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Features of the Operation of Autonomous Heat Generating Plants in the Climatic Conditions of the North

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Abstract: The pace of individual housing construction in the North since the 2000s has increased significantly. The geographical, climatic and territorial features of the North mostly require the usage of autonomous systems for building services. The health and quality of human life in extreme conditions depend on the effective operation and reliability of heat supply systems. The paper presents the test results of modern autonomous heat generating plants in Yakutia.

1. Introduction

Climatic features of Yakutia require increased reliability in the performance and functioning of engineering systems. The complexity in central planning of energy consumers and consolidation of generation systems is caused by the large distances between settlements and the population dispersal as well as a low population density [1]. One of the characteristic features of the Yakutia climate is a large annual temperature amplitude, which varies in the range of 50-127 ° C. The coldest five-day outside air temperature ranges from -50 ° C to -65 ° C, and in other regions of Russia from -25 ° C to -41 ° C, which makes a difference of more than 20 ° C. The significant heating period duration, the presence of ever frozen subsoil, poorly developed infrastructure, the great distance between settlements, mostly sparsely populated, create specific difficulties for the construction and maintenance of human life in the North [2, 3, 4].

The basic principles of the design and construction of energy-efficient buildings are widely known and aimed at reducing energy consumption through the use of building envelopes with a high level of thermal protection, rational architectural and planning solutions, modern heating, ventilation and water heating systems, and the use of alternative energy sources. The heat energy consumption of the heating system depends on the climatic parameters of the construction region. The economic feasibility of energy efficiency measures, in particular on the use of modern engineering solutions, is currently mandatory [5-6].

The proportion of the housing stock in Yakutia supplied with heating is 24%. Only in 18% of settlements, central heating supply exceeds 50%. Moreover, the public utility infrastructure wear is 70%. In general, rural settlements are not provided with high-quality public services. There is no complete centralized heat supply system in most settlements [7]. At the same time, the heat generation cost by centralized boiler stations significantly is the most expensive while comparing with existing analogues. According to [8], currently the tariff for heat and electric energy in the Far North reaches more than 18,000 rubles / Gcal and 30 rubles / kW * h. Changes in the real estate market and rising energy prices are forcing many people to build individual houses with built-in autonomous heating systems with gas or solid fuel boilers [9]. Due to the focal settlement areas with low population density and rural population living mainly in places of historical habitat, the construction of large heat generation facilities and infrastructure is impossible or impractical from an economic point of view. The features of decentralized energy supply are fully inherent in the Far North regions, caused by: harsh climate, temperature changes, high demand for energy development. Based on this, the demand for autonomous heat generating plants has been growing recently in these regions [10]. The absence of extended external heat lines makes it possible to practically eliminate the coolant loss in the heat supply system, as well as to limit heat loss to the environment.

2. Methods

Improving the reliability and efficiency of heat supply systems depends on the operation of heat generating plants, rationally designed boiler station cycle, widespread introduction of energy-saving technologies and alternative energy sources, saving of fuel, heat and electricity [11]. Since the beginning of the 2010s, solid fuel boilers using the so-called “upper combustion” principle have been actively introduced in Yakutia. Currently, over 900 units of boilers using this principle are operated in the republic. Large-scale operation is also being carried out in the Arctic regions. The main fuel source for such autonomous systems is lignite and firewood. Larch firewood, the coal of the Dzhebariki-Khaya coal deposit and lignite of the Kangalassky and Kharbalakhsky coal deposits are widely used in Yakutia, which is a huge advantage for the solid fuel boilers operation, due to the availability and relatively low fuel cost. The principle of "upper combustion" is that the air supply and the combustion process are limited to the upper part of the fuel layer. This method allows loading a significant amount of fuel into the furnace at a time. Accordingly, boilers are characterized as long-burning boilers and require less frequent maintenance. Moreover, the combustion process in boilers goes from top to bottom, so that the combustion process occurs in the upper layer, without affecting the lower layers. The boiler layout with the structural description is shown in Fig. 1. Combustion air is supplied to the combustion chamber through a pipe, at the end of which there is an air distributor that rests on the combustion zone and goes down with a gradual decrease in the fuel amount in the combustion chamber. The air distributor purpose is to properly distribute air in the combustion zones. Heating of the coolant occurs in the space between two coaxial steel cylinders of different diameters. In this case, the outer cylinder is closed by a heat-insulating layer from the external environment.

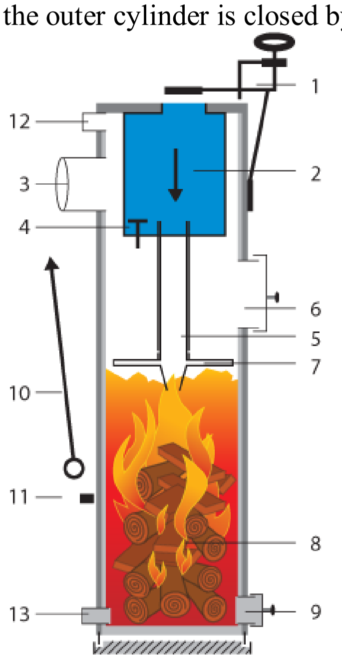

Figure 1. Boiler layout:
1. Damper with thermostatic air valve, 2. Air heating chamber, 3. Smoke extraction flue, 4. Damper, switching the type of fuel: firewood / coal, 5. Air injection pipe, 6. Fuel loading door, 7. Air distributor, 8. Fuel, 9. Ash removal doors, 10. Lifting rope with a ring, 11. Hook, 12. Hot water pipe, 13. Cold water pipe

The heating system of these boilers can be either natural or forced circulation. The population in rural areas mainly operates such boilers, as 95% of the rural total housing stock is wooden [12]. Experience has shown that solid fuel heat generators of imported and domestic manufacturers are not suitable for operation at low temperatures and do not meet the declared characteristics for combustion duration, efficiency rate and heat energy output. In order to increase the efficiency of the heat-generating plants, a group of scientific employees of the Northeast Federal University Engineering and Technical Institute conducted field studies. Testing was carried out during the boilers operational period in the winter.

3. Results

Thus, to determine the efficiency factor of boilers with the principle of "upper combustion" using the reverse balance method, we used the KGA-8 portable device, designed to analyze flue gases. Measurements were taken in February 2019. The Testo 435-4 multifunction meter and the SATG-90 thermal imager were used to measure the outside air temperature. Table 1 shows the results of experimental data obtained for Liepsnele solid fuel boilers installed for the industrial building heat supply.

Table 1. Boiler flue gas analysis results

Object:	Time	O2, %	CO2, %	CO, ppm	NO, ppm	Ty.g., C	SO2, ppm	H2, ppm	ALFA	Q2, %	Efficiency factor, %	Q3,%
Yakutsk, industrial building	12:42	15,9	4,7	1317	91	113	78	2681	4,11	15,3	82,8	1,7
	13:51	18,3	2,5	1057	79	135	61	2689	7,77	35,3	61,9	2,6
	15:13	16,9	3,8	268	74	142	12	1634	5,12	25,6	73,8	0,4
	16:07	18,6	2,2	290	57	141	16	1831	8,75	41,7	57,4	0,8
	17:07	17,6	3,1	71	56	141	4	401	6,17	34,2	65,6	0,1

Based on the data obtained, the dependence of the efficiency factor on the outside air temperature during daylight hours was compiled. The dependency diagram is presented in Fig. 2.

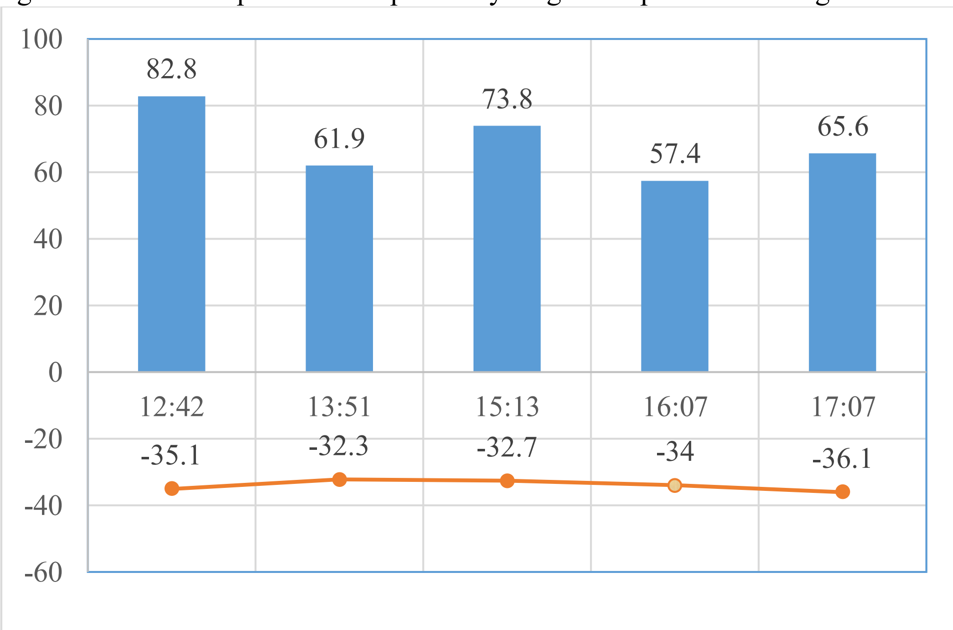

Figure 2. The dependence of the boiler efficiency factor on the outside air temperature during 1 daylight hours

The results show that efficiency factor indicators vary in the range of 57.4-82.8%. At the same time, the results of boiler efficiency factor obtained in the course of previous calculations, when using local fuel, show that the thermal efficiency of boilers mainly varies in the range of 39-85% [12]. Thermographic Imaging of boilers and its components using a thermal imager showed low heat loss (see Fig. 3-4).

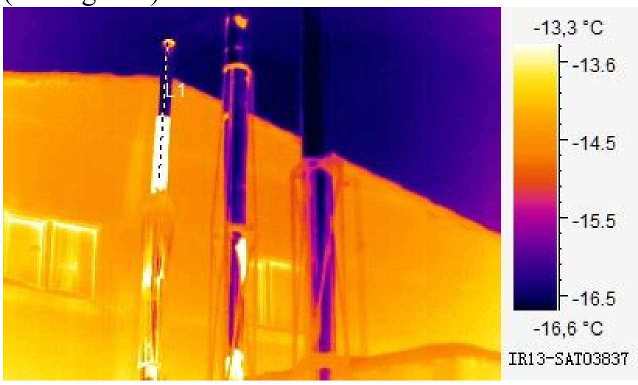

Figure 3. Chimney thermal-imaging. The maximum temperature in L1 area reaches up to -13.3 ° C. The average temperature in the area is -14.4 ° C; the minimum temperature in the area is -16.4 ° C. The outside air temperature at the time of shooting was -35.4 ° C.

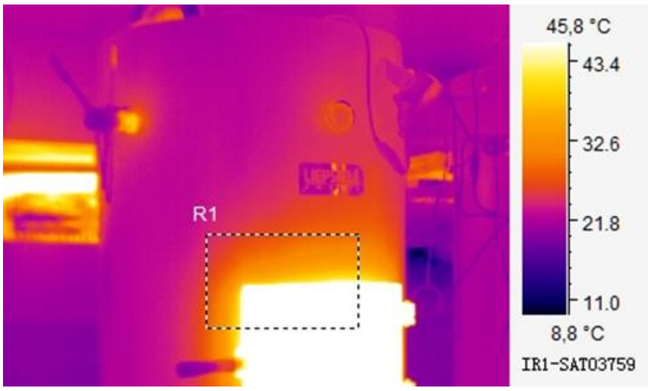

Figure 4. Boiler surface thermal-imaging. The maximum temperature in R1 area reaches 58.7 ° C. The minimum temperature of the area is 25.5 ° C. The outside air temperature at the time of shooting was 18.8 ° C.

Only the steel doors of the boilers showed the highest temperature fields. A high degree of thermal insulation of boilers and chimneys allows these plants to increase the efficiency of fuel combustion and the generation of thermal energy.

4. Conclusions

1. A high variation in the efficiency indicators can be caused by the increased chimney draught, which increases the speed of the flue gases, and, as a result, heat losses with flue gases. The increase in draught inside the boiler space and chimney, in particular, is associated with the excessive pressure of external air and wind backwater. In this case, the force of the resulting pressure directly depends on the height of the chimneys of the boilers and the outside air temperature [13].

2. Efficiency and duration of fuel combustion depends on fuel quality, internal and external temperature, while this type of boiler can provide resource and fuel savings due to design features and contribute to energy savings by controlling the degree of combustion [14-15].

3. Building heat insulation and its architecture play an important role in the operation of boiler equipment and the degree of fuel combustion [16]. In the Far North, the actual heat loss through the enclosing elements of the wooden housing stock is high, which affects the efficiency of heat supply and boiler equipment operation.

4. Experience has shown that solid fuel boilers with the "upper combustion" principle can be operated in climatic conditions of Yakutia. Heating systems using “upper” combustion solid fuel boilers make it possible to solve the problems of heat supply in decentralized settlement housing facilities where, due to transport and logistics, territorial features, it is impossible to lay gas supply

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networks or in places with undeveloped engineering infrastructure, in most cases caused by the lack of centralized heat generating plants.

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