Temperature Potential of the Seasonal Cooling Devices in the Work of Boiler-Plants

L M Baisheva¹, V N Ivanov², A V Ivanova³

¹Department of Heat and gas supply and ventilation, Institute of Engineering and Technology, North-Eastern Federal University named after M.K. Ammosov, Kulakovsky str. 50, Republic of Sakha (Yakutia), Yakutsk 677013, Russia
²Department of Heat and gas supply and ventilation, Institute of Engineering and Technology, North-Eastern Federal University named after M.K. Ammosov, Kulakovsky str. 50, Republic of Sakha (Yakutia), Yakutsk 677013, Russia
³Department of Heat and gas supply and ventilation, Institute of Engineering and Technology, North-Eastern Federal University named after M.K. Ammosov, Kulakovsky str. 50, Republic of Sakha (Yakutia), Yakutsk 677013, Russia

E-mail: lidiyabaisheva@mail.ru

Abstract. This article describes a complex system for the preservation of frozen soil and preliminary fuel-free air access. Thermal calculation of seasonally cooling devices to determine the air temperature after passing through the soil thickness and in any section of the pipeline, depending on its length is considered. Also, field measurements of the operation of cooling systems are carried out. The temperature difference of the seasonal cooling device can be used for preliminary fuel-free heating of the air necessary for the combustion of the boiler. The cold outdoor air passing through the seasonally cooled device on the one hand cools the ground of the base, and on the other he heats up. The use of preheated air passing through the seasonally cooled device saves heat for heating, reduces the consumption of air for combustion, and applies an intake ventilation system without preheating in heaters, which increases the efficiency of fuel combustion in a heat-generating installation. The proposed method of calculation has good values and can be used to calculate the temperature on the basis of seasonal cooling devices

1. Introduction

The regions of the Far North and the territories equated to them have significant potential for the introduction of energy-saving technologies at present. This is due to the presence of an extremely cold winter combined with the need to preserve the natural regime of permafrost. The duration of the heating period of the city of Yakutsk is 252 days, which is about 9 months, according to the current rulebook. Reducing the period of operation of heat sources on organic fuels by introducing energy-saving measures will produce a significant positive effect from the economy and preserve fuel resources, taking into account the particularly long heating period and high energy intensity.

2. Relevance of the study

The construction of buildings by the first principle of using permafrost is accompanied by the solution of the problem of preserving the temperature regime of the soil. There are two main types of
construction: the first - on piles, the second - on bedding with the use of a cooling system. The construction of a building on piles is a very expensive due to the complex and underdeveloped infrastructure, as well as the remoteness of the settlements of Yakutia. Thus, to reduce the cost and affordability of construction, other methods are considered, such as the use of bedded soil. But with this choice of construction, there are problems of preserving the frozen state of the soil and using changes in the cooling air temperature to preheat the supply air, which is a difficult task.

3. **Scientific significance**
Modern ideas about the temperature regime of the frozen foundations of structures, its quantitative patterns are based on the works - G.V. Porkhava, N.S. Ivanova, L.N. Khrustaleva, V.A. Kudryavtsev, H. Karslow, A.A. Konovalov et al. At present, this topic is also widely studied by both Russian and foreign scientists [1–7].

4. **Problem statement**
The construction of buildings by the first principle of using permafrost is accompanied by the solution of the problem of preserving the temperature regime of the soil. There are two main types of construction: the first - on piles, the second - on bedding with the use of a cooling system. The construction of a building on piles is a very expensive due to the complex and underdeveloped infrastructure, as well as the remoteness of the settlements of Yakutia. Thus, to reduce the cost and affordability of construction, other methods are considered, such as the use of bedded soil. But with this choice of construction, there are problems of preserving the frozen state of the soil and using changes in the cooling air temperature to preheat the supply air, which is a difficult task.

In the climatic conditions of the Far North and the Arctic, an important task is to increase the reliability and efficiency of heat-generating installations that are sources of heat supply. Selection of gas heat generators according to modern regulatory data does not require calculation and is limited to typical classifications, where the main criterion is power. Such an approach to the choice of a heat supply source does not take into account the particularities of the climate, which is especially important for regions with low outdoor temperatures.

The practice shows that foreign heat generators are not adapted to work in low outdoor temperatures, and most domestic manufacturers do not take into account climatic features. An analysis of the operation of boiler houses has shown that the greatest number of interruptions in heat supply is observed from November to February, during the period of the lowest air temperatures. Also, there is a significant over-consumption of fuel, a decrease in the efficiency of gas boilers and the problems of regulation automation. One of the main reasons is the diffusion stage of the combustion process. The supply of negative temperature air into the furnace affects the efficiency of the heat generating installation and leads to an increase in fuel consumption [8, 9].

At the same time, another feature of the operation of the boiler house on permafrost soils is that, regardless of the technical characteristics of the boiler, over time, each heating season increases the defrosting aura under the building. This process affects the base of the boiler room, leads to a shift from the central axis and disruption of the boiler room [10–19].

This paper discusses the conceptual and technological integrated system for the preservation of frozen state of soil and preliminary fuel-free heating of the air necessary for the combustion of a boiler room. Due to the temperature difference between the soil and the outside air in winter, the air for combustion, passing through the cooling system of pipelines, cooling the soil - heats up in the direction of travel. The combined system is designed to cool the soil in the cold season and preheat the supply air due to the temperature difference between the soil and the outside air in the winter period. The cold air passing through the piping system cools the soil and prevents it from defrosting under the building and heats up to the temperature of normal operation of the inlet devices.
5. Solution method

The thermal calculation of the seasonally cooling devices is reduced to the compilation of the heat balance to determine the temperature of the coolant, which is its main characteristic.

The energy conservation law, taking into account mass and momentum, has the form:

\[ c_a \rho_a \frac{dt}{dx} = \frac{d}{dx} \left( \lambda \frac{dt}{dx} \right) - c_a \rho_a v_{av} \frac{dt}{dx} + f \]  

(1)

where \( c_a, \rho_a \) - specific heat capacity and density of air, respectively kJ/(kg °C) and kg/m³; \( \lambda \) — thermal conductivity coefficient, W/(m °C); \( v_{av} \) — average coolant velocity, m/s; \( f \) is the function of the receipt of heat sources from the soil, kJ/m³ s.

Since diffusion heat transfer can be neglected in this case, the equation will take a simpler form:

\[ \frac{dt}{dx} + v_{av} \frac{dt}{dx} = f \]  

(2)

The construction of a general solution of this equation after integration reduces to the following by [20]:

\[ \Phi (v_{av} \tau + x; v_{av} T + fx) = 0 \]  

(3)

where \( \Phi \) is an arbitrary function.

From here we get the system of equations:

\[ \begin{cases} v_{av} \tau - x = c_1 \\ v_{av} T - fx = c_2 \end{cases} \]  

(4)

The formula describing the temperature at the outlet of the seasonally cooling devices channel is:

\[ t'' = t' + \tau f \]  

(5)

where \( t'' \), \( t' \) - the temperatures at the exit and at the entrance to the channel, respectively, °C, \( \tau \) is the time, sec.

The general form of the function \( f \) is as follows:

\[ f = \frac{a_{ef} (T_b - T_s)}{c_a \rho_a \pi d} \]  

(6)

where \( a_{ef} \) is the effective coefficient of convective heat exchange between the soil and air, W/(m² °C), calculated according to equation [21]; \( T_b - T_s \) - respectively, the temperature in the building and the soil, °C; \( d \) - diameter of the sow channel, m.

The usual seasonal cooling device has two channels - with warm and cold streams. The coolant, descending through the cold channel and taking heat from the ground, heats up from temperature \( t_a' \) to higher - \( t_a'' \). Then, according to the heat balance equation, we have:

\[ \int_0^y k_s \pi D \, dy = \int_{t_a'}^{t_a''} \frac{dt}{t_s - t_a} \]  

(7)

After integration we get:

\[ t_a'' = t_s - (t_s - t_a') \cdot e^{-\frac{k_s \pi D}{c_a \rho_a \pi d}} \]  

(8)
where $L_a$ is the air flow rate m$^3$/h; $\rho_a$, $c_a$ - density and heat capacity of air, respectively, kg/m$^3$ and kJ/(kg·K); $k_s$ - linear coefficient of heat transfer from the ground to the air, W/(m·K); $t_s$ - soil temperature, °C.

Also, this equation allows to calculate the air temperature after passing through the soil thickness and in any section of the pipeline, depending on its length.

6. Results of experimental studies

Field measurements of the operation of cooling systems in boiler rooms were carried out in Bestyakh, Pokrovsk Khangalassky district, in Maya Megino-Kangalassky district, in Abyi Abyisky district, in Batamai of the Kobyai district in the period from December to March 2019 (figure 1). Horizontal pipes with a diameter of 0.15-0.25 m are laid across buildings at a depth of 1 m approximately every 1.7-2.5 m and connected to the atmosphere by vertical pipes having an elevation of 1.5-3.6 above the ground surface on one side, on the other hand - 0.7-1.6 m.

![Figure 1. Boiler rooms with seasonal cooling devices.](image_url)

12 out of 58 surveyed pipes did not work, due to mechanical and weather phenomena (they were covered with snow and frost). Field measurements showed that the cooling systems perform their main function, the speed of air movement in the pipes reaches 1 m/s and more at a wind speed of only 1 m/s.

Field measurements of the speed of movement and the temperature of the air coolant at the exits from the cooling pipe system were made using a Testo 435-4 hot-wire anemometer. Also, the outside air temperature was measured. The most illustrative results of a full-scale study are shown in table 1.

| Parameters | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| $t'$ °C | -25.9 | -28.6 | -29.3 | -28.9 | -28.2 |
| $t''$ °C | -20.8 | -17.6 | -20.5 | -19.4 | -19.9 |
| $t'' - t'$, °C | 5.1 | 11 | 8.8 | 9.5 | 8.3 |
| $v$, m/s | 0.6 | 0.63 | 0.57 | 0.3 | 0.28 |

| Parameters | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| $t'$ °C | -38.6 | -39.1 | -39.3 | -39.5 | -39.5 |
| $t''$ °C | -33.9 | -31.9 | -29 | -36.5 | -29.1 |
| $t'' - t'$, °C | 4.7 | 7.2 | 10.3 | 3 | 10.4 |
| $v$, m/s | 1.2 | 1.02 | 1.8 | 0.5 | 1.2 |

| Parameters | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| $t'$ °C | -41.4 | -41.5 | -41.7 | -41.8 | -41.8 |
| $t''$ °C | -37 | -37.2 | -34.3 | -41.6 | - |
| $t'' - t'$, °C | 4.4 | 4.3 | 7.4 | 0.2 | - |
| $v$, m/s | 0.17 | 0.33 | 0.16 | 0.1 | 0.1 |

| Parameters | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| $t'$ °C | -32.9 | -32.8 | -32 | -32.3 | -32.9 |
Comparing the calculated values of the temperatures at the outlet of the seasonal cooling devices with the actual data, one can speak of a good convergence of the actual and calculated results according to the developed method (figure 2, 3).

The results of the field survey illustrate the good performance of the cooling system - air velocity at an average of 0.5 m/s or more, with a wind speed of only 1 m/s.

From the graphs it can be seen that the results of actual measurements show the validity of the previously derived formulas. The results of the actual measurements show the validity of the previously derived formulas.

7. Conclusion
Thus, the temperature difference of the sow can be used for preliminary fuel-free heating of the air necessary for the combustion of the boiler. The cold outdoor air passing through the seasonal cooling devices on the one hand cools the soil of the base, and on the other it heats up. Therefore, the cold outside air cools the soil, provides reliability, efficiency of using the base in permafrost areas. The use of preheated air passing through the seasonal cooling devices allows to save heat for heating, air supplied for combustion, to apply the inlet ventilation system without preheating in the heaters, which increases the efficiency factor, the stability of fuel combustion in the heat generating unit.
The proposed method of calculation has good convergence and is used to calculate the temperature at the outlet of the seasonal cooling devices.

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