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HEAT PUMP SYSTEMS, USING RENEWABLE ENERGY SOURCES FOR SNOW MELTING IN MOSCOW

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ABSTRACT

A new concept for snow removing from Moscow streets in wintertime that proposes development of the "distributed snow melting system" (DSMS) in the city is represented in this Article. The basic element for a suggested DSMS is a near-house heat pump snow melting site of 10÷15 m^2 using renewable energy sources (RES). In addition, DSMS can include heat pump snow melting systems for heating pavement at transport stops and in public places, and also specialized heat pump snow melting systems for snow, removed from city highways. Use of ambient air as a heat source for heat pumps snow melting system and results of the trial operation of experimental snow melting facility under Moscow climatic conditions are given.

Keywords: heat pump snow melting systems, distributed snow melting system, air-source heat pump, energy efficiency.

INTRODUCTION

Cleaning roads and streets from snow and its removal are the priority problems for the municipal authorities of large metropolises located in northern regions, especially in snowfall periods. For example, approx. 40% of total costs for winter roads maintenance in Moscow are spent for this purpose, which includes not only energy costs, but also transportation expenditures. Increase of distance between starting point and snow melting plant for 10 kilometers is equal in costs to amount of fuel required for melting of snow portion being transported (Koretskiy V.E., 2005). Moreover, since snow is being transported by motor vehicles, it causes additional environmental impact due to contamination with exhaust gases. The most effective solution of this problem is the wide use of small snow melting sites evenly distributed in the city (for example, located in house yard territories), where snow can be eliminated "on spot" by near-house heat pump snow melting sites. Advantages of RES use in process of snow melting appear not only in significant reduction of power consumption, but also with elimination of environment pollution, as well as with new provided possibilities of increasing of autonomy of snow melting systems (Huajun Wang, Linbo Liu, Zhihao Chen, 2010). In the nearest future these particular features will become determinative for large cities. Eventually, heat pump snow melting systems can be integrated in technical systems and structures of buildings (Takeuchi M et al, 1993).

It is common, that ground is used as a low grade heat source for heat pump systems (Vasilyev, G. P., 2009), but the air-source heat pumps are of great importance too. For example, papers (Vasilyev, G. P., Gornov V. F., Kolesova M.V., 2014, Vasilyev G.P., 2004) state that combined use of ambient air and ground is effective enough for heat hump systems in Moscow climate. But no proper research materials on use of air as a main source for heat pump systems operation for Moscow climatic conditions was found.

Current State of the Problem and Solution Proposed

Mean annual amount of soft snow falling in the resent years in Moscow is about 110÷190 cm. Approximate density of fallen snow is 0.2÷0.25 t/m^3, and during the process of cleaning it rises up to 0.30-0.35 t/m^3. 76 mln. m^2 of Moscow area has to be freed from snow while average annual amount of snow being removed is 36÷40 mln. m^3. It is easy to see, that roads cleaning and snow transportation in such amounts is associated not only with additional power consumption, but also with serious complications for the traffic: jams and increasing of car accidents, especially in rush-hours. Our opinion is that development of the "distributed snow melting system" (DSMS), based on a near-house heat pump snow melting site of 10÷15 m^2 using renewable energy sources (RES), could help to solve this problem. In addition, DSMS should include heat pump snow melting systems for heating pavement at transport stops and in public places, and also specialized heat pump snow melting systems for snow, removed from city highways.

It is estimated that use of DSMS proposed in this paper could compensate a significant part of energy, consumed for snow melting, by RES even within climatic conditions of such a northern city as Moscow. According to our evaluations, energy contribution of RES in a problem of snow removal from Moscow streets can achieve 80 %.

Thermal Balance of a Near-House Heat Pump Snow Melting Site

The review of the thermal balance of a near-house heat pump snow melting site and possible sources of lower-grade heat for its operation is given as follows.

Decade values of heat energy required in climatic conditions of Moscow for snow melting per 1 m^2 of open and screened sites that are averaged for 30-year observational period according to (Koretskiy V.E., 2005) are given in Table-1. This data can be applied for determination of power loads of near-house heat pump snow melting sites. Data is given for snow with density of 0.35 t/m^3.

Table-1. Heat energy required for snow melting per 1 m^2 of a site in Moscow climatic conditions, kW*h.

Month	Decade	Open site			Screened site		
		max.	min.	mean	max.	min.	mean
X	1	1.58	0	---	3.15	0	---
	2	1.58	0	---	3.15	0	---
	3	3.15	0	---	1.58	0	---
XI	1	9.45	0	---	6.3	0	---
	2	9.45	0	1.58	7.88	0	0.6
	3	12.6	0	1.58	9.45	0	0.6
XII	1	14.18	0	3.15	9.45	0	1.58
	2	15.75	0	4.73	12.6	0	3.15
	3	18.9	1.58	6.3	18.9	0	4.73
I	1	22.05	1.58	7.88	15.75	0	6.3
	2	23.63	1.58	9.45	15.75	0	6.3
	3	23.63	1.58	10.03	15.75	1.58	7.88
II	1	25.2	1.58	12.6	15.75	1.58	7.88
	2	28.35	1.58	14.18	18.9	1.58	9.45
	3	31.5	1.58	14.18	22.05	1.58	9.45
III	1	31.5	1.58	14.18	22.05	1.58	9.45
	2	28.35	0	14.18	23.63	1.58	9.45
	3	25.2	0	12.6	23.63	1.58	7.88
IV	1	25.2	0	9.45	15.75	1.58	4.73
	2	22.05	0	7.88	9.45	1.58	1.58
	3	6.3	0	3.15	3.15	0	---
V	1	1.58	0	---	1.58	0	---
	2	1.58	0	---	1.58	0	---
	3	0	0	---	0	0	---

Use of solar energy accumulated in the ground.

Moscow, located between 55° and 56° N and 37° and 38° E at the Central Russian Upland in the interfluve area of Oka and Volga, is one of the northernmost megalopolises of the world. Moscow center coordinates are 55°45' N and 37°37' E.

In Moscow sun shines for 1568 hours per year. Though the potential of this energy source is unlimited, density of a solar radiation is relatively small - approx. 0.6 kW per 1 m^2.

A possible solution for effective use of solar energy in heat pump snow melting systems is to store this energy in the ground.

A model of snow melting site, accumulating solar radiation in ground from May to September, is represented in Figure-1.

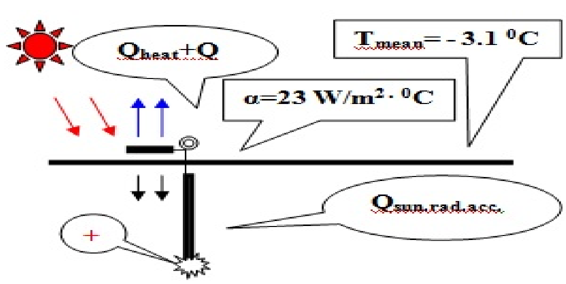

Figure-1. A model of snow melting site, accumulating solar radiation in ground from May to September.

The basic idea for a snow melting system represented in Figure-1 is that sun energy should be accumulated in ground during summer months, May-September, for being used in wintertime for melting the snow. Solar radiation is gathered by horizontal heat exchangers and then transferred in the ground to the depth up to 100 m by vertical heat exchangers. Power losses taking place in process of seasonal accumulation are to be compensated by heat pump.

Total amount of solar radiation (direct and diffused) coming to the horizontal surface in summer (May-September) in Moscow is 707.4 kWh/m^2.

Amount of heat dissipated from 1 m^2 of the ground surface for a part of the year, when snow can fall (November-March), is to be determined as follows:

$$Q_{heat} = \alpha \Delta t \times D, \tag{1}$$

where:

D = 3648 h - total hours of the heating season from November till March., i.e. the time period of snow falls and snow disposal;

α =23 W/(m$^2\cdot{}^0$C) - coefficient of heat transfer from the ground surface;

t_{mean} =-3.1^{0}C - mean air temperature for the heating season;

So the amount of heat dissipated from 1 m^2 of the ground surface for a snow fall period (November-March) can be computed by inserting the values into formula (1) (assuming that the temperature of ground surface is kept above freezing point)

$$Q_{heat.}=\alpha(1-t_{mean})D=23\cdot(1+3.1)\cdot 3648=344\,kWh, \tag{2}$$

If per 1 m^2 in wintertime falls 1 m of snow with density of 300 kg/m^3, the amount of heat energy necessary for melting this snow can be determined as follows:

$$Q_{melt\ snow}=r\cdot{*}M, \tag{3}$$

where:

r=92.8 Wh/kg – specific heat of snow melting;
M= 300 kg – mass of snow per a heating season.
Then,

$$Q_{melt\ snow}=r\cdot{*}M=92.8\cdot 300=27.8\,kWh, \tag{4}$$

And total heat energy required to remain 1 m^2 of surface clear of snow for the entire winter period is:

$$\sum Q=Q_{heat}+Q_{melt\ snow}=344+27.8=371.8\,kWh \tag{5}$$

Resulting value (5) well enough coordinates with the data of the Table-1 - if you sum data for maximal values for outdoor area you will get 382.8 kWh.

As it was stated earlier total amount of solar energy coming to the horizontal surface in summertime is 707.4 kWh/m^2, which is 1.85 times higher than net result

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of heat loss and energy input for snow melting for the cold period of the year for the same surface.

Use of ambient air as an energy source

The prospective source of low-grade heat for heat pump snow melting systems is ambient air. This source, as a rule, is characterized by significant variations of the temperature (diurnal and seasonal ones), thus affecting heat pump efficiency. Mean temperature have an influence upon a coefficient of performance (COP): the lower the temperature the lower the efficiency. In this regard ambient air is practical to be used as an energy source only at high enough ambient temperatures (minus 10 ˚C and higher).

Figure-2 outlines the variation of monthly average ambient temperatures in Moscow, and the Figure 3 – the expected monthly average COP for heat pump snow melting systems, using the ambient air as an energy source.

The analysis of data shown at Figure-2 and 3 demonstrates that the monthly average COP decreases from 3.5 in October to 2.5 in January. Thus, if neglecting defrostation, the average energy indicators of the air heat pump snow melting system appear to be quite attractive. But defrostation if taken into account will change the situation dramatically. The combined use of low-grade heat of ambient air and ground can be a decision. Encouraging is the fact that the snowfalls in Moscow are as a rule happen at ambient temperatures between 0 ºC and minus 10 ºC. This will make use of ambient air as an energy source for heat pump snow melting systems efficient enough.

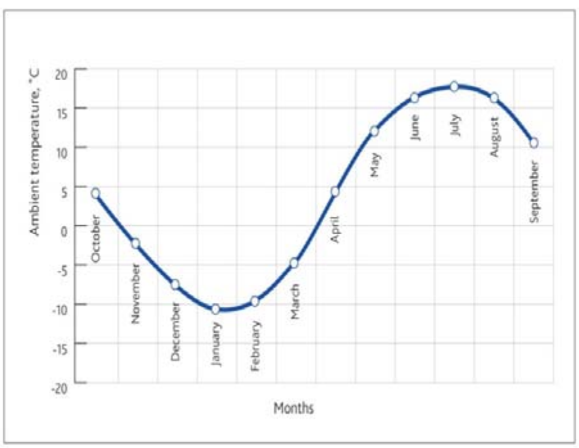

Figure-2. Variation of monthly average ambient temperatures.

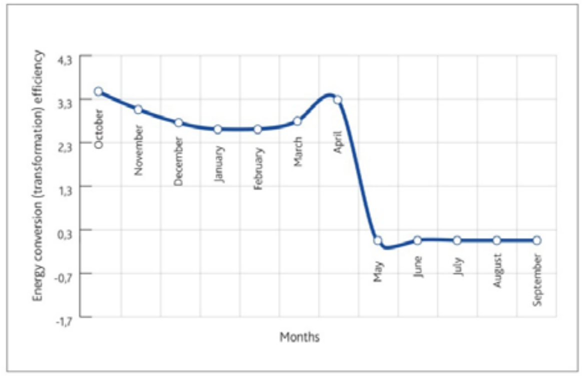

Figure-3. The expected monthly average COP for heat pump snow melting systems, using the ambient air as an energy source.

RESULTS AND DISCUSSIONS

As a result of the studies, basic requirements to the performance and configuration of near-house heat pump snow melting site as a basic element of DSMS in Moscow are determined.

According to the standard for urban territories cleaning in wintertime one street cleaner in 7-houre work day have to clean 1100 m^2. Based on this required capacity of near-house heat pump snow melting site can be calculated.

Moscow climate allows to distinguish 2 main modes of snowfall:

-with daily intensity (layer thickness) of up to 3.5 cm, occurring at intervals of 5-6 days and giving the main volume of snow per season;

-with intensity of up to 7.5 cm/day (fresh snow), happening once in 26-27 days.

Since the main precipitation in winter are 7.5 m^3 per 1000 m^2, then the most rational capacity of near-house heat pump snow melting system would be 15 m^3 of snow per day and site would have size of 10-15 m^2.

Figure-4 shows the experimental near-house heat pump snow melting site installed in one of Moscow yards.

The experimental site is equipped with air-source heat pump. The average consumption of the electrical energy is 10 kWh per 1 m^3 of snow with density of 250 kg/m^3.

Figure-4. The experimental near-house heat pump snow melting site.

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The full-scale approbation results of the experimental site are quite positive. For the entire experiment time (three winter months) it coped with its function: surface temperature was always above zero and snow melting was provided. Essential outcome of the studies is the fact that the possibility and efficiency of air usage as the low-grade heat energy source for heat pump snow melting systems in Moscow are demonstrated. Preliminary doubts connected with low ambient temperatures in winter in Moscow, frost formation on evaporators, etc. have been partially proved wrong, and partially found out have been technical resolutions for such challenges. Snow in Moscow during severe frosts is observed rarely. This circumstance allows to effectively use the outdoor air as a heat source for heat pump snow melting systems. The average COP value of heat pump during the experiment was 2.65, meaning that per 1 kWh of energy consumed 2.65 kWh of heat energy was produced. The problems of evaporators icing have been resolved by reversing of the heat pump cycle into the “defrost” mode; as for snow build-up on evaporators selected have been pertinent fans and distances between the evaporator fins ensuring the decrease of this effect influence.

CONCLUSIONS

The presented results demonstrate the feasibility of near-house air-source heat pump snow melting sites in Moscow. The rational capacity of one site is determined to be of 15 m^3 of snow per day. The research has shown that the basic and more frequent snowfall in Moscow is that generating the snow coat of 2-5 cm, accordingly to what the capacity of equipment was selected.

Based on near-house heat pump snow melting sites the “distributed snow melting system” is proposed. In addition, DSMS can include heat pump snow melting systems for heating pavement at transport stops and in public places, and also specialized heat pump snow melting systems for snow, removed from city highways.
Herewith, the snow melting sites can operate at night consuming energy without overloading the urban electric network and at cheaper energy cost.

The trial operation of the experimental site has proved the efficiency of ambient air use as an energy source under climatic conditions of Moscow. Preliminary doubts connected with low ambient temperatures in winter in Moscow, frost formation on evaporators, etc. have been partially proved wrong, and partially found out have been technical resolutions for such challenges. Snow in Moscow during severe frosts is observed rarely. This circumstance allows to effectively use the outdoor air as a heat source for heat pump snow melting systems. The average COP value of heat pump during the experiment was 2.65

Thus, problem of snow removing from Moscow streets with the use of RES reported to be both energy efficient and environmental friendly. The use of the DSMS based on near-house heat pump snow melting sites will allow the city to decrease energy consumption for snow melting and related costs by 80%.

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