Use of Air Heat Pump in Latvian Weather Conditions for Warming of Piglets Resting Places

Viktorija Zagorska[1], *Andrievs Ilsters*[2], *Imants Ziemelis*[1]
[1]Latvia University of Agriculture
e-mail: vzagorska@gmail.com, imants.ziemelis@llu.lv

[2]Latvia University of Agriculture, Research Institute of agricultural Machinery
e-mail: ilsters_uzc@apollo.lv

Abstract - The aim of the research is to ascertain in the conditions of production the suitability of the use of the outside air-to-water heat pump for providing energy for heating the water for resting places of piglets' panels. Researches were made in conditions of production in the pigsty with 96 farrowing pigpens. The results shows, that heat pump OCTOPUS in Latvian weather conditions (average relative air humidity all over the year is 80%) becomes covered with frost at the outside air temperature above the +10°C, what facilitates decrease of obtained heat energy for 40-50 %.

Add-on heat pumps are designed to be used with another source of supplementary heat, such as an oil, gas or electric furnace (in our case the electric furnace is used). Air-source heat pumps have also been used in some building ventilation systems to recover heat from outgoing stale air and transfer it to incoming fresh air or to hot water. In our experiments the method of the use of air heat pump is improved by blowing the ventilation stale air from the hall of the pigsty to the evaporators, the achieved results - heat pump is working in non-frost regime till +2°C.

Keywords – air heat pump, pigsty, Latvian weather conditions

1. INTRODUCTION

Provision of heat energy demand in the intensive production of piglets is very important all over the year. Amount of heat energy depends on different factors, including construction of resting places of piglets, climatic conditions, and age of piglets.

Air-source heat pumps draw heat from the outside air during the heating season. Air-to-water heat pumps are used in buildings with water heat carrier distribution systems. During the heating season, the heat pump takes heat from the outside air and then transfers it to the water heat carrier distribution system. The aim of the research is to ascertain in the conditions of production the suitability of the use of the outside air heat pump for providing energy for heating the water for resting places of piglets' panels. Researches were made in conditions of production during the period June 2009 till December 2009 in the pigsty with 96 farrowing pigpens, where in the resting places of piglets panels (heated with the warm water) are built-in. Air-source heat pumps can be add-on, all-electric or bivalent. Add-on heat pumps are designed to be used with another source of supplementary heat, such as an oil, gas or electric furnace (in our case the electric furnace is used). All-electric air-source heat pumps come equipped with their own supplementary heating system in the form of electric-resistance heaters. Bivalent heat pumps are a special type, developed in Canada, that use a gas or propane fired burner to increase the temperature of the air entering the outdoor coil [6]. This allows these units to operate at lower outdoor temperatures. Air-source heat pumps have also been used in some building ventilation systems to recover heat from outgoing stale air and transfer it to incoming fresh air or to hot water. In our experiments the method of the use of air heat pump is improved by blowing the ventilation stale air from the hall of the pigsty to the evaporators [3].

A possibility of transformation of heat energy determines coherence [5]:

$$COP = T_H(T_H - T_L)^{-1}, \qquad (1)$$

where

COP – coefficient of performance of a heat pump;

T_H – the highest (required for the user) temperature, K;

T_L – the lowest (heat source) temperature, K.

The higher temperature difference of heat source temperature and required for the user temperature, the smaller will be the COP. This is the reason why it is gainfully to use the air heat pump in pigsties, because heat for the piglets' panels is needed in summer also, when COP of heat pump can be the highest. During the warm weather conditions at positive outside air temperatures outside air heat pumps are running at eligible high COP, on the average 3-4 [8]. During the cold and frigid weather conditions, when COP of the heat pump dramatically decreases, it is hopefully to use outflow ventilation air of the hall of the pigsty as heat resource for heat transformation [3].

2. MATERIALS AND METHODS

For the performance of experiments one of the pig farm farrowing sow compartments with two sections was chosen. The consecutive technological rhythm at farm is realized with one week interval. The cycle in section from sow farrowing till weaning of piglets including cleaning and disinfection of section goes on for 7 weeks. There is a joint heat supply system with warm water circulation system for heating 96 panels of resting places. For the performance of experiments were set up two outside air evaporators beside the pigsty, compressor block with the automatized control panel inside the hall of the pigsty.

During the experiments amount of used heat energy for heating the floors was counted with ultrasonic heat meter, amount of electric energy needed for driving the compressor and electric boiler was registered with electric energy meters. If we know mentioned above measurements, we can determine efficiency of the heat pump using the following coherence:

$$COP = Q\,P^{-1}, \tag{2}$$

where Q - amount of obtained heat energy, kWh;

P - work consumed for heat pump operation, kWh.

During particular periods temperature of water (which is heating the panels) at start and end of the circuit was registered with HOBO data logger with precision 0.02°C.

In order to insure the necessary air change in warmed cattle-breeding premises, a lot of heat energy is lost through the operating ventilation system. The deviation of the warm inside air flow to the outside placed heat pump evaporators can considerably raise its COP during winter months, so insuring the necessary heating power. For implementation of such a solution, less available is a heat pump with a radiator type evaporator, because of the possibility that the plates of the evaporator are getting choked with dust and other particles existing in the flow of warm inside air. From that point of view less dangerous are heat pumps with passive vertical evaporators. On the base of the analyzed results, for practical experiments a heat pump produced by the company OCTOPUS (Sweden) has been chosen. An agreement with a pig farm, where panel floor heating by hot water is already installed, on the experimental investigation of the heat pump has been reached. The necessary heating power for one pen is approximately 180 W. It means that the total power necessary for floor heating is about 17 kW. It was stated that for this power the heat pump IS 81 corresponds best. The technical characteristic of the heat pump is given in Table 1.

Table 1. Technical characteristic of heat pump OCTOPUS IS 81

Parameters	Units of measurements	Value
Evaporators – vertical radiators	number	2
Heat carrier – R290 (propane)		
Power of Scrol type compressor	kW	5
Operational pressure of the compressor, min/max	bar/bar	1.5 23
Productivity	m^3h^{-1}	19.2
Average power of produced heat energy	kW	17
Maximal temperature of circulation water	°C	55
Power of additional electric heater	kW	9

3. RESULTS AND DISCUSSIONS

Evaluating results of the experiments from the farm technological regime point of view, some tendencies for ensuring heat energy for one resting place are seen in Table 2, Fig. 1 and Fig. 2. Firstly, need of the heat energy demand is varying cyclic: at the sow farrowing period heat energy demand is the highest and then gradually decreasing until the weaning of piglets when minimum of energy demand appears. Secondly, heat energy demand is affected by outside air temperature. In June at the start of the first farrowing cycle, when outside average temperature was about 15°C, heat energy demand for one panel heating was 33 kJh^{-1}. Heat energy decreased up to 11 kJh^{-1} at the period of the weaning of piglets. During the 2nd farrowing cycle (August till the middle of September) twenty four hours and period temperature fluctuations were very minimal and appropriate effect on the heat energy demand: 25 – 15 kJh^{-1}. In general the COP of the heat pump was stable as well, it was 3.25 – 3.30. During the 3rd farrowing cycle outside air temperature decreased gradually from 18°C to 5°C. Need of heat energy was ensured till the start of October (when only the compressor of the heat pump was operating) when outside air temperature was above 10°C. When outside air temperature declined under 10°C intensive frosting of the surface of evaporators started and electric boiler started being switched on. The COP of the heat pump decreased substantially wherewith.

To find possibilities and solutions of the prevention of intensive frosting of evaporators and wherewith maintaining the COP of the heat pump on the quite high level, during the autumn period were made train of experiments when outflow air of pigsty was breezed to the one of evaporators. Results of the experiment when outflow air of pigsty was breezed to the one of evaporators are generalized in Table 3, Fig. 5 and Fig. 6.

When blowing outside air to the evaporator with intensity in average 1.5 $m^3 \cdot sek^{-1}$ achieved results was dependent on outside air temperature. At outside air temperature 10°C when frosting of the evaporator was minimal, increase of heat power was up to 1 kW what in point of fact is a little bit more than power required for operation of ventilator - 0.5 kW. At outside air temperature 6°C, increase of heat power achieved up to 3 kW. Insignificant increase of heat power still remained when outside air temperature was declining more, but it was not able to thaw the frosting of the surface of evaporator due to operation of compressor. Therefore around the evaporator screens were placed (Fig.3 and Fig. 4) and from the hall of the pigsty to the surface of the evaporator warmer air was supplied with temperature 7-9°C what improved usage of heat. Positive effect with increase of power for 2.4 – 3.2 kW was still achieved at outside air temperature +2°C [1, 2].

Like it was mentioned before, if the outdoor temperature falls to +2 °C, when the heat pump is operating in the heating mode, moisture in the air passing over the outside coil will condense and freeze on it. The amount of frost buildup depends on the outdoor temperature and the amount of moisture in the air (in Latvia average outside air relative humidity is about 80%, and the lowest outside air temperature is -33°C).

This frost buildup decreases the efficiency of the coil by reducing its ability to transfer heat to the refrigerant. At some point, the frost must be removed. More advisable it would be to organize the defrost cycle. The heat pump will switch into the defrost mode. First, the reversing valve switches the device to the cooling mode. This sends hot gas to the outdoor coil to melt the frost. At the same time the outdoor fan, which normally blows cold air over the coil, is shut off in order to reduce the amount of heat needed to melt the frost. While this is happening, the heat pump is cooling the air in the ductwork. The heating system would normally warm this air as it is distributed throughout the house [7]. It is advisable to organize new train of experiments with, firstly, defrost cycle of the heat pump and secondly, blowing the air directly from the pigsty farrowing sections, where temperature is about 18°C - 20°C. Analyzing the available literature [4, 5, 6, and 7] and making calculations it is expected to extend energy efficiency for operation cycle till -15 °C. This will give the good possibility to decrease the payback time of the heat pump capital costs. Using data from authors previous and present experiments [1, 2], the payback time of a heat pump system, using heat pump in its original way will be about 9 years; blowing ventilation air to the evaporators and using screens [3] it would be possible to achieve 7 year payback time, and implementing defrost cycle it is possible to payback the capital costs of heat pump for only 5 years. Of course it is necessary to arrange train of experiments to get the practical results, but analyzing available literature it seems to be realistic.

Table 2. Amount of heat energy for ensuring required temperature of panel of resting places for piglets

Nr of the farrowing cycle	Period of time, month	Outside air temperature, °C	Use of heat energy, $kJ \cdot h^{-1}$		COP of the heat pump
			At farrowing	At weaning of piglets	
1.	10.06.-02.08	12 – 26	33	11	3.25
2.	3.08.-22.09	18 – 22	25	17	3.3
3.	23.09-09.11	18 – 5	25	24	2.80
4.	10.11 –	5 – 2	35		3.00

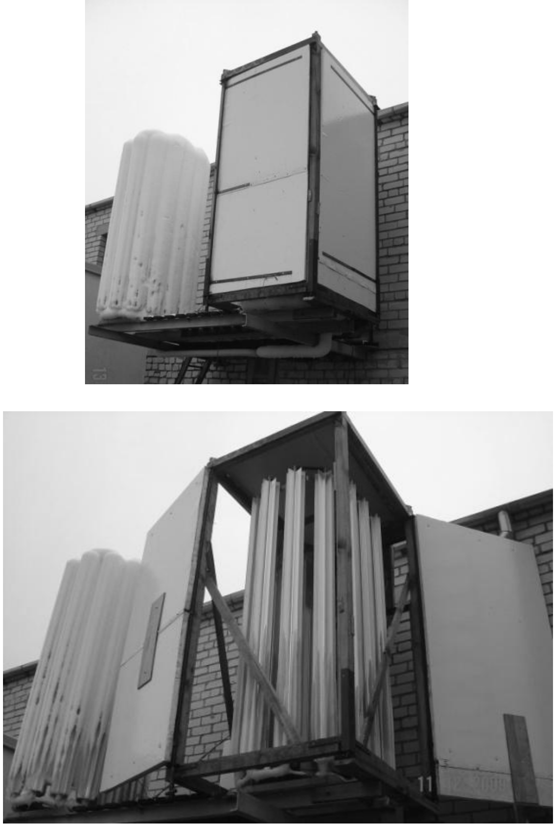

Figure 3. Evaporator of the heat pump covered with screens during the supply of warm air

Figure 4. Covering screens are opened. Plates of the evaporator almost thawed

During the use of heat pump it was kept track of operating regime. Making the analysis of the switching on/off of the compressor, it is operational cycle duration in dependence on set up of back-flaw water temperature

from 36°C to 38°C (Table 4). From Table 4 follows, that rising the working temperature from 36°C to 38°C, the duration of the operational cycle of the compressor becomes longer. The same situation appears when outside air temperature declines until heat pump starts operating in uninterrupted regime without switching off. From the point of view of exploitation of heat pump it is preferable that durations and interruptions of the cycle would be longer. Mentioned above conditions contributes to defrost of the evaporator during the interruption of operation of the compressor at sufficiently high outside air temperatures.

Important assessment tool of evaluation of the heat pump are costs of the fuel. At the particular object liquefied gas before experiments was used as fuel (predominant propane). During the summer period, when the power of a heat pump is sufficient without operation of an electric boiler, difference in costs of energy sources (electric energy - liquefied gas) reached 598 € or in average 150 € per month (Table 5). In July 2009, when energy demand was the lowest, difference in costs was only 94 € (Fig. 7). During autumn period (2.25 months), when average outside air temperature was below +10°C, for ensuring required energy amount for heating power of the heat pump was insufficient, therefore electric boiler was operating and difference in costs reached only 254 € or in average 112 € (Table 6, Fig. 7). It is necessary to reduce operation of electric boiler because price of electric energy is higher than price for liquefied gas and the COP of electric boiler is only 0.98. Electric boiler was operating nearly 10% of the heat pump operational time during the autumn period.

Table 3. Results of experiments with airflow around the evaporator

Parameter	Unit of measurement	Outside air temperature+6 °C			Outside air temperature +2 °C	
		without ventilator	with ventilator	with screens	with screens	without ventilator
1	2	3	4	5	6	7
Heat energy	kWh·h^{-1}	9.7	11.1	12.9	10.4	9.7
Electric energy cons.	kWh·h^{-1}	4.0	4.2	5.1	4.4	5.2
COP		2.5	2.6	2.5	2.4	1.9
MAX power	kW	9.4	12.4	13.2	10.8	8.5
Increase in power	kW		3.0	3.2	2.4	

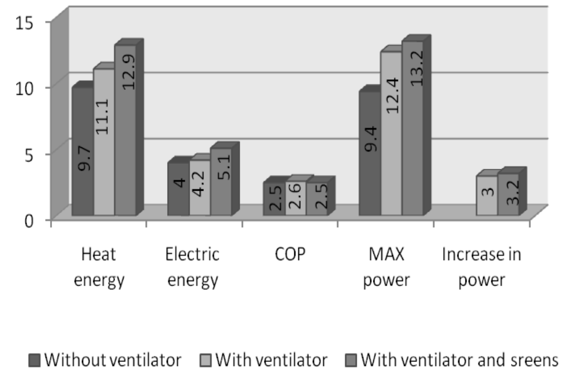

Figure 5. Results of experiments with airflow around the evaporator at +6°C

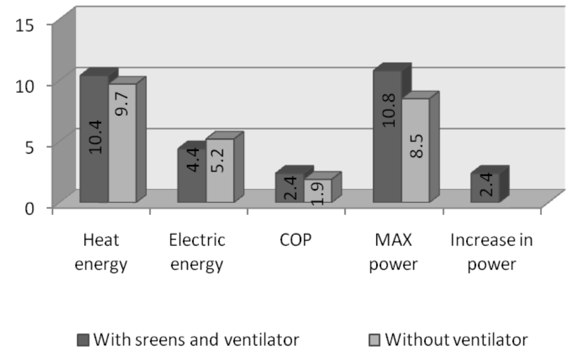

Figure 6. Results of experiments with airflow around the evaporator at +2°C

Table 4. Switching on/off operational rhythm of the compressor of the heat pump depending on set up of back-flow water

		Set up of back-flow water temperature, °C / at amount of heat energy for heating the panel, Wh·h^{-1}		
te	m	36 / 60	37 / 105	38 / 120

	Duration of the cycle, h	Operation of the compressor, %	Duration of the cycle, h	Operation of the compressor, %	Duration of the cycle, h	Operation of the compressor, %
10	Non-stop	100	3	85	Non-stop	100
15	1.2 – 1.4	35 – 45	3	85	0.25-non-stop	90 - 100
20	1.2 – 1.4	35 – 45	1.5	65	0.15	Variable
25	1.2 – 1.4	35 – 45	1.5	65	0.12	55

Table 5. Balance and costs of energy resources during the summer period

Period of time	Average outside air temperature of the period, °C	Heat energy demand for heating the resting places, kWh	Electric energy for heat energy extraction, kWh	COP of the heat pump	Price of liquefied gas, without VAT €·t^{-1}	Difference in costs of electric energy and liquefied gas, €
VI	14.0	7241	2368	3.06	456	139
VII	17.4	3922	1180	3.32	474	94
VIII	16.0	6816	2097	3.25	491	167
IX	13.6	5850	1804	3.24	584	199
Total		23829	7449	3.20		**598**

Table 6. Balance and costs of energy resources during the autumn period

Period of time, month	Average outside air temperature of the period, °C	Heat energy demand for heating the resting places, kWh	Electric energy for heat energy extraction, kWh		COP of the heat pump	Price of liquefied gas (without VAT), €·t^{-1}	Difference in costs of electric energy and liquefied gas, €
			Compressor	Electric boiler			
X	5.0	7255	2753	342	2.34	499	111
XI 1. decade	0.4	1988	703	502	1.61	570	15
XI 2. decade	7.0	4089	1228	587	2.23	570	86
XII 1. decade	3.5	2347	917	206	2.09	570	43
Total		15679	5601	1637	2.17		**254**

Price of the electric energy is 0.084 €/kWh (without VAT)

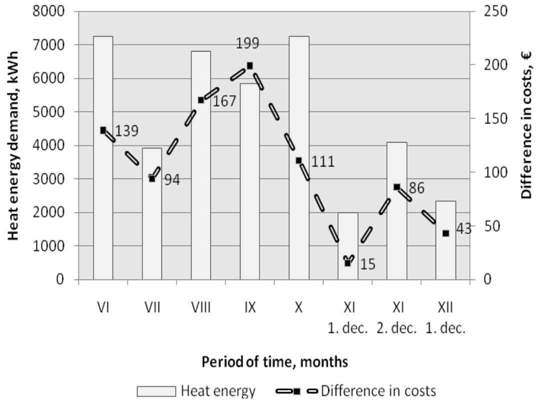

Figure 7. Heat energy demand for heating the resting places and difference in costs during summer/autumn period

5. CONCLUSIONS

1. The results shows, that heat pump OCTOPUS in Latvian weather conditions (average relative air humidity all over the year is 80%) becomes covered with frost at the outside air temperature above the +10°C, what facilitates decrease of obtained heat energy for 40-50 %.

2. The payback time of a heat pump system, using heat pump in its original way will be about 9 years; blowing ventilation air to the evaporators and using screens it would be possible to achieve 7 year payback time, and implementing defrost cycle and making the combination with previous method it will be possible to payback the capital costs of heat pump for only 5 years.

It is necessary to arrange train of experiments to get the practical results, but analyzing available literature it seems to be realistic.

6. AKCNOWLEDGEMENTS

Paper becomes written by financial support of European Structural Fund – Attraction of human resources for investigation of renewable energy resources - realized by Project Department of Latvia University of Agriculture (contract no. 2009/0225/1DP/1.1.1.2.0/09/APIA/VIAA/129).

REFERENCES

[1] A. Ilsters, I. Ziemelis, and I. Kristutis, “Possibility of Heat Pump use for Piglet Resting Place Heating”, in Proc. The 8th International Scientific Conference “Engineering for Rural Development”, Jelgava, Latvia, May 28. – 29, 2009, pp. 202-206.

[2] A. Ilsters, V. Zagorska, and Z. Jesko, “Warming of piglets resting places by air heat pump in dependence on outside air temperature”, in Proc. The 9th International Scientific Conference “Engineering for Rural Development”, Jelgava, Latvia, May 27. – 28, 2010, pp. 106-111.

[3] A. Ilsters, H. Putans, V. Zagorska, I. Ziemelis, LV “Patent Nr. 14147 – Device for piglet sty warming and ventilation”, The Official Gazette of the *Patent* Office of the Republic of Latvia,*2010*, 749–869, pp. 749. (in Latvian)

[4] Air-source Heat pumps (2009), available at: http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12620, 07.07.2010

[5] Blumberga D. *Heat pumps*, RTU tipografija, Riga, Latvia, 2008, ISBN: 978-9984-32-362-6

[6] Heating and cooling with a heat pump. Natural Resources Canada’s Office of energy Efficiency, Energuide, 2004, ISBN: 0-662-37827-X.

[7] Improved Defrost Cycle for Heat Pump Systems and Comparisons of heating systems for Moderate Climates (like Georgia) by Joe Mehaffey (2008), available at: http://www.gpsinformation.org/joe/HeatPump2.html, 14.07.2010

[8] Swedish building heating companies: Octopus Energi AB KarlssonKlimat AB and Octopus Teknik AB (1998), available at: http://www.octopus.tm/old/eheat.htm, 07.07.2008

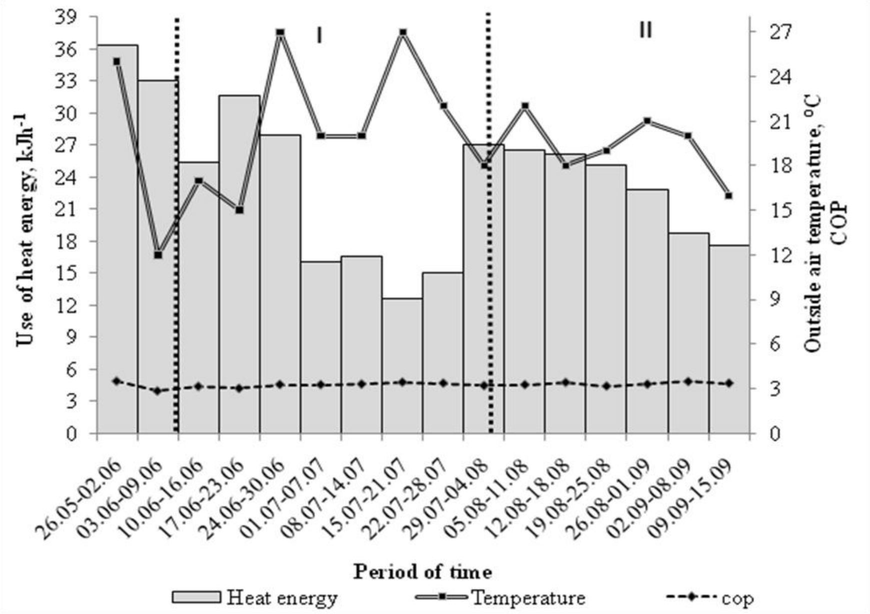

Figure 1. Average parameters of the heat pump operation by week intervals during 1st (I) and 2nd (II) farrowing cycle, which are assigned to one heated panel

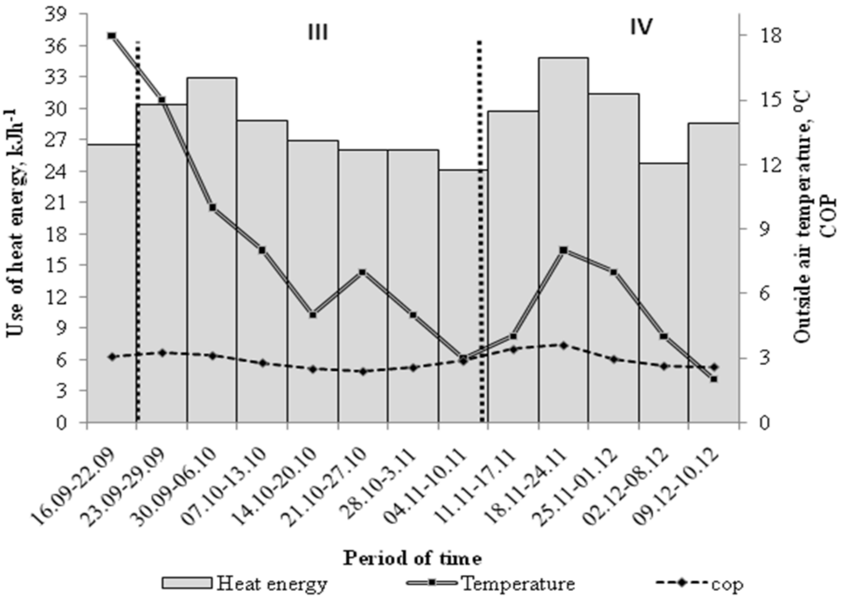

Figure 2. Average parameters of the heat pump operation by week intervals during 3rd (III) and 4th (IV) farrowing cycle, which are assigned to one heated panel