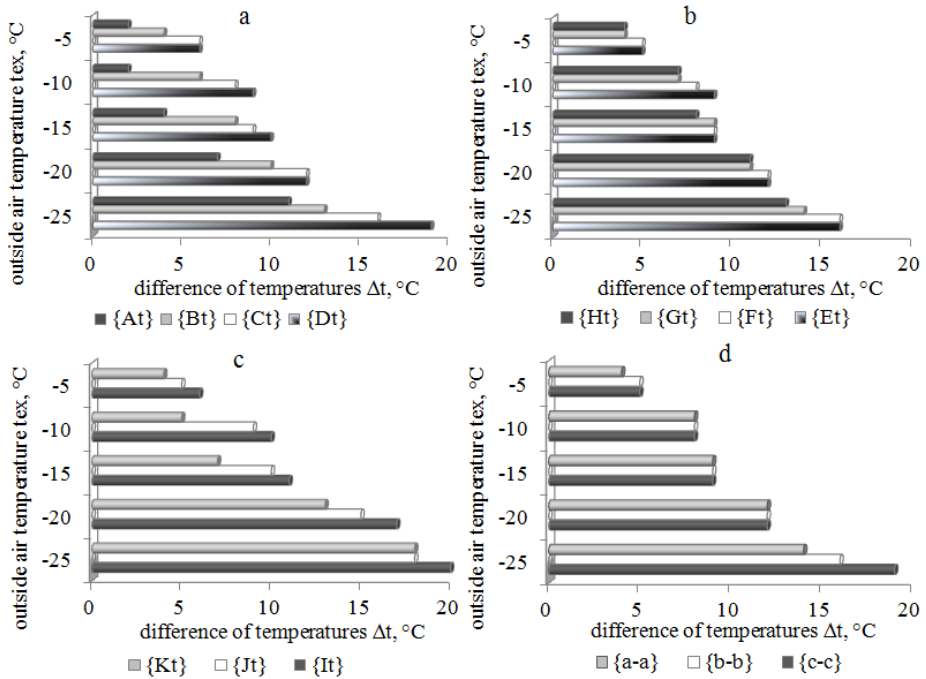


Fig. 4. Difference of temperature along slopes (a), on the central support (b), out on surface of overlapping (c), on the horizontal sections(d).

The temperature difference substantially exceeds the allowable value of 4 °C at all points vertical sections and significantly increases with decreasing outside temperature (below -15 °C) and reaches a maximum value $\Delta t=20$ °C. The exception is part of the cornice {A_t}, where normative temperature range is provided near external walls with outside air temperature up -15 °C.

Analysis of temperature in the central part of the roof height of the cross sections at the points {E_t}, {F_t}, {G_t}, {H_t} showed that the maximum temperature difference between the groundsel and the roof ridge is 1–4 °C and Δt also reaches a maximum value when the outside temperature is lowered.

The temperature difference increases on surface of overlapping from the eaves to the central support ({I_t}, {J_t}, {K_t}) and is equal 4–8 °C. The temperature difference in the horizontal sections is uniform.

Calculation of the specific heat input from the heating pipes and hot water is also performed on the range of outdoor temperature in increments of 5 °C. The calculation was based on measurements of the surface temperature of the pipes. The temperature of water was recorded from protocol the of registration of thermal energy at the input node. Calculations are made on the basis of expected values of measured temperatures. Results of calculation are presented in fig. 5.

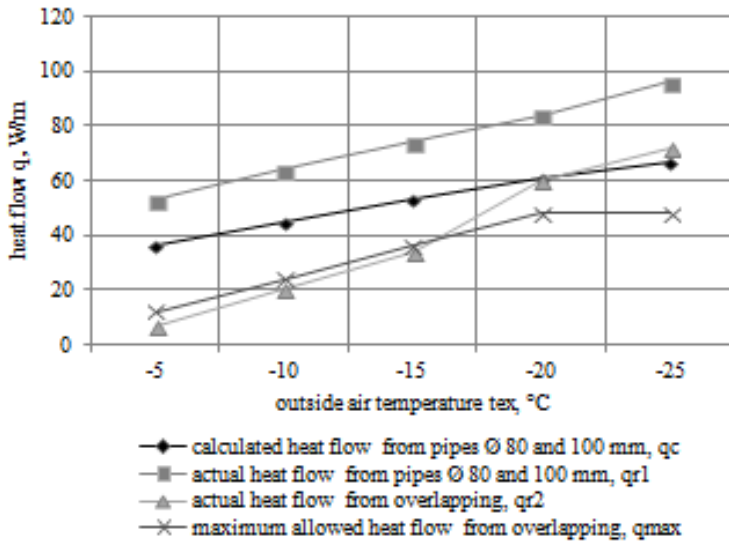


Fig. 5. Heat flow through the surface of insulation pipelines and overlapping of attic at different ambient temperatures.

The actual heat flow from the pipe exceed the calculated value on 30%, which proves ineffective insulation. Heat gain through overlapping two times less than from pipes of heating and hot water supply.

Data on wind conditions during the measurements are shown in Fig. 6. The average wind speed over the observation period was 40% of the standard value. At measurements it has been established that the air velocity at attic wasn't fixed in 50% of cases by the device. Air velocity wasn't detected when of the smoke test. In other cases, when the wind speed on the street was of more than 1 m/s, the speed in the supply holes was in the range of 0.2-0.7 m/s and in the exhaust holes 0.3-1.8 m/s.

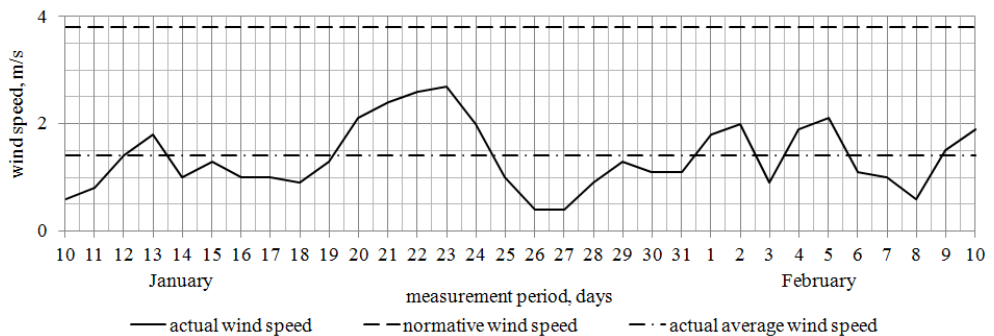


Fig. 6. Comparison of actual and normative values for wind speed measurement period.

Based on the measurements was identified the actual pressure of heat and pressure of wind (Formula 3). Calculation results are presented in Fig. 7. Pressures of heat is up to 30% of pressures of wind, provided that air velocity is normative. The actual speed value is several times lower than the normative that does not allow for the desired mode of constant ventilation of the attic space.

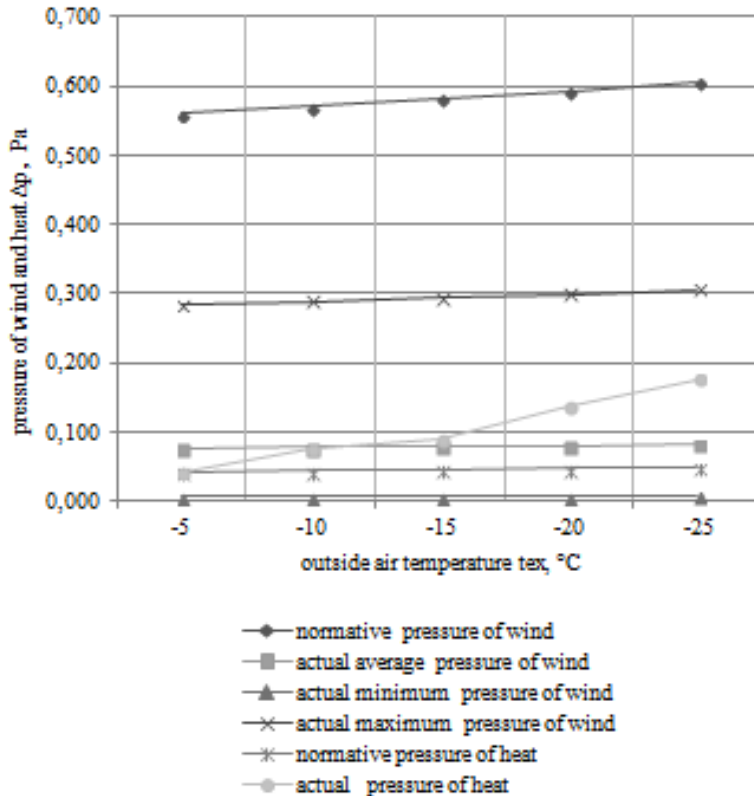


Fig. 7. Pressures of heat and wind at different climatic conditions.

4 Conclusions

Studies suggest the following conclusions.

1. The investigations led to the following conclusions. Roof repair was made three years ago. Insulation was performed by calculation. But insulation does not rule out heat gain into the attic. Criterion of quality of exploitation Δt will be provided only when $t_{ext} \leq -5$ °C. Melting snow in this temperature range originate due to atmospheric heat and radiance of the sun.

2. Method of temperature and air velocity measurements in the attic requires modification, because the presence of local sources of heat distort picture of measurements and does not allow to obtain uniform results and use the average values in the calculation.

3. Method of calculating the ventilation holes is not effective enough, because it does not take into account non-uniformity of the magnitude and direction of wind impacts it. Technique is effective only when the following conditions:

- the wind speed must always be equal to the normative value;
- the intensity of pressure wind must be constant;
- the direction of the impact of pressure wind should be perpendicular to the opening of the venting device.

Consequently, the constant heat input converted traditional pitched roofs with a cold attic in the category of warm roofs. Therefore, ice and condensation is possible throughout the snow season. To avoid this, it is necessary to reconstruct attic with insulation of roof and walls or upgrade the engineering systems and to dismantle pipes from the attic.

References

1. URL: <http://www.irn.ru/articles/8489.html> (2006)
2. P.V. Druzhinin, A.L. Barash, A.D. Savchuk, E.Ju. Jurchik. *Diagnostika i remont*. **4**, 7-13 (2010)
3. V. Rybakov, A. Panteleev, G. Sharbabchev, E. Epshtein. *Applied Mechanics and Materials*. **584-586**, 1876-1880 (2014)
4. N.Vatin, A.Gorshkov, D.Nemova, A.Urustimov, A.Staritsyna, P.Rymkevich. *Applied Mechanics and Materials*. **725-726**, 9-14 (2015)
5. A.A. Romanova, P.P. Rymkevich, A.S. Gorshkov. *Technico-tehnologicheskie problem servisa*. **3**, 15-19 (2016)
6. S. Wang, Z. Shen, L. Gu. *Energy and Buildings*. **47**, 360-368 (2012)
7. P. Haese, M. Teubner. *Int. Journal of Heat and Mass Transfer*. **45**, 4925-4936 (2002)
8. W. Tobiasson, J. Buska, A. Greatorex. *ABOK*. **3**, 20-25 (2011)
9. L. Thor, *Heat Transfer Applications for the Practicing Engineer* (John Wiley & Sons, 2011)
10. M. Pierce. *Causes and Cures of Attic Condensation and Roof Ice Damming Problems*. Department of Design&Environmental Analysis Cornell University Ithaca, NY. *Housing Fact Sheet*. 11-17 (2005)
11. M.E. Dement'eva. *Natural and Technical Sciences*. **9-10 (77)**, 390-391 (2014)
12. W. Robert Humbarger. *Interface magazine (RCI institute)*, 32-35 (2009)
13. Russian Standard SP 50.13330.2012.
14. M.E. Dement'eva. *Proceedings of MSUCE*, **4**, 158-165 (2015)
15. URL: http://rp5.ru/Arhiv_pogody_v_Moskve (2016)