Andrzej MYCZKO [1], Jerzy KARŁOWSKI [1], André J.A. AARNINK [2]
[1] Institute for Building Mechanization and Electrification of Agriculture in Warsaw
[2] Animal Sciences Group, Division of Animal Production, Lelystad, The Netherlands

DETERMINATION OF HEAT PRODUCTION IN DEEP LITTER AND IN ENERGY ROOF

Summary

Investigations of the installation for recovery and accumulation of heat generated in the animal building were executed. In the floor under the deep litter a tubular heat exchanger was placed, and on the roof placed was a set of solar collectors consisting of water panels integrated with the elements of the roof. Liquid from "energy roof" was directed to the bore-holes where the heat was transferred to the ground deposit. The heat was used in winter season for warming up the production rooms, offices and bathroom.
Comparison of heat amount coming from solar radiation with heat transferred to the liquid showed that energy roof prepared in Polish conditions reached the efficiency of 40%, what was 50-80% of performance achieved by original panels delivered by Dutch company R&R Systems b.v. Worse heat transfer was caused by poor quality of the glue used for joining. In the production room there was an effect of reduction of emissions of ammonia and greenhouse gases. The Netherlands experiments confirmed results of calculations by a special computer model. The COP (coefficient of performance) of the heat pump was a little lower than expected (3,2 versus 3,5).

OKREŚLENIE PRODUKCJI CIEPŁA Z GŁĘBOKIEJ ŚCIÓŁKI I DACHU ENERGETYCZNEGO NA BUDYNKU INWENTARSKIM

Streszczenie

Przeprowadzono badania instalacji do odzysku i kumulacji ciepła, umieszczonej w budynku inwentarskim. W posadzce chlewni, pokrytej głęboką ściółką, umieszczono wężownicę do odzysku ciepła ze ściółki, natomiast na dachu umieszczono wodne kolektory słoneczne – prototyp „dachu energetycznego". Czynnik obiegowy kierowany był do rur zagłębionych w odwiertach geotermicznych, które stanowiły gruntowy magazyn ciepła. Ciepło wykorzystywano w miesiącach jesienno-zimowych do ogrzewania pomieszczeń produkcyjnych, socjalnych i biurowych.
Porównanie ilości ciepła pochodzącego od promieniowania słonecznego z ciepłem przejętym przez kolektory pozwala na stwierdzenie, że dach energetyczny wykonany w warunkach polskich pracował ze średnią sprawnością 40%, co stanowiło 50 do 80% wartości uzyskiwanej w oryginalnych panelach holenderskiej firmy R&R Systems. Duży wpływ na gorsze warunki wymiany ciepła miała dokładność przyklejenia paneli wodnych do blachy pokrycia dachowego. W pomieszczeniach produkcyjnych z głęboką ściółką uzyskano efekt obniżenia emisji gazów cieplarnianych oraz amoniaku. W warunkach holenderskich doświadczalnie potwierdzono wyniki uzyskane za pomocą specjalnie opracowanego programu obliczeniowego. Uzyskany współczynnik efektywności COP dla pompy ciepła był równy 3,2 i był mniejszy niż oczekiwany 3,5.

1. Introduction

At the Climate Conference in Kyoto the different industrialized countries in the world have set the goal to reduce the production of greenhouse gases by 5% before the year 2012. Main greenhouse gases are carbon dioxide, methane, nitrogen and sulphur oxides. Abundant use of fossil energy causes production of large amounts of carbon dioxide that is not recycled in the carbon chain. A lot of methane is produced during anaerobic digestion of animal waste. Animal waste is a main source of ammonia as well. The high emission of ammonia from livestock production systems causes uncontrolled nitrogen enrichment of natural areas, including surface waters. In the soil the acidifying ammonia disturbs the mineral balances, causing lethality of woods. Little has been done so far to significantly reduce fossil energy use in pig production. With regard to ammonia actions have been taken in different Western European countries, including The Netherlands, to reduce these emissions. Research already delivered various ammonia reducing systems. However, research was focused on slurry systems. Little is known, as yet, about ways to reduce ammonia emission from straw systems. Straw systems for pigs will become increasingly popular, especially with regard to consumer demands for animal friendly production systems. The objective of this project was to reduce energy use and reduce emissions in pig production by introducing an innovative heat extraction system from straw manure in pig houses. This heat can be used for the sections of the farm with a heat demand. In this way energy use on pig farms can be reduced considerably. Furthermore, it is expected that this system will reduce emissions of greenhouse gases and acidifying ammonia considerably. Different SME'-s from Poland, The Netherlands and Germany will work together in a partnership with research institutes to bring the following innovation to market: A system that extracts heat from the straw manure to reduce gaseous emissions and the use of fossil energy on pig farms. With the same technology extra heat can be extracted from the roof of pig houses (the ''energy roof''). This heat can be used on the pig farm or for other purposes, e.g. greenhouses, heating of asparagus beds, tourist' activities. Surplus heat, extracted during warm periods of the year, can be stored in the soil, and used again during cold periods of the year. The project was divided into seven main work packages. In one of them two prototypes were tested on pig farms in Poland and The Netherlands.

2. Objective

In Work Packages called "Design, implementation and monitoring of two prototypes" the objective was to determine heat production in deep litter and in energy roof in two prototype systems.

3. Materials and methods

Thermal investigations of energy roof and the system of accumulation of heat in ground deposit were carried out in Agricultural Experimental Farm AR at Zlotniki, Poland. Temperature measurements were executed by means of measuring set consisting of temperature Pt100 sensor and the converter type TCD. The signal from Pt100 sensor was transformed into standard current signal 4-20 mA for automatics. For supplying the thermometers a PS -025 pulse supplier of nominal voltage 24 VDC and max. current 1A was used. The deviation of temperature in °C for applied temperature sensors with the processing unit the class B for the temperature range to 100°C is ±0,8°C (for hot water), and for measurements of temperature to 50°C is ±0,4°C (cold water). The error of processing by TCD measuring converters is about 0,15% of the range of processing, what is ±0,2°C. In connection with above mentioned the exactness of measurement of temperature of hot water is ±1°C and for cold water ±0,6°C. The measurement of temperature outside was done with similar exactness. The measurement of mass flow of a liquid medium in the heat exchangers was done by means of one-stream flow meters with transmitters of impulses. On the side of collectors on the roof there are flow meters type JS90-2,5-NK (adapted to continuous work with temperature liquid near 90°C and nominal capacity 2,5 m^3/h) and one impulse per each 10 dm^3. On the side of the heat exchanger connected to the collector of boreholes there is flow meter type JS-10-NK (adapted to continuous work at liquid temperature 50°C and nominal capacity 10 m^3/h) and one pulse per each 100 dm^3. For both the types of flow meters the relative error for the range of measurements (from average to maximum stream) is approx. ±3%. The accuracy of measurement of quantity of water flowing through the energy roof, at the flow rate 1m^3 /h was ±30 dm^3. At the maximal flow rate of water in circuit of borehole collector, the accuracy of measurement of flow was ±300 dm^3. The measurement of intensity of solar radiation was executed by means of LB-900 microprocessor measuring arrangement connected to the external radiation sensor. The sensor of visible radiation with a flat surface of type CM3 PYRANOMETR (from Kipp & Zonen) was used in the investigations. The spectral range of sensor is 305-2800 nm. The sensor measures the signal, transmits it to the analogue-digital converter and on basis of measured voltage from sensor as well as the digital calibrating data, the results are stored in the memory. Then the microprocessor calculates the current result of measurement of intensity radiation. The results in the form of digital signal are transmitted to the digital governor system for data collecting. The temperature measurements are processed and transformed into current signal 4-20 mA on analogue input of analogue module AIO 444, and the impulses from flow meters – to the counter input of this module. From module AIO 444 the processed measuring values are transmitted by the converter of transmission M - Bus Slave - RS 232 to the central unit of system Micro XL. The unit is equipped with memory (EPROM 512 KB), what enables to collect results of measurements from installed sensors of the system in pre-programmed intervals. Collected results were periodically (ca. every 2–3 weeks) transmitted from central unit to the system and afterwards - to sheet spreadsheet EXCEL and saved on a hard disc.

4. Results and discussions

4.1. Assessment of heat demand in rooms of piggery

Farrowing sector consists of 3 rooms, with 10 farrowing pens each. Besides that in separate small room there are two farrowing pens for sows needed separation and special care. Sector for weaned young pigs is located in three rooms with warming-up devices.

Table 1. Production rooms demanding heating
Tab. 1. Pomieszczenia produkcyjne wymagające ogrzewania

	Name of the room	Demand for heat [kW]	Number of rooms	Total heat demand [kW]
1.	Farrowing sector	6,69-7,35 *)	3	20,07-22,05
2.	Sector for weaners	4,27-6,23	3	12,81-18,69
3.	Corridor	10,0	1	10,0
4.	Administrative rooms and office	Exact data missing	6	40,0
			Total demand for heat:	**82,88-90,74**

*) including 10 infra-red lamps 175 Watt = 1,75 Kw

4.2. Heat recovered from deep litter

A heat pump of nominal heating power 40,0 kW for heat recovery was installed. After adjustment it was possible to reach heat capacity 48 kW. For supplying the satisfactory amount of heat additionally the gas boiler of nominal power 65 kW was applied. This made possible to balance heat demand during extremely low outside temperatures.

Table 2. Production rooms generating the heat
Tab. 2. Pomieszczenia produkcyjne wytwarzające ciepło

	Name of room	Heat production from one pen [kW]	Number of pens	Total heat production [kW]
1.	Finishers' sector (60 pigs/pen)	3,5	4	14,0
2.	Finishers' sector (60 pigs/pen)	4,7	3	14,1
3.	Playpen for 80 sows	4,0 – 6,0	1	4,6 – 6,0
			The total production of heat:	**32,1 – 34,1**

4.3. Heat recovered from energy roof

After extending the installation at Experimental Farm in Zlotniki by energy roof and connecting it to the existing experimental installation via plate heat exchanger, preliminary investigation were started. The aim of the investigation was to check the possibilities of transferring the heat from the energy roof to the ground heat storage. The measurements lasted over 100 days. Three chosen five-day periods in different months: August, September and October are described in this report and taken into considerations.

4.4. Conditions of investigations

The intensity of total solar radiation was monitored during preliminary exploitation. On this basis one can affirm, that the average radiation in for example analysed period in August (from 22 to 25.08), during hours of work of circuit of solar collectors on the roof was 380,12 [W/m²]. It corresponds to total radiation in the working day 4,07 [kWh/m²/day]. For analysed periods in September (13-17.09) and October (13-17.10) these values were equal respectively 326,4 [W/m²] and 2,94 [kWh/m²/day] as well as 172,7 [W/m²] and 1,47 [kWh/m²/day]. It should be mentioned, that the arrangement of roof collectors worked from 8:00 till 18:30, in September from 8:30 till 17:30 and in October from 8:30 till 17:00. The averages of intensity of radiation in individual days of analysed periods are presented in Table 1. The results taken from measurements did not differ from average values for the same seasons and for similar climatic zones in last few years. The assembly of roof collectors was filled was 40% water solution of polypropylene glycol known in Poland under the trade name ERGOLID–EKO. Temperature of crystallization of this liquid is not higher than – 20ºC. In time of tentative exploitation the flows by the individual parts of roof were in the range from 0,38 to 0,42 [m³/h]. The flows in individual parts of roof were adjusted by means of the set of throttle valves, which needed manual re-adjustments periodically. Average flow through the roof was approx. 0,4 [m³/h] which corresponds a total flow through all roof collectors approx. 1,6 [m³/h]. Calculated area of roof collectors was 8 m x 7,1 m = 56,8 m², and density of the liquid was 1,038 [kg/dm³]. The specific flow was equal 0,008 kg s^{-1} m^{-2}. It was smaller than the rate recommended by the manufacturer of roof panels, applied to building of roof collectors. The value of flow was set below the assumed one. The reason was that at bigger flows a low increment of temperature of the liquid in roof loop was recorded. Mass flow in circuit of roof collectors was approx. 0,451 [kg/s].

4.5. Results of measurements

In time of operation, in discussed five-days observational periods, maximal differences of temperature in heat exchanger on the side belonging to the loop of roof collectors appeared in August. The differences were in the range of 5,4-5,9 [°C], and average drop was 5,6 [°C]. For September and October these values were equal respectively: 4,0-4,8 [°C] and average drop of temperature 4,5 [°C] as well as 2,6-4,3 [°C] and average drop of temperature 3,2 [°C]. The increments of temperature of working medium fluctuated within similar range in individual kinds to iron covering roof (taking into account the drops of temperature in joining pipes). The energetic results of roof from exemplary analysed five-days operational periods are presented in Table 39. The heat stream reached in the exchanger in primary circulation loop joined to the roof in August was equal from 8213 to 8974 [W]. This enabled at certain time of work of installation during the day to reach daily gain from 86,2 [kWh/day] to 94,2 [kWh/day] of energy. The energy roof and the installation worked with power 8730 [W] and in course of five-days test period in August got 91,7 [kWh/day] in average. In September and October these values were equal 6973 [W] and 62,7 [kWh/day] and 4930 [W] and 41,9 [kWh/day] respectively. After a comparison the heat quantities achieved from roof collectors with heat energy delivered by solar radiation, it can be stated that the installation on the roof operated with efficiency approximately 40%. The differences of temperature on inlet and outlet of the heat exchanger on the side of roof collectors, which corresponds to liquid temperature increment during the flow through water panels, were small. The temperature of water delivered to the collectors had the influence on this. The temperature was dependent on the heat taken over by the receiver sets of the secondary circuit of roof heat exchanger (in summer period - the ground collectors). The temperatures of liquid at the outlet from roof collectors exceeded the running temperature of surrounding air not more than from ten to twenty degrees. This is the evidence of imperfect construction of the roof and made difficult the heat transfer from iron sheet to the liquid flowing in the water panels. (There were aerial spaces under large surface of sheet metal as a result of small stiffness of construction of roof). This disadvantage was eliminated in the next experimental system installed in the cow stable in IBMER Poznan within the frame of separate IBMER's project.

The heat storage system is under construction (May 2004). The comparison of results of measurements on individual kinds of roof surfaces, taken during the time of tentative exploitation, does not permit to express an opinion of individual kinds of iron sheets applied to cover the roof. Liquid temperature increments achieved when flowing through individual kinds of construction of roof were almost equal.

4.6. Quantity of heat stored and regained from ground deposit

Flow through the loop of boreholes during the time of investigations was more stable and was equal approx. 2,1 [m³/h]. It differs from 1,6 [m³/h] because of heat exchanger separating the circuit of the roof from circuit of the boreholes. At the density of circulating liquid (20% solution of ethanol) 0,958 [kg/dcm³], the mass flow was ca. 0,559 [kg s^{-1}]. It is to affirm, that the whole heat got from the roof, taking into account the efficiency of heat exchanger and the installation, can be passed on to the ground store. Achieved results of exploitation showed that in first year of operation the heat can be delivered to a ground store. After full winter operation the probably got differences of temperature of circulating liquid flowing through boreholes will be bigger, which will permit in the same conditions to recover back more heat from roof collectors. One should analyse connecting to this circulation, the system of heat recovery from the deep litter in playpens for pigs.

Table 3. Results of measurements of solar radiation
Tab. 3. Wyniki pomiarów promieniowania słonecznego

Date	Average intensity of radiation	Maximum radiation	Minimum radiation	Cumulated daily radiation
	W/m^2	W/m^2	W/m^2	$W/m^2/day$
22.08.	446,1	898,4	97,9	4,68
23.08.	416,6	819,1	120,0	4,37
24.08.	362,9	686,4	25,5	3,81
25.08.	356,4	1028,8	11,3	3,74
26.08.	359,1	805,4	64,8	3,77
Average	**380,1**			**4,07**
13.09.	306,4	592,7	92,0	2,76
14.09.	313,9	672,5	113,1	2,82
15.09.	317,1	732,1	95,0	2,85
16.09.	334,0	787,2	75,7	3,00
17.09.	360,8	688,2	91,0	3,25
Average	**326,4**			**2,94**
13.10.	335,2	479,7	103,1	2,85
14.10.	213,0	422,6	27,7	1,81
15.10.	62,5	184,9	23,0	0,53
16.10.	88,0	238,4	11,8	0,75
17.10.	165,0	636,4	25,8	1,40
Average	172,7			1,47

Table 4. Results of energetic measurements of solar roof collectors
Tab. 4 Wyniki pomiarów energetycznych kolektorów słonecznych na dachu

Date	P – the average power of roof collector in the day	Q – the quality of heat collected by the roof collectors during the day	ΔKS – the drop of temperature on heat exchanger on side of solar collectors	M – mass flow trough roof collectors
	W	KWh/day	^oC	$kg\ s^{-1}$
22.08.	8973,9	94,2	5,9	0,449
23.08.	8862,4	93,0	5,7	0,461
24.08.	8213,4	86,2	5,4	0,455
25.08.	8896,2	93,4	5,6	0,472
26.08.	8706,9	91,4	5,6	0,461
Average	**8730,6**	**91,7**	**-**	**-**
13.09.	6151,6	55,4	4,0	0,455
14.09.	7011,8	63,1	4,5	0,461
15.09.	7338,7	66,0	4,6	0,472
16.09.	6981,0	62,8	4,6	0,449
17.09.	7381,9	66,4	4,8	0,455
Average	**6973,0**	**62,7**	**-**	**-**
13.10.	6700,2	56,9	4,3	0,61
14.10.	4921,3	41,8	3,2	0,455
15.10.	4147,9	35,3	2,6	0,472
16.10.	4097,6	34,8	2,7	0,449
17.10.	4786,1	40,7	3,0	0,455
Average	**4930,6**	**41,9**	**-**	**-**

5. Conclusions

Pilot in Poland

- Comparing got quantities of heat from roof collectors with the heat energy delivered by solar radiation; one can affirm that the installation on the energy roof operated with efficiency of 40%.
- The comparison of results of measurements on individual kinds of roof surfaces, taken during the time of tentative exploitation, does not permit to express an opinion of individual kinds of iron sheets applied to cover the roof. Liquid temperature increments achieved when flowing through individual kinds of construction of roof were almost equal.
- The materials chosen for the coverage for energy roof require the exceptional care of fitting, and in peculiarity the good adhesion the water panels to sheet metal.
- It is to affirm, that the whole heat got from the roof, taking into account the efficiency of heat exchanger and the installation, can be passed on to the ground store.

- Achieved results of exploitation showed that in first year of operation the heat can be delivered to a ground store. After full winter operation the probably got differences of temperature of circulating liquid flowing through boreholes will be bigger, which will permit in the same conditions to recover back more heat from roof collectors.
- The observations and the results of measurements make able to affirm, that period of several months is not sufficient for complex opinion of system operating in one-year cycle. Due to the stochastic character of weather phenomena it would be advisable to perform investigations in longer period, for example 2–3 years.
- For realization of energy roof in conditions of Poland it is possible the usage of the water panels and the use of accessible materials for insulating and covering the roofs.
- The materials chosen for the coverage for energy roof require the exceptional care of fitting, and in peculiarity the good adhesion the water panels to sheet metal. High-qualified labors and the experienced company should do the fitting of energy roof circuits of the liquid.
- The element of the roof in period of good weather conditions made possible to receive energy on a level of 400-700 W/m², which made up 50-80% value of effects achieved by the modules coming from firm Dutch company R&R Systems b.v.
- The color of painting the iron sheet of the roof has not larger practical meaning.
- The intensity of flow of liquid circulating through collectors as well as the temperature of the initial liquid inflowing to water panel have the largest influence on quantity of transferred heat.
- In most cases extracting the heat from deep litter brings a positive effect in the form of reduction gaseous emission. The biggest reduction is for CO_2, CH_4 and NH_3. A slight growth can be noticed in the case for N_2O, but this can be a result of local instability of concentration.
- Extremely high reduction of steam water evaporation was not a result of heat extraction and can be explained in only possible way: The heat recovery system was in operation when there was a demand for warming up the offices and sectors for young pigs. High water consumption can be explained by behavior of pigs in hot days. The pigs drank more and used drinkers as showers for cooling themselves. As a result they used more water than they could drink and a lot of water was spoiled.

Pilot in The Netherlands

- The energy yield of the straw/manure was a lot lower than the expected yield calculated with the computer model ‘Pig heat and straw’. The main reasons were the too thin straw layer and the wetness of parts of the straw/manure bed.
- Ammonia emission from the straw manure seems not to be higher than from a conventional sow housing system.
- The energy yield of the solar roof was similar as the expected yield calculated with the computer model ‘Pig heat and straw’.
- Only little heat was stored in the soil. This could not compensate for the amount of heat extracted from the soil.
- The COP (coefficient of performance) of the heat pump was a little lower than expected (3.2 versus 3.5).
- The yearly costs of the pilot system were higher than estimated with the computer model ‘Pig heat and straw’. Because the energy yields were lower than expected, the total savings in energy could not compensate the extra costs of the system.

6. References

[1] Aarnink, A. J. A., and P. Nijenhuis. 2004. Computer model 'pig heat and straw' v1.2 No. 2004. Agrotechnology and Food Innovations.

[2] Aarnink, A. J. A., M. J. M. Wagemans, and G. M. Nijeboer. 2004. Emissies uit een welzijnsvriendelijke stal voor vleesvarkens; het 'canadian bedding system'. Rapport 084, Agrotechnology and Food Innovations, Wageningen.

[3] Aarnink A.J.A., Myczko A., Karlowski J.: „Use of a heat pump for environmental and welfare friendly pig housing systems with straw, Exploratory Award”.

[4] Aarnink, A.J.A. 1997. Ammonia emission from houses for growing pigs as affected by pen design, indoor climate and behaviour. Wageningen 1997. [in English]Anonymous. 2004. Handboek voor de varkenshouderij. Praktijkonderzoek Veehouderij, Animal Sciences Group, Lelystad. Anonymous. 2005. Wijziging regeling ammoniak en veehouderij Staatscourant. p 1-9,

[5] Den Haag. Block R. "Manure treatment outside the pig house. Options the for the biogas generation from straw”. A report D5.1 for the project Pig Heat and Straw. Canh, T. 1998.

[6] Ammonia emission from excreta of growing-finishing pigs as affected by dietary composition. Wageningen 1998. [in English]

[7] Kuczyński, T. 2002. Emisja amoniaku z budynków inwentarskich a środowisko. Redakcja Wydawnictw Naukowo-Technicznych Zielona Góra 2002. [in polish]

[8] Myczko A., Nawrocki L., Karlowski J.: „The influence of the extracting and storing of heat energy cumulated in a building for animals on the value of harmful gases in a ventilated air”, Szklarska Poreba, Institute for Building, Mechanization and Electrification of Agriculture, Branch Poznan. Monteny,

[9] G. J. C. M. G., and M. A. Hilhorst. 2001. Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. Nutrient Cycling in Agroecosystems 60: 123-Nawrocki L., Myczko A.: “The heat recovery from straw beddings on a pig farm”, Probl. Inż. Rol., 1998, R. 6 No. 4(22), s. 125-130.

[10] Nawrocki L., Myczko A., Kanikowski J.: „Pompa ciepła na głębokiej ściółce”, („Heat pump on a deep bedding”), Trzoda Chlewna, 6/1999, p. 105- 108.

[11] Van Ouwerkerk, E. N. J. 1999. Anipro: Klimaat- en energiesimulatiesoftware voor stallen. Nota V99-109, IMAG Wageningen.