Строительство уникальных зданий и сооружений. ISSN 2304-6295. 2 (53). 2017. 50-60

Construction of Unique Buildings and Structures

journal homepage: www.unistroy.spbstu.ru

The method and computation of air change required for attic rooms

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Article info	Article history	Keywords
scientific article **doi: 10.18720/CUBS.53.4**	Received: 08.08.2016	roof; roofing; cornice; snow; ice; ice dams; attic; temperature and humidity regime; attic floor slab; insulation;

ABSTRACT

The article deals with the recommendations how to eliminate ice dam formation on pitched roofs of the buildings with cold attics during heating period. The case of how to calculate required air change in cold attic rooms, where building structures which separate attics from rooms or utilities with high temperature (heat supply sources) are not insulated, is given in details. It is proved that natural ventilation system can ensure this condition only within short terms. It is necessary to both carry out works to ensure air change and insulate building envelopes, which separate cold attics from rooms with higher air temperature in order to satisfy all the requirements to eliminate reasons of ice dam formation on roofs.

Content

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1. Introduction

A layer of ice formed on pitched roofs is one of the up-to-date issues of how to maintain residential premises located in the historical center of Saint-Petersburg. Disturbance of temperature and humidity regime in attics is considered to be the main reason of why ice layers are formed. Due to deterioration of insulation quality of floor slabs and hot-water pipe system in attics, inside air temperature dramatically increases in attics while winter time operation, and this leads to ice melting on roofs and water flow towards cornice, where the water gets frozen in the area of roof eaves, especially in the case of rain water pipes with water frozen in larger amounts.

Reasons of ice (icicles) formation on pitched roofs are analyzed in a detailed way in works [1, 2]. An example of heat-balance equation made for cold attics allowing for both heat gains and heat loss through building envelopes in attics is given in the work [1].

The conditions of how to regulate the temperature and humidity regime in cold attic rooms during period with the lowest outside air temperature are considered and justified in the article [3]. According to the heat-balance equation there was developed a set of engineering activities to regulate the temperature and humidity regime such as:

- insulation of building envelopes, which separate cold attics from rooms or utilities with higher temperature (dwelling rooms, stairwells, ventilation ducts);

- insulation of hot-water pipe system arranged in attics (if there are any);

- providing air change due to arrangement of air supply and exhaust outlets (air holes), which secure heat removal because of on-going air intake into attics.

The list of the activities suggested can be considered as an abundant one and makes it possible to satisfy the requirement stated in the Property maintenance standards and rules [4] provided the parameters for heat-balance equation of cold attic rooms are accurately chosen [4]:

$$t_{в}^{ч} - t_{н} \le 2 - 4\ {}^{o}C\ , \qquad (1)$$

where $t_{в}^{ч}$ – air temperature in attics, ºC;

$t_{н}$ – outside air temperature, ºC.

As it is shown in the Property maintenance standards and rules [4] the condition (1) is given inexplicitly: a range of temperature drop values is assumed. For this reason when making the heat-balance equation it is suggested to consider and ensure both the lowest (temperature drop should be less than 2 ºC) and the highest (temperature drop should be less than 4 ºC) bounds (1).

The article [5] deals with the methodology of how to make the heat balance equation for cold attics. This methodology is aimed to provide the scientific basis for engineering activities to prevent the ice building-up on roofs during the periods with the lowest outside air temperature. The set of activities that leads to reduction of heat energy breakdowns because of buildings is listed. These activities are subject to contribute to heating up and improvement of microclimate parameters in top-floor rooms of the buildings under operation. In order to perform these activities various materials and technologies, which may ensure necessary level of insulation in concrete building and satisfy both fire prevention and safety requirements and sanitary and hygienic requirements in accordance with existing standards valid for the Russian Federation are used.

The factors which have impact on the temperature and humidity regime of pitched roofs in cold attics are described in the article [6].

A brief analysis of technical facilities performance is given in the article [7]. These technical facilities may be used to deal with ice and icicles on roofs: heating cables, hydrophobic coating compositions, laser devices, electrical impulse, ice and snow manual removal and etc.

A design solution how to dispose of melt water accumulated in the area higher than bottom edges of roofs is given in the article [8]. This solution makes it possible to solve the problem of icicles formation and improve service life of roofing. There is also an economic analysis where major repairs based on conventional methods and reconstruction using light steel thin-walled structures are compared.

Hydrothermal reasons of ice formation on roofs in the buildings heated and suggestions how to eliminate ice formation backed by long-term construction experience are given in the article [9].

A set of activities to insulate attic floor slabs as a method to eliminate ice formation on roofs of the buildings under operation is described in details in the article [10].

A manual for architectures and designers how to make models with account for energy parameters of the whole building is given in the article [11]. An analysis is presented and parameters of structures with major impact (building type, materials used, building shapes, insulation of building envelopes and etc.) are determined.

Energy sources, which have negative impact on environment, are described in the article [13]. The objective of the work is to determine ecological properties of materials and to consider alternative materials in building structures including the ones that are used for attic floor slabs.

The findings based on thermal-imaging surveys about impacts on ice formation on the surfaces due to thermal and technical defects of enclosures are given in the article [14].

A ventilation system for pitched roofs is suggested in the article [15]. The best thing about his ventilation system is that it is equipped with additional vertical exhaust ducts fixed to the ones outside the attic, and this ensures efficient air change.

Insulation of attic floor slabs with the use of cast-in-place foam concrete is described in the article [16]. A computational and experimental methodology based on accurate implementing of the consecutive sequence of 8 actions with the aim to obtain required physical and mechanical properties.

Thermal conductivity of the products made of expanded polystyrene foam is researched; heat transfer of building envelopes made of insulation materials based on expanded polystyrene foam is analyzed in the article [17].

An issue of foam concrete to be used for pitched roofs is described in the article [18]. Carrying capacity of foam concrete is researched; thermal and technical characteristics and possible ways to use foam concrete with the purpose of attic floor slabs insulation is considered in the same article as well.

It is shown in the article [19] that view windows on roofs may contribute to natural ventilation of roofing but it's not simple to forecast behavior of certain air change features since ventilation in attics depend on a number of factors such as: wind speed, wind direction, difference in temperature, difference in pressure. This article assumes air consumption when there is natural ventilation in attic rooms in the case of an actual building in different weather conditions.

Developed mathematical models, which describe thermal air regime of a ventilated attic floor slab, are presented in the article [20]. The mathematical models are proved to be actual and up-to-date. It is stated that these mathematical models can be used to analyze and evaluate changes of temperature and heat flow, and to estimate ventilation of the area under roofs in different weather conditions.

There is a wide-spread assumption that it is enough to ensure required air change in order to regulate temperature and humidity regime in cold attics [15]. However, there is no any prove for this assumption in scientific works.

Despite the variety of all the results and methods, which are described in scientific works, it is still not enough to give unambiguous answers to the following questions: is it possible to regulate and humidity regime in cold attics provided there is only one single air output with no insulation works assigned for insulation of heat flux sources, and what volume of the cold air is required to supply into attics in this case.

The fact that there are no substantiated theories and experimental data gave grounds for extra researches.

The scope of the research is to evaluate the temperature and humidity regime in attic rooms in a block-of-flats, to determine air required to satisfy the condition as applied to a certain research object.

The research object is located at the address: Saint-Petersburg, pr. Obukhovskoy Oborony 90-92.

Picture 1. Research object

General description of the research object

A dwelling block-of-flats built in 1877, shown in Picture 1, which is made of solid loam bricks with the thickness of 510 mm (2 bricks), plastered outside with stucco based on lime and sand. Total usable floor area of the building is 3288.37 square meters. Number of flats – 31.

The house is a typical commercial building built in the beginning of XX century located in of the ‘commuter’ districts of Saint-Petersburg. It is a four-storey building with a pitched roof, a cold attic and no basements.

There are heat supply system ducts in the attic. The attic floor slab is made of concrete slabs with 18-22 cm thick slag on top (at attic). There is steel roofing with 0.5 mm thick zinc-coating.

5-7 mm thick inlet air holes (picture 2) are made around the perimeter.

Picture 2. Inlet air holes at the cornice

2 dormer windows are used for ventilation in the attic (Picture 3).

Picture 3. Dormer window

Exhaust holes are presented as roof cowls of cylindrical shape (picture 4, 5), placed in a chequer-wise order at both sides of the roof ridge (Picture 6).

Picture 4. The cowls in the roof structure

Picture 5. The cowls in the roof structure

Picture 6. Exhaust holes (view from the roof)

Areas of building envelopes (A_i^+), through which heat flow during the heating season goes to an attic account for:

- attic floor slab – 507 m^2;
- staircase walls – 46 m^2;
- staircase surfaces – 33 m^2;
- entrance door from staircase to the attic – 2 m^2;
- ventilation ducts with direct access to the roof through the attic – 34 m^2.

Areas of building envelopes, which separate the attic from the outside air (A_k^-) are:

- roof surface – 756 m^2;
- end wall – 72 m^2.

Building volume of the cold attic amounts to 1215 m^3.

Areas are given according to the measuring works.

2. Methods

Thermal and technical features of the attic envelopes

Values of resistance to heat transfer of the envelopes in the attic account for:

- attic floor slab (porous gravel made of 180-220 mm thick blast-furnace slag on top of the 100 mm thick concrete slab) – 1.3 m^2·°C/W;

- staircase walls (250 mm thick lime-brick masonry based on concrete and sand mortar) – 0.5 mm^2·°C/W;

- staircase surfaces (220 mm thick reinforced concrete hollow slab) – 0.35 m^2·°C/W;

- entrance door from staircase to the attic (non-insulated, made of wood) – 0.3 m^2·°C/W;

- ventilation ducts with direct access to the roof through the attic – 0.5 m^2·°C/W;

- roof surface (steel sheet with 0.5 mm thick zinc-coating) – 0.16 m^2·° C/W;

- end wall (510 mm thick lime-brick masonry based on concrete and sand mortar) – 0.79 m^2·° C/W.

Features of the hot-water pipe system

Top 121 rm long pipe routing of the heating system is arranged in the attic. 85 running meters of them are 50 mm diameter pipes, and 36 running meters are 32 mm diameter pipes.

An estimated temperature of hot water in the pipes is 95°C.

The linear density of heat flow through the insulation surface of the pipes qpj, arranged in the attic, is 25 W/m for 50 mm diameter pipes, 22.2 W/m is for 32 mm diameter pipes at an average temperature of outside air 18°C according to the Table 12 Building Regulation 23-101-2004 under given conditions.

If the outside air temperature is assumed as 24 °C below zero then on the assumption of the upper condition (1) bound the air temperature in the cold attice $t_в^ч$ should not exceed 20 ºC below zero, as for the lower condition (1) bound – 22 ºC below zero.

At an average temperature of environment air 20 ºC below zero the linear density of heat flow through the insulation surface of the pipes qpj, arranged in the attic, is 43 W/m for 50 mm diameter pipes, 38.2 W/m is for 32 mm diameter pipes.

At an average temperature of environment air 22ºC below zero the linear density of heat flow through the insulation surface of the pipes qpj, arranged in the attic, is 44 W/m for 50 mm diameter pipes, 39.1 W/m is for 32 mm diameter pipes.

Analytical approach

Experts state that, when reconstructing roofs, it is enough to arrange air supply and exhaust outlets (air holes), at top and bottom parts of the roof to make the issue of ice formation disappear. Let us consider a certain dwelling house built in Saint-Petersburg in the beginning of the XX century (Picture 1) to evaluate the required air change (nα) to satisfy the condition (1).

The heat-balance equation for the cold attic can be presented as follows [1-4]:

$$\left(t_в - t_в^ч\right)\cdot\sum_{i=1}^{n}\left(\frac{A_i^+}{R_i^+}\right) + \sum_{j=1}^{n}\left(q_{pj}\cdot l_{pj}\right) = \left(t_в^ч - t_н\right)\cdot\sum_{k=1}^{n}\left(\frac{A_k^-}{R_k^-}\right) + 0,28\cdot V_ч\cdot n_\alpha\cdot\left(t_в^ч - t_н\right), \quad (2)$$

where tв – inside air temperature in the top floor rooms of the building, ºC; it is taken according to the requirements of the state standards GOST 30494 set for residential and public buildings, GOST 12.1.005 set for manufacturing buildings, °C, or inside air temperature in the rooms under operation can be determined while conducting field measurements;

$t_в^ч$ – the same as in the equation (1), ºC;

A_i^+, R_i^+ – consequently, the area, m2, and resistance to heat transfer, m2·°C/W, a bounded zone i between heated rooms of the building and rooms in the cold attic (attic floor slab, ventilation duct walls, partition walls between attic rooms and staircase space and etc.);

qpj – linear density of heat flow through the insulation surface of the i-diameter pipes per 1 rm with account for heat loss through isolated supports, flange couplings and reinforcement, W/m (for attics and basements the values qpj depending on a specific pipe and average temperature of a heat carrier are given in the Table. 12 Building Regulation 23-101);

lpj – the length of a j-diameter pipe, m (actual data are taken for the buildings under operation);
tн – the same as in the equition (1);

A_k^-, R_k^- – consequently, the area, m2, and reduced resistance to heat transfer, m2·°C/W in the case of the zone k related to outside envelopes of attics (floor slabs, exterior walls, filling of window openings if there are any);
Vч – the volume of inner space of the cold attic, m3;
nα – multiplicity factor on the rooms of the cold attic, h-1.
Following the equation (2) it is possible to establish the equation for required air change:

$$n_\alpha = \frac{\left(t_в - t_в^ч\right)\cdot\sum_{i=1}^{n}\left(\frac{A_i^+}{R_i^+}\right) + \sum_{j=1}^{n}\left(q_{pj}\cdot l_{pj}\right) - \left(t_в^ч - t_н\right)\cdot\sum_{k=1}^{n}\left(\frac{A_k^-}{R_k^-}\right)}{0,28\cdot V_ч\cdot\left(t_в^ч - t_н\right)}, \quad (3)$$

where all the designations are the same as in the equation (2).

3. Results and Discussion

The purpose of research [6-10, 15, 16] were: the analysis of the causes of ice dams on roofs of buildings and justification of measures to eliminate them. In all the works proposed measures aimed at reducing the heat input and lowering the air temperature in the attic. However, other authors have not analyzed the required air (air flow quantification) loft for given climatic conditions without regard to the other - passive or active, methods of normalization of temperature and humidity of the attic. This is the novelty of the research and how it differs from the studies conducted by other authors. It is shown that to achieve the normalization of temperature and humidity in the premises of the attic at the expense of only natural ventilation attic is not possible.

Computation based on analytical dependence and research object data

Let us take the estimated outside air temperature $t_н$ equal to 24 ºC below zero (the air temperature for the coldest 5 days, reliability of 0.92, in the context of weather conditions in Saint-Petersburg).

In this case, to satisfy the condition (1), as it was described before, the air temperature in the cold attic $t_в^ч$ should not exceed 20 ºC below zero.

Let us consider the case when there are no any extra works meant for envelopes insulation (attic floor slabs, walls and staircase surfaces, ventilation ducts), which separate the attic from the rooms with higher temperature. And let us compute the value of air change required to satisfy the condition (1) with the given outside air temperature under weather conditions of Saint-Petersburg equal to 24 ºC below zero (air temperature for the coldest 5 days).

Let us take the inside air temperature in the top-floor rooms of the building equal to 20 ºC, the inside air temperature in the staircases equal to 16 ºC.

Let us apply the values of geometrical and thermal and technical parameters of envelopes in the attic, and the parameters of hot-water pipes arranged in the attic, which are known, in the formula (3). To satisfy the upper bound of the condition (1), – the temperature drop between the air temperature in the attic and the outside air temperature not more than 4 ºC, we'll obtain:

$$n_\alpha = \frac{\left(20-(-20)\right)\cdot\left(\frac{507}{1,3}+\frac{34}{0,5}\right)+\left(16-(-20)\right)\cdot\left(\frac{46}{0,5}+\frac{33}{0,35}+\frac{2,0}{0,3}\right)}{0,28\cdot 1215\cdot\left(-20-(-24)\right)}+$$
$$+\frac{85\cdot 43+36\cdot 38,2-\left(-20-(-24)\right)\cdot\left(\frac{756}{0,16}+\frac{72}{0,79}\right)}{0,28\cdot 1215\cdot\left(-20-(-24)\right)}\approx 8,1\left(ч^{-1}\right).$$

In a similar manner, to satisfy the upper bound of the condition (1), – the temperature drop between the air temperature in the attic and the outside air temperature not more than 2 °C, we'll obtain:

$$n_\alpha = \frac{\left(20-(-22)\right)\cdot\left(\frac{507}{1,3}+\frac{34}{0,5}\right)+\left(16-(-22)\right)\cdot\left(\frac{46}{0,5}+\frac{33}{0,35}+\frac{2,0}{0,3}\right)}{0,28\cdot 1215\cdot\left(-22-(-24)\right)}+$$
$$+\frac{85\cdot 44+36\cdot 39,1-\left(-22-(-24)\right)\cdot\left(\frac{756}{0,16}+\frac{72}{0,79}\right)}{0,28\cdot 1215\cdot\left(-22-(-24)\right)}\approx 32,5\left(ч^{-1}\right).$$

Consequently, in relation to the case under consideration to satisfy the upper bound of the condition (1) it is required to ensure air change in the attic rooms with a multiplicity factor more than 8 h-1, and to satisfy the lowest bound of the condition (1) it is required to ensure air change with a multiplicity factor more than 32 h-1. It is impossible to ensure such air change when there is natural ventilation in the attic. It should be noted that estimates of the required air change are competed provided the condition is satisfied; according to which hot-water pipes in the attic are insulated and the linear density of heat flow through the insulation surface qpj does not exceed the standard one.

4. Conclusion

The formula, which makes it possible to compute the multiplicity of air change required to satisfy the condition contributing to eliminate ice formation on cornices and pitched roofs of the buildings with cold attics, was obtained on the basis of the heat-balance equation. In the case of the typical former commercial building the required multiplicity of air change accounted for 8.1 h-1 (to ensure temperature drop between the air temperature in the attic and the outside air temperature not more than 4 ºC) up to 32.5 h-1 (to ensure temperature drop between the air temperature in the attic and the outside air temperature not more than 2 ºC), that is impossible to ensure when there is natural ventilation. It is required to supply the necessary volume of air change mechanically (in a compulsory manner) and insulation of envelopes, which separate the attic from the rooms with higher inside temperature (top-floor rooms, staircases, through ventilation duct walls) to satisfy the condition (1) during the whole heating season. Insulation of hot-water pipes arranged in the cold attic should be performed in any case.

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Воздухообмен, требуемый для нормализации температурно-влажностного режима холодных чердаков

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ИНФОРМАЦИЯ О СТАТЬЕ

УДК 728.1

doi: 10.18720/CUBS.53.4

История

Подана в редакцию: 08.08.2016

Ключевые слова

крыша;
кровля;
карниз;
снега;
льда;
наледи;
чердак;
температурно-влажностный режима;
чердачное перекрытие;
утепление кровли.;

АННОТАЦИЯ

В статье представлены рекомендации по устранению причин образования ледяных дамб на крышах зданий с холодным чердаком и скатной кровлей в отопительный период эксплуатации. Более подробно рассмотрен случай расчета требуемого воздухообмена помещений холодного чердака без теплоизоляции строительных конструкций, ограждающих чердак от помещений или инженерных коммуникаций как источников поступления тепла. Доказано, что естественная система вентиляции может обеспечить достаточное количество воздухообмена только в короткие сроки. Чтобы удовлетворить все требования для устранения причины образования льда на крышах, нужно провести ряд работ по обеспечению воздухообмена и утеплению ограждающих конструкций.

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Н.И. Ватин, А.С. Горшков, А.Ю. Дадченко, П.П. Рымкевич, В.Я. Ольшевский Воздухообмен, требуемый для нормализации температурно- влажностного режима холодных чердаков / N.I. Vatin, A.S. Gorshkov, A.Yu. Dadchenko, P.P. Rymkevich, V.Ya. Olshevskiy. The method and computation of air change required for attic rooms ©

Литература

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N.I. Vatin, A.S. Gorshkov, A.Yu. Dadchenko, P.P. Rymkevich, V.Ya. Olshevskiy. The method and computation of air change required for attic rooms . Construction of Unique Buildings and Structures. 2017. 2(53). Pp. 50-60.