ELIMINATION OF OUTSIDE AIR HEAT PUMP EVAPORATORS ICING

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Abstract. If the surrounding air temperature decreases under +10 ºC, the outside air passive heat pump evaporators will become covered by hoarfrost and ice. This deteriorates the efficiency and operational parameters of such type heat pumps. An experimental investigation has been carried out to discover the possibility of the evaporator icing prevention in the production conditions at a weaned piglets' farm. Warm air flow from the piglets' room by means of the ventilation system and the smoke gas from the boiler house chimney have been fanned on the evaporator heat transfer plates. During the experimental investigation the outside air temperature decreased up to -21 ºC. The icing was averted and the heat transfer coefficient or coefficient of performance of the process (COP) within the limits of 2 – 3 was kept due to the warm and wet air flow fanned on the evaporator heat transfer plates. The obtained experimental results and their analysis are given in the paper, which can substantiate the usefulness of the implementation of such a method of the use of air source heat pump in similar objects and conditions.

Keywords: heat pump, evaporator, icing, coefficient of performance.

Introduction

Detailed investigation supported by practical implementation of the technological solutions in the country is needed in order that Latvia could develop wider use of alternative energy resources. Particularly it refers to the use of air source heat pumps in the meteorological conditions of Latvia. It is important to find the heat pump place in the energy supply system of Latvia for today and the days to come [1].

At the Research Institute of Agricultural Machinery Agency of the Latvia University of Agriculture investigations in the use of outside air source passive evaporator heat pumps (further "heat pump") in agricultural objects where the heating is needed all the year round have been made during several years. The characteristic object is a building for new born and weaned piglets in pig farms, one compartment of which has been chosen for our investigation in production conditions. The experimental investigation carried out during 2009 and 2010 showed that the operational parameters of these heat pumps on a large scale are dependent on the outside air temperature [2]. If the outside air temperature decreases under +10 – +8 ºC the hoarfrost is starting to emerge (turning further into ice) on the evaporators of the heat pump heat transfer plates, making the application of the heat pump economically ineffective. In domestic animal farms, including piggeries, the room ventilation warm and wet outlet air (15 – 20 ºC and 70 – 80 % humidity) contains 30 – 50 $kJ \cdot kg^{-1}$ heat energy [3]. This energy can be used for decreasing or averting the evaporator icing. A certain amount of heat is lost also with the flue gases flowing out from the boiler house of the farm.

The objective of the research was to clear out and substantiate the usefulness of the application of the warm air, flowing out from the animal rooms by means of the ventilation system as well as the flue gas from the boiler house, as the source of heat energy for outside air heat pumps with passive evaporators.

Materials and methods

For our experimental investigation an air heat pump with two connected in series passive evaporators was used. The operation of the heat pump compressor was provided by an electric motor of 5 kW power and the rated power of the transformed heat energy 17 kW. The power of the additional electric heater was 12 kW, which during the investigation was not used. The heat pump was working at real production conditions and mounted at one of the pig pens' sections with two compartments where in total 900 weaned piglets distributed in 46 pens were kept. The heat pump passive evaporators were placed on the roof of the pig house, but the compressor with the rest of the equipment in the ante-room of the farm was placed. The hot water of the temperature 45 – 50 ºC was prepared for the weaned piglets resting place floor heating (the floor temperature should be up to 35 – 36 ºC) by the heat pump. The operational regime of the heat pump was managed automatically by keeping the backflow from the pens water temperature within the limits of 36 – 38 ºC. The exploitation of the heat pump and the data registration was commenced in August 2011.

The corresponding solution for decreasing the hoarfrost of the evaporators was worked out before the start of the experimental investigation and during the investigation it was implemented. Using the supplementary ventilator with changeable up to 1.2 – 1.4 $m^3 \cdot s^{-1}$ efficiency, to the first evaporator the warm inside air from the piglets' room through 8 m long plastic tube was fanned. In order to direct the warm air flow along the evaporator plates, corresponding screens were used. A similar construction was used for fanning the smoke gas from the farm boiler house chimney to another evaporator (Fig. 1).

Fig.1. **Heat pump evaporators covered by special screens (in the centre), warm air fanned tube from the piglets room (on the left) and flue gas fanned tube from the chimney of the farm boiler house (on the right)**

The data on the consumed amount of heat energy for the piglets' floor panel heating and electric energy for the heat pump running were recorded. The amount of the electric energy consumed for the ventilator operation has been stated concerning its operation time at the constant load 200 W. The operation of the heat pump at different periods of exploitation has been analyzed by the determination of the coefficient of performance of the system (COP) and the energy transformation coefficient using coherences (2a) and (2b) [1; 4].

$$COP = \frac{Q}{P_c}; \tag{2a}$$

$$K = \frac{Q}{P}, \tag{2b}$$

where K – energy transformation coefficient;
Q – amount of heat energy, kWh;
P_c – amount of electric energy consumed for the compressor operation, kWh;
P – total electric energy consumed, kWh.

For the registration of the consumed electric energy a 3-phase electric meter with accuracy 0.01 kWh was used. For the registration of the consumed heat energy the heat meter CONOMETER™ 1000 with accuracy 1 kWh was used. The heat meter allows measuring the efficiency of the hot water flow, the water temperature circulating in the heat pump heat exchangers and at the end of the heating loop, the power of the consumed heat energy at every moment of time can be measured also. The change of the warm air flow temperature by the use of HOBO data logger with accuracy of 0.02 ºC was registered.

Results and discussion

The air heat pump evaporator hoar frosting and icing starts at the surrounding air temperature below +10 – +8 ºC. At the daily average temperature above +5 ºC hoarfrost formatted during night, by day, when the temperature raises, it thaws and the exploitation parameters of the heat pump do not decrease essentially. The situation changes when the daily air temperature falls up to +3 ºC. By day the hoarfrost often does not thaw completely and if such weather conditions continue the thickness of the ice layer on the evaporator heat transfer plates increases. It results in the deterioration of the exploitation indexes, and if some additional undertakings are not taken, the use of the heat pump has to be interrupted. The experimental results of the heat pump operation at two different heat transfer water maximal temperatures 50 ºC and 45 ºC, obtained in December, 2011 (during 21 day) and in January, 2012 (during 8 days) at the outside air temperature within the limits from +3 ºC to -3 ºC are summarized in Table 1. The heat transferring water flow end temperature was 44 ºC and 38 ºC accordingly. The average heat pump exploitation parameters for both cases at the natural outflow of the hot air from the ventilation opening along a tube up to the evaporator are given. These data were compared with the results obtained in case, when the warm inside air flow to the evaporator covered by screens, was intensified by the use of an additional ventilator. In separate cases the smoke gas was fanned from the boiler house chimney to the second evaporator. The comparison of the results shows that the obtained and consumed amount of heat energy as well as the COP of the heat pump increases, when the warm air flow fanned to the evaporator by the additional ventilator was intensified (Table 1).

Table 1

The exploitation parameters of the heat pump with passive evaporators at the outside air temperature from +3 ºC to -3 ºC

Regime of heating	Conditions	Heat consumption KWh·h^{-1}	Max. heat power kW	Energy for compressor KWh·h^{-1}	COP	K
44 ºC (boiler) 38 ºC (backflow)	Without ventilator	6.80	12.5	2.49	2.76	2.76
	With ventilator and screen	7.13	14.6	2.29	3.11	2.81
	Difference, %	+5	+17	-8	+13	+1
50 ºC (boiler) 45 ºC (backflow)	Without ventilator	10	10.9	4.17	2.43	2.43
	With ventilator and screen	11.45	13.9	4.30	2.69	2.43
	Difference, %	+14	+27	+3.1	+10.7	0

A small increase in the ratio between the obtained heat energy and consumed electric energy K was fixed only when the consumption of heat was relatively small. The more essential acquisition from the undertakings is the provision of the heat pump normal operation regime in winter conditions via icing prevention of the heat transfer plates of the evaporators. Estimating the heat pump operation at different exploitation regimes, certain basic case for further experimental investigation of the heat pump evaporators fanning with warm air from the piglets' room was chosen.

The average efficiency of the additional ventilator about 0.6 $m^3 \cdot s^{-1}$ was kept. From outside the group of heat transfer plates of the first evaporator was covered by a tight cover but from inside it was covered by corresponding screens. The warm air was fanning along the restricted space between the cover and screen from the top to bottom. The warm air was cooled and the condensate ran down. The heat pump with the evaporator equipped in such a way was in exploitation since February 8, 2012. In the morning of some days (February 10, 11, 12 and 16) the outside air temperature decreased to – 18 ºC – -21 ºC. The consumption of the transformed heat amount was stated by the number of the connected heated floor panels. The total average results are given in Table 2. Exploitation indexes of the heat pump in the regime 50 ºC (boiler) and 44 (the end temperature of the heat transfer water) at negative outside air temperature are given in Fig. 2.

Table 2

The exploitation parameters of the heat pump with passive evaporators at constant warm air flow fanned to the evaporators

Outside air temperature, ºC	Number of panels to be heated	Heat consumption, $KWh \cdot h^{-1}$	Max. heat power, kW	Energy for compressor $KWh \cdot h^{-1}$	COP	K
+3 – -3	46	10.7	16.4	3.40	3.14	2.97
-3 – -20	23	7.90	16.0	2.99	2.63	2.47

During the experimental investigation the ratio K between the produced heat energy and consumed electric energy changes within the limits from 2 to 3. The main reason for the COP decrease at lower outside temperature was not sufficient heat insulation of the warm air tube, as well as the decrease of the ventilation intensity in the piglets' room. If low temperature (about -20˚C) is only at nights, then by day, when the surrounding air temperature decreases, the ratio between the produced heat energy and total consumed electric energy K from 2-2.1 increases even up to 2.6-2.8. For comparison, during summer months the heat transfer coefficient on the average was 3.5-3.7.

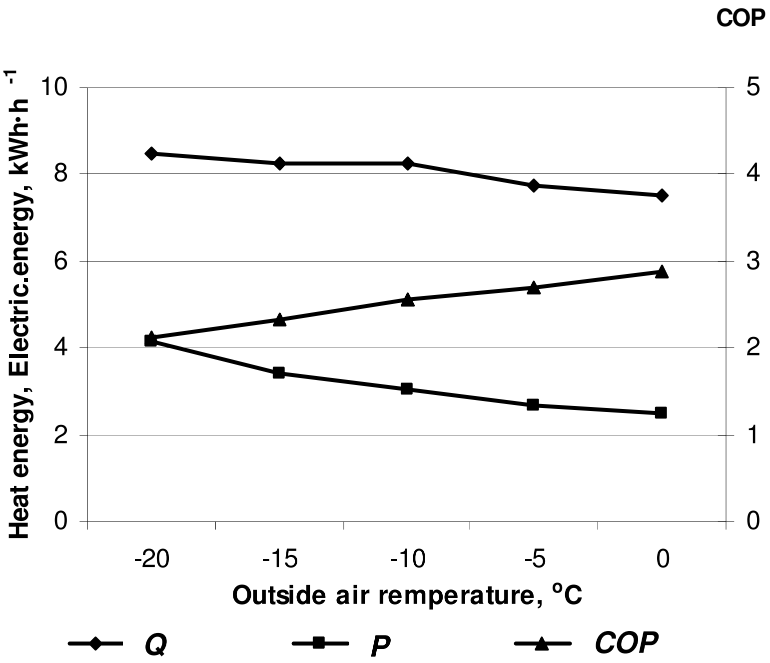

Fig.2. **Experimental results of the passive evaporator heat pump exploitation in winter conditions at negative outside temperatures**: *Q* – heat energy consumption; *P* – electric energy consumption; *COP* – coefficient of performance of the heat pump

It follows that at low outside air temperatures the fanning of the heat pump evaporators with the warm air flow completely averts the icing of the evaporators and improves the exploitation indexes of the heat pump. The condition of the heat pump evaporator heat transfer plates during the heat pump operation at low surrounding air temperature in is presented Fig.3.

The data about the character of the temperature change in the zone of the heat transfer plate of the heat evaporator are obtained. The temperature in every 15 seconds during 5 twenty-four hours at outside air temperature within the limits of -15 ºC to 1 ºC has been registered. The temperature sensors were placed in the middle zone of the warm air flow between two heat transfer plates. The warm air flow temperature and the character of its change in the inflow zone into the evaporator, that is, in the top part of the evaporator were influenced by the outside air temperature and according to it, the intensity of the piglets' room ventilation. The mode of the change in warm air temperature at its outflow, that is, at the bottom of the evaporator, additionally essentially was influenced by the operation of the compressor. The temperature of the warm air flow decreases, when the compressor switches on, reaching its minimal value when the compressor switches off. After that the warm air flow temperature is increasing till the compressor starts on again.

The data presented in Table 3 show that the amplitude of the temperature fluctuation in a wide zone of the warm air initially was on the average 0.5 – 2.5 ºC. Knowing the initial heat content in the warm air flow and the fall in the temperature, it is possible approximately to state the recovered amount of heat using the I-d diagram. For example, when warm saturate air at 15 ºC of temperature is cooled down by 2 ºC, 4 – 5 $kJ \cdot kg^{-1}$ of heat energy is being freed. At the air flow intensity 0.6 $kg \cdot s^{-1}$, the recovered amount of heat is 9 – 11 $MJ \cdot h^{-1}$. The temperature on the surface of the heat transfer plates was by 8 – 10 ºC lower than the air flow temperature, registered in the spot, where the temperature sensors were placed. This allows foreseeing that the actual amount of the heat recovered from the warm air is bigger. The heat pump exploitation parameters are pointed to this as well.

Fig.3. **Heat pump evaporators during the experimental investigation. In order to see the heat transfer plates, the outside cover is opened (left side photo). At the bottom of the right side photo between two evaporator colons the location of the temperature sensor is seen**

Table 3

The change in fanning warm air temperature flowing through the evaporator plates

Average fanning air temperature, ºC	Out flowing air temperature, ºC		Change in air flow temperature, ºC	
	maximal	minimal	maximal	minimal
10	9.4	8.6	0.6	1.4
12.5	12.0	10.9	0.5	1.6
15	14.1	13.0	0.9	2.0
17.5	16.5	15.1	1.0	2.4
20	19.0	17.4	1.0	2.6

The results of fanning the evaporators by the smoke gas from the boiler house chimney are evaluated not uniformly. Regardless the temperature of the smoke gas is high (60 – 80 ºC), the boiler is operating cyclically with interruptions. The fanning of the smoke gas to the second evaporator during the time when the first evaporator was operating successfully, did not allow detailed evaluation of its influence on the heat pump exploitation parameters.

Conclusions

1. The fanning of the warm air flow on the passive heat pump evaporators averts its heat transfer plates icing in winter time and promotes the operation of the heat pump with the heat transfer coefficient high enough. At the outside air temperature from 0 to -5^{o}C the heat transfer coefficient is 2.8 on the average. If the outside temperature decreases up to -20^{o}C, the heat transfer coefficient remains above 2.
2. Fanning the evaporators with warm and wet air from the pig rooms averts the icing of the evaporators and improves the heat transfer coefficient of the system.
3. The experimental investigation proved that the use of the outside heat pump during the whole year is perspective in heating such objects were intensive ventilation is necessary, for example, pig farms.

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