Prospects for the use of wind power for heat supply to consumers in the western sector of the Russian Arctic

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Abstract. The problem of heat supply to remote dispersed consumers of the Arctic and the possibility of such a local renewable energy source as wind to be involved in are considered. The wind potency distribution over the western sector of the Russian Arctic is shown. Areas with enhanced wind potency are identified, which are the most promising ones for heating needs. Wind energy cadastre principal characteristics of the region are studied (average long-term wind speeds, seasonal distribution in average monthly speeds, wind speed frequency, etc.). There is a winter wind speed peak in coastal areas, which coincides with the cold season peak demand for heating power and electricity. This is the main prerequisite for the successful joint operation of current boiler rooms with wind power plants (WPP), which are able to provide a significant part of the heating load. It is shown that the use of wind energy will save (displace) a significant amount of expensive imported fuel and significantly reduce the working cost of heat generated. The climatic characteristics of the region are studied, and the values of reduced (taking into account the wind) outdoor temperature are estimated. The way how the wind strains the initial picture of the distribution of average annual air temperatures is shown. The consumer heating-load curve and its provision by WPPs possible participation and boiler rooms are considered. The share of high wind potency WPPs reaches 60-80% in one year.

1. Introduction
Significant natural resources are concentrated in the Russian Arctic. The development of these resources is paid an increased attention. It is obviously that this is impossible without adequate power supply.

Given the severe climatic conditions of the Arctic (low air temperatures, increased wind intensity), the heat supply management for consumers is to be of great importance. The use of imported fossil fuels for this purpose is associated with high transport costs and significant financial expenses. Therefore local energy resources, including nonconventional renewable ones, such as, for instance, wind energy, deserve attention [1], [2], [3]. The article is concerned with the prospects of the use wind energy for heat supply to consumers in the western sector of the Arctic.

2. Wind characteristics in the western sector of the Russian Arctic
When identifying the prospects for the use of wind energy, a system of wind characteristics is usually developed, grouped under the concept of a wind energy cadastre [4], [5]. There among these
characteristics are the average annual wind speeds, seasonal distribution in average wind speed level, the wind speed frequency, etc. The general characteristic of the wind potency is determined by the average annual wind speeds (Fig. 1).

It can be seen from the Fig.1 that the coastal areas of the White and Barents Seas are the most favorable for WPPs, where the average annual speeds reach 6-8 m/s [6].

Wind is a negative climatic factor, defining the increased heat loss of buildings. Applying of WPPs for needs of heat supply will convert the wind into a full-fledged energy source, making for the saving of expensive fuel. When using wind for this purpose, the variability of wind energy is no longer critical, since wind energy fluctuations will be leveled due to the accumulating ability of heated buildings.

3. The effect of wind on heat consumption conditions
In the absence of wind the heat loss of a building is determined by the expression [7]:

$$Q_0 = qV(t_{in} - t_{out})$$

where q is the specific thermal characteristic of the building, kW/(m$^3$ °C); V - external volume of the building, m$^3$; $t_{in}$ and $t_{out}$ - internal and outside air temperature, °C. The increase of consumer heat loss from the wind can be taken into account using the correction factor $k_v$ or the reduced outside temperature $t_{out}^{red}$:

$$Q_V = Q_0 k_v = qV(t_{in} - t_{out}^{red})$$

The dependence of the factor on the wind speed is presented in the Fig. 2. Fig. 3 presents a map of the average annual air temperature distribution over the territory of the European North of Russia. Long-term results summarizing of observations of air temperature at weather stations showed that the average annual air temperature ranges from 2 °C above zero degrees in the southern regions of the Republic of Karelia to 5-7 °C below zero degrees in the far northeast of the region [8].
k_{U}

\[ U, \text{m/s} \]

Given the wind, its effect appears to be equivalent to a 5-8 °C decrease in the average annual air temperature, which is quite substantial (Fig. 4). The wind significantly deforms the picture considered above. Further studies showed that the calculated reduced (taking into account the wind) temperature of the coldest five-day period, which must be giving consideration when deciding on the boiler room power, reaches 53-57 °C below zero degrees in northeastern places.

**Figure 3.** Average annual air temperature (°C) in the regions of the European North of Russia

Monthly and annual heating requirements can be expressed as follows:

\[ W_M = 24qV \sum_{i=1}^{n_m} \Delta t_i \quad W_A = 24qV \sum_{i=1}^{n_a} \Delta t_i \]

(3)

where \( n_m \) and \( n_a \) - the monthly and annual durations of the heating period, days; \( \Delta t_i = k_w (t_{in} - t_{out}) \) - the average temperature difference between the internal and outside air during the \( i^{th} \) day, having regard to the wind.
Figure 4. Average annual reduced (taking into account the wind) air temperature (°C) in the regions of the European North of Russia

Giving dependence (3) the WPPs possible participation in the heating-load curve coverage was analysed (Fig. 5). If heating is only supplied by boiler room, then it provides full heat $W_A$. During periods with strong wind, joint operation of a WPP with a boiler room can be used for heating. Therefore, a part of the heating-load curve can be provided with WPP, and the other with the boiler room [9].

Figure 5. Fragment of the WPPs participation in the heating-load curve coverage (KSC RAS wind-power experimental area)
1 - heating-load curve, 2 – WPP’s useful energy gain, 3 – WPP’s surplus energy, 4 - power generated by the boiler room
4. Possible involvement of WPPs in heat supply

The participation $\alpha^T$ of WPPs in heating-load curve coverage for the entire heating period is determined by the expression:

$$\alpha^T = \frac{W_{WPP}^A}{W_A}$$  \hspace{1cm} (4)

Fig. 6 presents an assemblage of curves, determining the WPPs possible participation in the heating-load curve coverage. It covers a wide range of the ratio of rated and average annual wind speeds, as well as the ratio of boiler room and power output of WPP (parameter $\beta^T$) [10].

A summary of the results of $\alpha^T$ calculation are presented in Fig. 6.

**Figure 6.** The dependence of the WPPs participation in the heating-load curve coverage of the parameter $\beta^T = N_{WPP}^{\max}/N_{BR}^{\max}$ and the ratio of the rated and average annual wind speed $v/\overline{v}$. Average annual temperature $t_{\text{out}} = 0 \, ^{\circ}C$.

**Figure 7.** The dependence of WPPs participation in the heating-load curve coverage on the average monthly wind speed and average outdoor air temperature $t_{\text{out}}$ at $\beta^T = N_{WPP}^{\max}/N_{BR}^{\max}$, $\Delta \cdot t_{\text{out}} = +15^{\circ}C$, $\bullet \cdot 0^{\circ}C$, $\phi \cdot -15^{\circ}C$.

At an average annual outdoor temperature below $0^{\circ}C$ (far northeast of the region), participation $\alpha^T$ decreases. Researches revealed that in this case, the dependence of the WPPs participation in the heating-load curve coverage can be quite accurately approximated by the expression:

$$\alpha^T = 1 - \exp \left[ -3.2 \left( \frac{v}{\overline{v}} \right)^2 (\beta^T - \delta) \right].$$  \hspace{1cm} (5)
where \( \nu_r \) - rated wind speed that specifies the maximum power output of WPP, \( \bar{\nu} \) - average annual wind speed, \( \delta \) - parameter, that takes into account the average temperature of the outdoor air \( t_{avg} \) \( (\delta=0 \text{ at } t_{avg} = 0 \, ^\circ \text{C}) \).

The results of formula evaluation (5) are presented in Fig. 7. Curves presented are superimposed on monthly actual data and give satisfactory convergence with them.

The foregoing leads to the conclusion that the expression (5) can be used for an approximate assessment of the WPPs possible participation in the heating-load curve coverage in a wide range of outdoor temperatures. Calculations show that WPPs participation in the most windy areas reaches 60-80%.

5. Conclusion

The western sector of the Russian Arctic has an increased wind potential. The average annual wind speed at a height of 10 m reaches 6-8 m / s in the coastal areas of the Barents and White Seas. In the mainland this speed is only of 3-4 m / s. The highest wind speed is observed in the cold season. This coincides with the seasonal peak demand for heating consumers. The foregoing defines the prerequisites for the use of wind energy for heat supply. WPPs participation in the heating-load curve coverage can save (displace) about 60-80% of imported fossil fuels combusting at local boiler rooms and significantly reduce the working cost of the heat generated.

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