# THE USE OF WARM OUTFLOW VENTILATION AIR FOR INCREASE AN OPEN AIR HEAT PUMP EFFICIENCY

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**Abstract.** In the paper two years (2012-2013) experience on the use of renewable energy resources in production conditions of technological processes in agriculture is analyzed. There an outside air heat pump with passive evaporators was investigated. The recovered heat energy for new borne piglets resting place floor panels heating was used. At low outside air temperature in autumn and winter months the evaporator of the heat pump becomes covered by hoarfrost and ice, which lower the heat pump's efficiency. It can be avoided directing the warm pigsty air delivered out by the ventilation system on the heat pump evaporators. The investigation results show that directing the warm inside air on one of two evaporators, already ensure normal heat pump work during all winter period, even at outside air temperature -20 ºC. The fall in hot air temperature after the washing of first evaporator does not exceed 10 ºC, indicating that some air flow can be directed for the second evaporator's heating too.

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

## Introduction

The consumption of fossil energy resources for premises heating can be decreased by more widely use of alternative energy recourses including open air heat pumps. Its implementation for the maintenance of necessary microclimate in pigsties is perspective, because of:

- the need for piglets resting place heating is necessary all the year round;
- the hot air brought out by the pigsty ventilation system can be used for the increase of efficiency of a heat pump.

The group of researchers of Latvia University of Agriculture agency Research Institute of Agricultural Machinery is dealing with the problem. Due to polluted pigsty air brought out by the ventilation system, an outside air heat pump with passive evaporators for the study has been chosen. The results of previous year's investigation have proved that:

- open air heat pumps during hot weather period (at outside air temperature below +10ºC) insure the coefficient of performance (COP) of the heat pump above 3.5 giving some economic effect. The cost of electric energy consumed for the operation of a heat pump's compressor, is covered if the COP of the heat pump is above 2.5 [1].
- at lowest outside air temperature the heat pump's evaporator starts to be covered by hoarfrost and ice and it COP decreases [2].
- the condensate of warm and polluted inside air from a pigsty when washing a evaporator helps to keep clean the evaporator's plates, improving its exploitation parameters [3].

The objective of the research is using a heat pump with passive evaporators in production conditions to ascertain the possibility for reaching as high as possible COP of the heat pump operation in cold weather conditions, when evaporators are washed with warm inside air, brought out by the ventilation system and directed on evaporators from bottom to top, and to determine the degree of air cooling down, if evaporators are covered by special screens. The amount of hot inside air exhausted from a pigsty and given for washing the evaporators is limited by the ventilation regime of the pigsty. The necessary amount of air changed by the ventilation system is calculated using coherence [4]:

$$V_v = V_c (K_k - K_g \frac{\rho_k}{\rho_g})^{-1}, \quad (1)$$

where $V_c$ – amount of $CO_2$ produced by a pig, $l \cdot h^{-1}$;
$K_k$ – admissible concentration of $CO_2$ in the air of a pigsty, $l \cdot h^{-1}$;
$K_g$ – concentration of $CO_2$ in outside air, $l \cdot h^{-1}$;
$\rho_k$ – density of inside air, $kg \cdot m^{-3}$;
$\rho_g$ – density of outside air, $kg \cdot m^{-3}$.

Produced amount of $CO_2$ by weaned piglets depending on the age of animal is 18-25 $l \cdot h^{-1}$. At admissible $CO_2$ concentration in the inside air 3.0 $l \cdot m^{-3}$, the intensity of air exchange in a pigsty is 7-9 $m^3 \cdot h^{-1}$. The average parameters of the pigsty air are: temperature 20 ºC and relative humidity 70 % with the corresponding heat value 46 $kJ \cdot kg^{-1}$. Depending on the level of cooling down it is possible to recover up to 30 $kJ \cdot kg^{-1}$ of air heat. In Table 1 calculation results on recovered amount of heat energy from exhausted pigsty air with temperature 20 ºC and relative humidity 70 % when cooling down by 5; 10; 15 and 20 ºC are given. During cold weather periods the change of air in a pigsty is endeavoured to restrict. Therefore it is important at minimal air exchange rate to use the accumulated into the pigsty air heat completely.

Table 1

**Recovered amount of heat from exhausted pigsty air with the temperature 20˚C and relative humidity 70% at cooling it down by 5; 10; 15 and 20˚C**

| Cooling down by, ˚C | Initial temperature 20˚C | |
|---|---|---|
| | Recovered heat, kJ $kg^{-1}$ | % |
| 5 | 5 | 11 |
| 10 | 17 | 37 |
| 15 | 27 | 58 |
| 20 | 37 | 80 |

The carried out calculations and analyze show that the recovered heat from exhausted by the ventilation system inside air, gives a possibility to decrease the consumption of heat energy for a pigsty and piglets resting place heating.

## Materials and methods

For experimental investigation of an open air heat pump with two in series connected open passive vertically placed evaporators was used [5]. The compressor of the heat pump was activated by an electric motor of 5 kW power and nominal heat power 17 kW. Into the heat pump is mounted an electric heater (power 9 kW), which during the experimental investigation was switched off. The heat pump was mounted at one of weaned piglets section with two departments, in each of witch 425 animals were located.

The evaporators are placed on the roof of the pigsty near the opening of the outflow air. The principal scheme of the facilities disposition in Fig. 1 is given. The outflow air from two beside outflow openings 1 to the bottom part of one of evaporators 5 is flowing through 0.5 m diameter tube 4 covered by heat insulation with total length 18 m. The evaporator's heat transition plates 5 from outside and inside were covered by fitting covers 6 and 7. For delivering the air from the pigsty two ventilators with efficiency up to1.3 $m^3 \cdot s^{-1}$ were used. The pigsty ventilation openings were covered by covers 2, which degree of opening determines the intensity of outflow air.

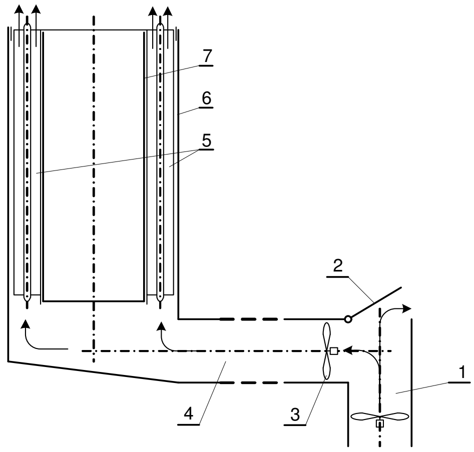


Fig. 1. **Scheme of experimental evaporator with corresponding facilities:** 1 – ventilation outflow canal; 2 – cover of outflow canal; 3 – ventilator; 4 – tube for air feeding; 5 – evaporator's stands with heat transfer plates; 6 – external cover; 7 – internal cover

The hot water prepared by the heat pump with the temperature 40-45 ºC driven by a water pump through a pipe system flows to weaned piglets resting place floor panels for its heating. The heat load of a floor panel in each of piglets' pens for keeping the temperature on the panels' upper surface 35-36 ºC was 360 W. The regime of the heat pump operation was adjusted by back flow water temperature within the limits of 40-45 ºC. For measuring the consumption of electric energy 3–phase electric meter with precision up to 0.01 kWh was used. For measuring the consumed heat energy heat meter SONOMETER™1000 with precision 1kWh was used. During the experimental investigation periodically the possibility to read the intensity of the heat carring water flow, the temperature of heating water at outflow and inflow of the heat pump and the power of heat energy in the interval of 15 seconds has been used. With HOBO type measuring instruments the outside air temperature, from the ventilation system out flowing air temperature and relative humidity, as well as the evaporator's plates washing air temperature was measured. The flowing out from the evaporator plates' air temperature into the heat transfer zone of two by the side standing heat transfer plates and in the middle between two besides standing evaporators' stands in every 30 seconds has been registered (Fig. 2).

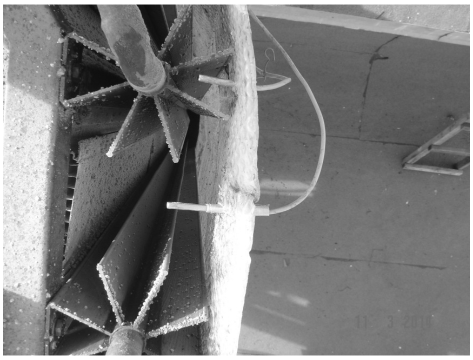

Fig. 2. **Disposition of temperature sensors at the top of evaporators**

Fig. 3. **Experimental device in winter**

The operation of the heat pump was evaluated in separate exploitation periods (Fig. 3) computing the heat transfer coefficient and the coefficient of energy consumption as ratio between amount of heat energy produced and consumption of electric energy for the operation of the heat pump's compressor [1]. More elaborated evaluation of the heat pump operation depending on exploitation conditions was made during the time of the heat pump's compressor operation. The changes in transformed heat energy power (precision 0.00 kW) and in the temperature of heated water (precision 0.1 ºC) in every 15 seconds using the heat meter SONOMETER™1000 were measured and registered.

## Results and discussion

During the summer months of 2012 and 2013 the average COP of the heat pump was within the limits of 3.48 up to 3.88. The heat pump's operation results for weaned piglets resting place heating in autumn and winter months in Table 2 are summarised. It is seen that during 2013-2014 years of experimental investigation, the heat pump's COP is higher. It can be explained by different outside air temperature. It is to be noticed that the warm outflow ventilation air was delivered at only one of evaporators.

During October–November months when average air temperature decreased up to +7 ºC and lower, the average COP was above 2.93, on several days performing thawing of the heat pump's evaporator plates. From the data given in Table 3 it follows that at separate periods the delivery of hot pigsty internal air on evaporators' plates improve the COP.

For example, on October 23 and 29, 2012, when several days outside air temperature was under +4 ºC, the evaporator's plates became covered by hoarfrost and ice so intensively that the COP decreased to 2.29. The maximum power of heat transfer was not higher than 10.5 kW. Starting the delivering of hot ventilation air to the plates of the evaporator, the ice layer gradually thawed and washing the clear plates with hot air facilitated the COP increase up to 3.13, and the heat transfer power in separate heat pump working periods reached 15.3 kW. The similar results were obtained also in other periods of analogues weather conditions.

Table 2

**The heat pump's operation results in autumn and winter months of 2012/2013 and 2013/2014**

| Month | Average outside air temperature, ºC | | Value of heat pump's COP | | Heat consumption, kWh·h$^{-1}$ | |
|---|---|---|---|---|---|---|
| | 2012/13 | 2013/14 | 2012/13 | 2013/14 | 2012/13 | 2013/14 |
| September | +13 | +13.1 | no data* | 3.61 | – | 9.57 |
| October | +6.9 | +8.5 | 2.93 | 3.55 | 6.12 | 8.96 |
| November | +4.0 | +7.5 | 3.01 | 3.24 | 8.18 | 10.24 |
| December | -4.8 | +2.7 | 3.10 | 3.33 | 8.51 | 8.89 |
| January | -6.2 | -12 | 3.04 | 2.99 | 8.38 | 8.31 |
| February | -2.2 | +2 | 3.09 | 3.35 | 7.73 | 6.38 |
| March | -5.5 | – | 3.11 | – | 8.48 | – |
| April | +4.2 | – | 3.20 | – | 8.48 | – |
| Average in period | | | 3.07 | 3.35 | 7.98 | 8.72 |

* Repair of the heat pump

Table 3

**Influence of short-term air washing on heat pump's exploitation parameters at the temperature from +5 ºC up to –3 ºC**

| Year, month | Date | Temperature | | Heat, kWh·h$^{-1}$ | Feeding by hot air, m$^3$·s$^{-1}$ | COP |
|---|---|---|---|---|---|---|
| | | Hour 8-9 (morning) | Hour 13-14 (midday) | | | |
| October, 2012 | 23-29 | 0 | +4 | 5.89 | – | 2.59 |
| | 29-31 | -2 | +4 | 7.24 | 0.5 | 3.13 |
| November, 2013 | 6-7 | +2 | +5 | 10.00 | – | 2.86 |
| | 7 | +1 (fog) | +5 | 9.37 | 0.8 | 3.47 |
| | 8-11 | +2 | +3 | 9.76 | – | 3.03 |
| | 11 | +1 (fog) | +7 | 9.71 | 0.5 | 3.23 |
| | 21-25 | +3 | +8 | 10.57 | – | 3.14 |
| | 25 | 0 | +3 | 10.1 | 0.5 | 3.29 |

The hot air from pigsty ventilation system uninterruptedly feeding the heat pump's plates with hot ventilation air from the pigsty in winter 2012-2013 and 2013-2014, starting from December insured the heat pump operation possibility at negative outside air temperatures. The heat consumption during the time of experimental investigation essentially did not change and was at the same level of 8-8.7 kWh·h$^{-1}$. In cold months of 2012-2013 the average value of the heat pump's COP – 3.09 kWh h$^{-1}$ was reached in January, when outside air temperature in working hours of some days felt down up to -20.4 ºC, the COP of the heat pump decreased up to 2.99 (Table 2). In Table 4 experimental results about the heat pump's operational parameters at low outside air temperatures with 5 ºC intervals down to -20 ºC are summarised.

The hot water temperature for feeding piglets resting places within the limits of 43-45 ºC was kept. Independently of the outside temperature one of the heat pump's evaporators was feed by flowing out from the pigsty air with the temperature from +19 to +21ºC, due to sufficient heat insulation of the feeding canal. Constant heat pump evaporator washing air intensity was 0.4-0.5 m$^3$·s$^{-1}$ and small changes in the feeding air temperature insured the main heat pump's parameters such as the necessary amount of hot air, constant average produced heating power (10-11 kW) and stable (2.9-3.1) COP of the heat pump.

The data summarised in Table 4 in Fig. 4 are illustrated. The change in temperature of the hot air flow passing the evaporator's heat transfer plates in different zones during the operation of the heat pump's compressor is shown. The mode of the temperature change during January 25, 2014, when the outside air temperature in the morning was -20.2 ºC, but during the day it heightened up to -6.7 ºC, is seen. It follows that during the day delivered from the pigsty and feeding the evaporator hot air temperature has changed insufficiently within the limits from +19 ºC up to +21 ºC.

Table 4

**Influence of constant air washing on the heat pump's exploitation parameters at outside air temperature up to -20˚C**

| Parameters | | Unite of measure | Interval of outside air temperature, ºC | | | |
|---|---|---|---|---|---|---|
| | | | **0 to -5** | **-5 to -10** | **-10 to -15** | **-15 to -20** |
| Heat consumption (providing) | | $KWh \cdot h^{-1}$ | 8.12 | 9.82 | 8.86 | 7.78 |
| Heat power | average | kW | 10.5 | 9.9 | 10.5 | 10.8 |
| | maximum | kW | 11.5 | 11.0 | 11.0 | 11.4 |
| Duration of compressor's cycle | | h | 0.2 | 0.32 | 1.7 | 1.3 |
| COP | | | 3.03 | 3.13 | 2.88 | 2.93 |
| Outside air | temperature | ºC | -3.5 | -7.7 | -12.7 | -16.2 |
| | relat. humidity | % | 85 | 81 | 94 | 92 |
| Hot air for evaporators' feeding | temperature | ºC | 19.2 | 21.0 | 19.8 | 19.6 |
| | relat. humidity | % | 60 | 62 | 67 | 68 |
| | intensity | $m^3 \cdot s^{-1}$ | 0.4-0.5 | 0.4-0.5 | 0.4-0.5 | 0.4-0.5 |
| Air temperature between two evaporators plates at outflow | average | ºC | 11.2 | 11.5 | 10.0 | 8.9 |
| | amplitude | ºC | 4.3 | 5.3 | 4.0 | 8.7 |
| | decline | ºC | 8.0 | 9.5 | 9.8 | 10.7 |
| Air temperature between two evaporators stands at outflow | average | ºC | 16.0 | 17.5 | 17.5 | 14.9 |
| | amplitude | ºC | 0.7 | 1.7 | 2.55 | 3.0 |
| | decline | ºC | 3.2 | 3.5 | 2.3 | 4.7 |

The duration of the compressor's working cycles in daytime was essentially shorter than in night hours. It can be substantiated with the fact that the efficiency of another evaporator of the heat pump, not covered, increased due to higher temperature in daytime. The character of the change of heat pump's heat power was stated reading the data from the heat meter.

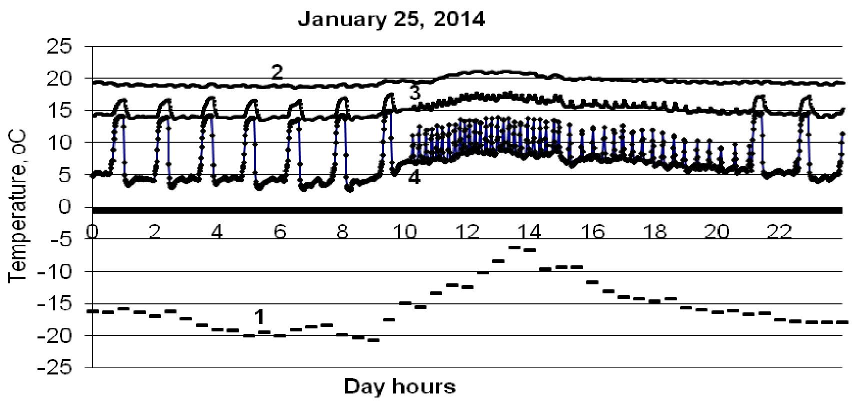


Fig. 4. **Daily changes in outside and inside air flows temperature before and after the air delivering n different zones of evaporators' heat transfer plates:** 1 – outside air temperature; 2 – feeding the evaporator hot air temperature; 3 – hot air temperature at the outflow between the evaporators' heat transfer plates; 4 – hot air temperature at the outflow between heat transfer stands

The decline of feeding air temperature into the zone of heat transfer plates on the average was 8-10 ºC, but between two by the side standing evaporators' stands only 3-5 ºC. Experimental data shoved that the evaporator has used only about a half of heat energy accumulated in the hot ventilation air.

## Conclusion

1. Short term feeding by out flowing from the ventilation system air the heat pump evaporators' plates, averts the plates icing and restore normal operation of the heat pump heightening its COP.
2. During constant frost weather conditions uninterrupted feeding by the hot air from the ventilation system outflow the evaporators' plates' leads to normal functioning of the heat pump ensuring its COP above 2.9.
3. The average drop in the hot ventilation outflow air temperature, when delivered into one of two sections evaporator's heat transfer zones, on the average is 5-10 ºC, which corresponds to the total heat content decrease up to 40 %.
4. The problem of feeding the second section with the air flow from the first section of the evaporator in order to increase the heat pump's COP, is to be solved.

## References

1. Blumberga D. Heat pumps. Riga, 2008, pp. 139 (in Latvian).
2. Ilsters A., Ziemelis I., Kristutis I. Possibility of Heat Pump Use for Piglet Resting Place Heating. Proceedings of the 8th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, 2009, pp. 202-206.
3. Ilsters A., Ziemelis I. Elimination of Outside Air Heat Pump Evaporators Icing Proceedings of the 11th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, 2012, pp. 122-127.
4. Koller G. et al. Schweinestalle. DLG-Verlag Frankfurt/Main, 1981, s. 194 (in German).
5. Heat pump Octopus. Technology and models [online] [13.01.2014] Available at: http://www.airheatpump.lv/?lg=lv8m_id=108s_id=11 (in Latvian).