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The effect of freezing rain on ventilation equipment

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Abstract. Ice rain is precipitation consisting of small and solid frozen droplets-spheres of small diameter. Currently, this weather phenomenon is permanent in the territory of Central Russia and can be repeated 3-4 times during the winter season. Ice rains cause significant damage to green spaces and urban infrastructure, have an adverse effect on the performance of engineering equipment of buildings. The article presents the results of a field study of the functioning of an emergency ventilation system equipped with a flare system for harmful substances in conditions of ice crust formation. The factors that cause wear and decrease in the efficiency of engineering systems in conditions of ice rain are listed. After several cycles of freezing and thawing, the exhaust system remains operational without extraneous noise and vibrations, the exhaust devices operate normally, there is no imbalance of the fan impeller. The icing of the protective cover of the electric motor does not affect the bearings, winding, terminal box, impeller and other elements of the electric motor. For ventilation installations located in harsh climatic conditions, a reinforced protective cover design with a louvered grille is recommended. In case of extreme weather conditions, accompanied by severe icy-frost deposition (over 0.8 cm), it is recommended to exclude technological processes accompanied by salvo emissions of harmful substances.

1 Introduction

Ice rain is a solid precipitation formed mainly at subzero temperatures as a result of temperature inversion in the lower troposphere. Periodically, this weather phenomenon can be observed at ground temperatures above 0 °C (warm freezing rain (WFR)) [1]. The critical factors determining the temperature difference are the size of raindrops, the rate of temperature change in the atmosphere, relative humidity, wind speed and direction [2].

Freezing rainfall causes significant damage to greenery, trees and power lines. The formation of ice, crystalline or granular frost leads to an increase in the number of road accidents and injuries, cancellation of flights, power and Internet outages (Figure 1).

In Moscow, the first large-scale case of ice precipitation was recorded in 2010. Currently, this natural phenomenon has become permanent and, according to the Hydrometeorological Center of Russia, it is repeated 3-4 times during the winter season. Based on research [3], it

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can be concluded that atmospheric pollution increases the likelihood of ice rain formation. Harmful substances change the pH of precipitation, as well as reduce the temperature when droplets freeze, which prolongs the process of ice rain.

Global warming leads to an increase in the probability of precipitation formation during the cold season in various regions [4-5]. One of the reasons influencing the frequency of ice rain is the presence of fluctuations in the total ozone content [6].

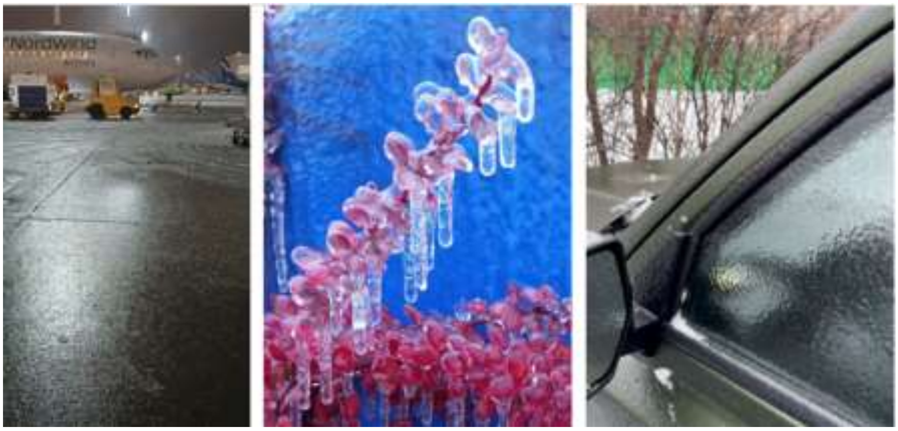

Fig. 1. The consequences of the ice rain in Moscow.

One of the features of ice rains in the Central part of Russia is the long-term preservation of icy deposits, up to several weeks [7]. Ice rains bring significant losses. The losses of the Moscow United Electric Grid Company in 2010 amounted to 1.3 billion rubles. In Moscow, about 50 thousand trees were felled and broken, and the Moscow authorities allocated more than 90 million rubles for their cleaning and restoration of landscaping. In 2020, in Primorye, the amount of damage from ice rain exceeded 1 billion rubles, and more than 170 thousand people were left without power supply. In 2022, an emergency regime was introduced in the Nizhny Novgorod region. In total, the Regional Management Center received about 3 thousand complaints about power outages. The state has paid about 500 million rubles in compensation for the damage caused by the ice rain.

The amount of ice accretion on the surface, T_i, cm, perpendicular to the direction of falling raindrops can be calculated using formulas 1-2 [8]:

$$T_i = 1/ \rho_i \cdot[(0.1\cdot P\cdot \rho_0)^2+0.36\cdot W\cdot V^2]\cdot\Delta t, \quad (1)$$

p_i and p_0 are ice density and water density, respectively, g/cm3; P is the precipitation rate of raindrops, mm/h; W is the liquid phase content, g/m3; V is wind speed, m/s; Δt is time, h.

The content of the liquid phase, W, g/m3, depends on the intensity of precipitation:

$$W = 0.067\cdot P^{0.846}, \quad (2)$$

Ice and frost can affect the operation of engineering equipment in buildings, which increases the risk of accidents at hazardous production facilities. Long-term operation of air conditioning systems in adverse environmental and weather conditions leads to an increase in the cost of the building's life cycle [9].

In a number of production processes, the formation of a salvo emission of harmful substances is possible. According to the instructions of technologists, exhaust emergency ventilation is provided for such facilities, which allows reducing the concentration of harmful substances in the working area of the room [10]. One of the main requirements is to ensure the constant operability of the equipment and the emergency ventilation dispatching system at the facility [11].

The article presents the results of an experimental study of the effect of ice rain on the operation of the flare system of the emergency ventilation system, taking into account the cycles of freezing and thawing.

2 Materials and methods

The test facility is an exhaust emergency ventilation system consisting of an air duct network, a radial fan and a flare system. When the sensor is activated, which records the excess concentration of harmful substances in the working area of the room, the exhaust fan is turned on. The air flow, reaching the calculated speed of movement, knocks out the flare flaps (Figure 2).

Fig. 2. Photo of the test facility.

When placing ventilation equipment in climatic zones with severe weather conditions, special attention should be paid to protecting the fan motor as its most vulnerable part. The most widely used protective covers of the structures shown in Figure 3 are currently available.

a) b) c)

Fig. 3. The designs of the protective covers of the fan motor: a) the hood-visor; b) the casing-box; c) reinforced casing with louvered grille.

In the presented full-scale installation, a reinforced casing with a louvered grille was used.

The simulation of precipitation in the form of ice rain was carried out in a climate chamber at subzero temperatures. The main purpose of the tests was to determine the operability of the flare system during the formation of an ice crust, as well as the effectiveness of the protective cover of the electric motor. Additionally, experimental studies were conducted on the effects of freeze-thaw cycles on the operation of equipment in order to verify the tightness of the ventilation system design.

3 Results

According to the data of the Main Geophysical Observatory named after A.I. Voeikov, the duration of ice rains in 60% of cases ranges from 5 minutes to one hour. Prolonged precipitation (over 4 hours) is extremely rare, mainly at night. During the period of ice rains, an increase in relative humidity of up to 90% is observed. Ice rain is mostly of mild or moderate intensity [12-13].

To select the conditions for conducting a field study, the value of ice accretion was calculated using formulas 1-2 (Figure 4). The data obtained were compared with the conditions of formation and thickness of the ice crust of the most destructive cases of ice rains recorded in Russia.

In December 2010, the first major case of significant ice rain was recorded in the Central Region of Russia (the width of the ice strip was 150-250 km from Smolensk to Samara) [13]. In Moscow, the thickness of the ice crust recorded at the meteorological station of the All-Russia Exhibition Center ranged from 10 to 11 mm, with the duration of icy deposits of 17 days and wind speeds from 0 to 2 m/s. The surface temperature ranged from -3.3 to -6 °C. The thickness of the ice glaze measured at the Nemchinovka station in the Moscow region was 19 mm. At the Murom meteorological station in the Vladimir region – 23 mm, at the Arzamas station in the Novgorod region – 20 mm. The most extreme conditions were observed in the east of the Moscow region (Cherusti station). The maximum thickness of the ice crust in this region was 24 mm, and the duration of icy deposits was 24 days. According to eyewitnesses, in some cases the amount of ice accretion reached 50 mm.

November 2020 was remembered by residents of Primorsky Krai for a devastating ice storm, recorded in this territory for the first time in the history of meteorological observations [14]. The thickness of the icy deposits ranged from 12 to 51 mm, the average value of ice accretion was 27 mm, and the precipitation rate of raindrops ranged from 1 to 2 mm/h. Precipitation broke the record for its duration. According to the weather station named after V.K. Arsenyev, located at Vladivostok airport, the ice rain lasted about 11.5 hours at a surface temperature from 0 to -1 °C and a wind speed of 3-4 m/s.

According to the weather station named after V. P. Chkalov, the duration of the ice rain in November 2022 in Nizhny Novgorod was about 6 hours at a temperature of -1 °C and a wind speed of 2-5 m/s. As in the other cases considered, precipitation had a weak intensity. The thickness of the icy deposits in some areas was about 40 mm.

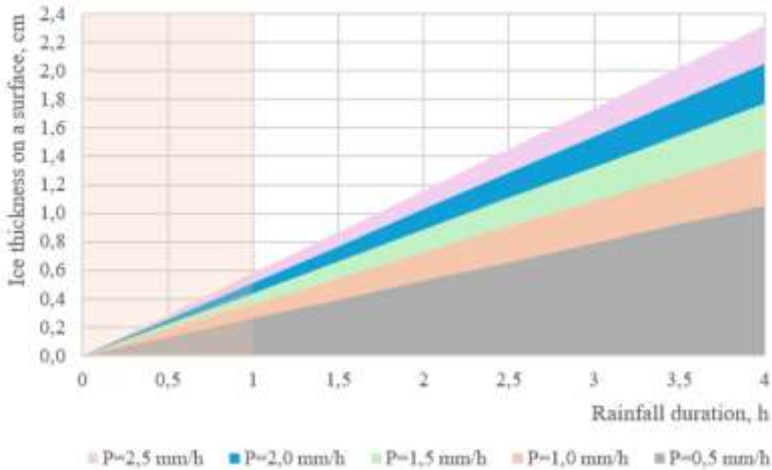

Fig. 4. The thickness of the ice crust on the equipment depends on the duration of precipitation.

Calculations of the thickness of the ice crust formed on the equipment were carried out for the intensity of precipitation corresponding to light rain from 0.5 to 2.5 mm at the maximum of the average wind speeds in January for Moscow according to formulas 1-2. The maximum value of ice accretion an hour after the start of rain was $T_i = 0.58$ cm.

Analyzing the weather data of the listed meteorological stations during the formation of ice rains, it can be concluded that one of the features of weather conditions during this period is the alternation of various types of precipitation: drizzle, light showers, snow and hail. This factor is one of the reasons for the increased accretion of icy-frost deposits, above critical values (over 20 mm). Formulas 1-2 allow you to determine the thickness of the glaze only when exposed to ice rain on the surface, without taking into account the formation of complex deposits in the form of freezing snow and frost. To verify the calculated values obtained using formulas 1-2, an additional calculation was carried out for the ice rain that took place in Nizhny Novgorod in 2022, since according to the weather station, no difficult precipitation was recorded during the period under review. The calculation was performed at an average wind speed of 3.5 m/s and a six-hour duration (Figure 5).

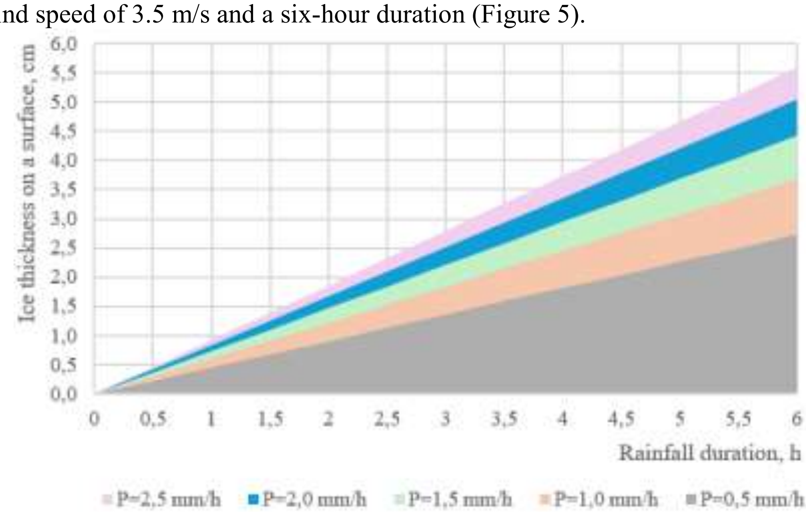

Fig. 5. The thickness of the ice crust depends on the duration of precipitation for the ice rain in Nizhny Novgorod in 2022.

The average ice accretion was 4.29 cm. The values obtained as a result of calculations correlate with the data recorded by the weather station and eyewitnesses of the event. Thus, these formulas can be used to determine the thickness of the glaze for ice rain without mixed precipitation types.

As a result of a trial start of the fan during icing simulation (T_i = 0.6 cm, which corresponds to the maximum accretion value for Moscow with an ice rain duration of less than 1 hour), the flare system is triggered in normal mode (Figure 6). A small part of the ice crust falls into the fan housing when the exhaust duct is opened, without causing displacement of the impeller and deformation of the blades. An increase in ice accretion (T_i = 0.8 cm) leads to a short-term delay in the opening of one flare flap until the fan enters operating mode. A further increase in the thickness of the icy deposits leads to sticking of the valve flaps.

Fig. 6. Checking the operability of the flare system when simulating an ice rain.

After several cycles of freezing and thawing, the exhaust system remains operational without extraneous noise and vibrations. When exposed to ice rain, the protective cover of the electric motor is covered with an ice crust, vertical icy deposits (icicles) form on the louver grille. The formed ice layer does not affect the operation of the fan and does not cause overheating of the electric motor. When removing the protective cover, a small amount of moisture was found that did not pose a threat to the technical condition of the equipment (Figure 7). No moisture was found in the terminal box of the electric motor. The tightness of the installation is at an acceptable level for long-term operation.

a) b) c)

Fig. 7. Photo of the test unit: a) ice crust formed on the protective cover of the electric motor b) moisture on the fan motor after several cycles of freezing and thawing c) moisture on the impeller and inside the fan housing.

4 Discussion

The main environmental factors affecting the durability of the engineering equipment of buildings include: high relative humidity, freezing and thawing cycles, low pH, precipitation and high temperature [15].

The ice crust formed on structures and equipment when exposed to ice rain can create significant loads [16]. The formation of icy deposits on the flare system and the protective cover of the electric motor of the emergency ventilation system in case of ice rain of moderate intensity with a precipitation duration of less than 1 hour does not affect the operation of the equipment. A small amount of ice crust falling into the fan housing when the exhaust duct is opened does not lead to an imbalance of the impeller and deformation of the blades. The presented studies were of a short duration, under conditions of prolonged exposure to freezing and thawing cycles, the wear of the fan structure and the exhaust valve will occur more intensively. An increase in the thickness of icy deposits over 0.8 cm leads to sticking of the valve flaps.

The icing of the protective cover of the electric motor does not affect the bearings, winding, terminal box, impeller and other elements of the electric motor. Therefore, for installations operating in harsh climatic conditions characterized by heavy precipitation, snow drifts and ice rains, it is recommended to use a reinforced cover structure with a louvered grille.

It is recommended to conduct further studies taking into account changes in the rate and duration of precipitation, as well as in conditions of formation of complex icy deposits (a mixture of ice crust and freezing snow). Since ice rains are often acidic [3], they can have an impact on corrosion and destruction of engineering systems. A study of the durability of steel joints [17] showed that under freezing and thawing conditions, the strength of connecting structures decreases, especially in an environment with low pH. The destruction of gaskets and connecting parts of the ventilation system leads to a decrease in its tightness and an increase in equipment power consumption.

Freezing rain affects not only the durability of ventilation systems, but also their efficiency. The formation of ice on the supply air intake grilles, exhaust deflectors and sunshades increases the aerodynamic resistance of the network and leads to a significant increase in energy consumption of the systems.

Natural ventilation systems are particularly susceptible to negative effects (Figure 8). Icing of the deflectors leads to a decrease in the cross-sectional area of the air passage holes, worsens the intensity of rotation of the deflector or leads to its complete stop. An increase in resistance on the exhaust head of the ventilation duct when using natural ventilation systems leads to a sharp decrease in indoor air exchange, which is especially dangerous for apartment buildings that use gas equipment. A prolonged decrease in air exchange in the premises of sanitary facilities leads to the formation of increased relative humidity, mold formation and destruction of finishing materials and enclosing structures.

Fig. 8. Icing of the deflector of the natural ventilation system.

5 Conclusion

The long-term preservation of icy deposits, typical for the Central region of Russia, leads to destabilization of the fuel and energy, industrial and transport sectors of the economy.

In case of prolonged ice rain, more than 1 hour, accompanied by mixed types of precipitation, it is recommended to carry out a preventive inspection of exhaust ventilation systems equipped with a flare system. These devices can be used in industrial enterprises in emergency ventilation systems, as well as smoke protection systems of buildings for various purposes. Additionally, it is worth noting the need to examine the electric motors of fan installations with lightweight protective covers, since they are most susceptible to precipitation.

The factors that have the greatest impact of ice rain on the durability, efficiency and operability of ventilation equipment include:

1. The formation of ice deposits on equipment that cause an increase in pressure losses in the ventilation network (air intake grilles, exhaust duct heads, sunshades, deflectors and flare systems), as well as loads on equipment placed on the roof of the building.
2. Increased relative humidity, which causes increased corrosion of metal and connecting parts;
3. The acidity of precipitation, which accelerates the destruction of the coatings of the air duct network and fan installations;
4. An increase in freezing and thawing cycles of equipment, leading to an increase in the number of emergencies of electrical equipment, control devices, automation and dispatching systems.

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