RIGA TECHNICAL UNIVERSITY
The Faculty of Building and Civil Engineering
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ENERGY-EFFICIENT AND ENVIRONMENT-FRIENDLY VENTILATION SYSTEMS IN PIGGERIES

Summary of Doctoral Thesis

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CONFIRMATION

I confirm that I have developed the present Doctoral Thesis, which is submitted for consideration at Riga Technical University for scientific degree of the doctor of engineering sciences. The Doctoral Thesis has not been submitted at any other university for the acquisition of a scientific degree.

Anna Ramata …………………………….(Signature)

Date: ………………………

The doctoral thesis is written in the Latvian language; it contains Introduction, 5 chapters, Conclusions, References, 37 drawings and illustrations, 14 tables; altogether 117 pages. The References have 96 titles.

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Contents

Introduction

The rising prices of energy resources and energy, is an essential factor in the economics of industrialised pork production process as compared with the capital investments, materials and labour. Therefore energy saving has the greatest impact upon production and the end-product. The production units of intensive animal husbandry are considerable consumers of energy resources. An essential part of the total energy consumption at the production unit is used up to ensure the microclimate that is so necessary for the animals. The animals and their microenvironment are closely linked because when the microenvironment conditions change, the animals react to these changes in a different way. Optimisation of the operation schemes of the ventilation devices and their consumption of energy is an important measure from the viewpoints of the animal welfare, the cost reduction, and the environment conservation. Intense scientific research is going on in the world how to ensure microclimate in the animal houses, how to reduce energy consumption and apply various heat retrieval devices in the ventilation systems. They have been dealt with by A. Krēsliņš, A. Lešinskis, P. Šipkovs, A. Šķēle, J. Jurševskis, Ē. Ziemelis, A. Ilsters, R MacDonald., P**.** Eng**,** B. K .Pedersen, V. I. Bodrov, M. B.Rajak, G.Jegiazarov.

In Latvia, the Law "On Animal Protection" and the relevant regulations of the Cabinet of Ministers No. 743 „The Pig Welfare Requirements" prescribe the pig keeping conditions. On January 2, 2008 the Cabinet of Ministers adopted Regulations No.5 „General Welfare Requirements for Agricultural Animals" which were issued in agreement with the Animal Protection Law. Reduction of the production costs and, consequently, the prime cost of the end product depend to a great extent on how much energy is consumed, how effectively and efficiently it is used.

Methodology has been elaborated in the Promotion Work for the calculation of energy consumption for various sets of ventilation systems in the air treatment processes using systems optimization. The operation of various air treatment devices is analysed by the variations in the enthalpy of the outdoor air, the inlet air and the outlet air treatment processes. When working out the calculation methodology, I used the climatological data of Latvia about the repetition frequency of the combinations of the outdoor air parameters in a 5-years' interval, recalculating them to the enthalpy of the outdoor air parameters. Thus it was determined how much energy is required for a heating season in order to ensure a microclimate which complies with the animal welfare norms.

The high concentration of animals is the main source of odours because the concentration of production is a precondition of good economic indicators. The work deals with various possibilities how to restrict propagation of bad odours. One of them is manure recycling into biogas. Biogas production using manure has several advantages for the environment conservation, for example, reduction in the methane, ammonia and nitrogen dioxide emissions, less bad odours, much higher quality of the nitrogen fertiliser within the recycled manure. Biogas production is an environment-friendly, efficient technology of refuse recycling.

Topicality of the Research

The strategy of the European Union (EU) provides for reaching sustained agricultural production with an aim to ensure efficient equilibrium between the commercial agriculture and conservation of the environment.

The rising prices of energy resources and electric energy, is an essential factor in the economics of industrialized pork production process as compared with the capital investments, materials and labour. Therefore energy saving has the greatest impact upon production and the end-product. The production units of intensive animal husbandry are considerable consumers of energy resources. Microclimate is one of the most important factors that ensures animal welfare, and, together with other factors, it creates conditions which are favourable for the growth, preservation and development of animals, raising their productivity. An essential part of the total energy consumption at the production unit is used up to ensure the microclimate that is necessary for the animals. The animals and their microenvironment are closely linked because when the microenvironment conditions change, the animals react to these changes in a negative way. Optimization of the operation scheme of the ventilation devices and their consumption of energy is an important measure from the viewpoints of animal welfare, the cost reduction, and the environment conservation.

Structural changes are going on in the pig-breeding branch, and production is being concentrated on the larger farms. In 2009 the number of the small farms (1-9 pigs) decreased by 9.12 %. In contrast to the year 2008, the number of pig-breeding farms with 5000 to 10 000 animals in their herd increased by 29.5 %, whereas the number of farms with 500 to 1000 animals grew by 48.3%. These farms should pay attention to such a model of farming which is oriented to the market and serves simultaneously for public benefit. It should work in compliance with the environment, animal health and welfare standards and requirements, as well as ensure a non-waste production technology. The Promotion Work deals with the optimization issues of energy consumption in industrial pig-breeding that are connected with animal welfare, environment sustaining and conservation.

Methodology of Research

When calculating the heat balance in animal houses we took into consideration the optimal microclimate parameters for each group of economic utilisation of pigs and the applied keeping technology. This involved the following assessments: the heat endurance of the envelopes; maximum density of animals and their total weight in the box; the total amount of heat and moisture excreted by the animals. The microclimate parameters to be considered are: ventilation intensity; the lowest critical temperature; the admissible air velocity; moisture content; CO_2 concentration.

The microclimate research was carried out taking into account the Latvian pig-breeders' experience and practice that the animals are kept in three basic groups by their age, live weight and the group of their economic utilization:

1) pre-farrowing and farrowed pigs with piglets up to the 21st day (piglets from their birth till they reach 7 kg weight);
2) the weaned piglets 22 – 65 days of age;
3) the breeding pigs/young fattening pigs 65 – 165 days of age.

In the work we studied the mechanical inlet – outlet ventilation systems for each animal house:

- the traditional mechanical inlet system with air heating in the air heater (I),
- the system with air heating in the air heater and adiabatic moistening (II),
- with heat and moisture regenerative heat exchanger, air heater and moistering(III).

Using the climatological data about the repetition frequency of the combinations of outdoor air temperatures and moisture for Rezekne, I calculated the enthalpy and duration of the interval of temperatures and relative moisture in each one-year's heating season. By the necessary difference in enthalpies of the indoor air, outlet air and outdoor air parameters in the animal houses I determined the energy consumption during the heating season, analyzed the operation schemata of the ventilation devices and air parameters in piggeries. The experimental computer model created in order to perform calculations comprises data about the heat balance in the boxes of pigs, outdoor air parameters, the indoor air parameters in the animal house and the energy consumption of the devices used for the treatment of air.

The Aims and Tasks of the Promotion Work

To create an environment-friendly microclimate system in piggeries which would ensure optimum animal productivity and energy consumption.

In order to achieve this result, the following tasks were set:

- to analyze the microclimate conditions in the animal boxes and the factors affecting them considering the specificity of the technological processes of production;
- to determine the annual (heating season's) energy balance, by including several factors: the heat endurance of the envelopes, fluctuations in the climatic parameters of the outdoor air, the repetition frequency of the combinations of relative moisture and temperature, and their duration in the heating season;
- to draw up a methodology for the calculation of energy consumed by the air treatment devices in various combinations and operation schemata of ventilation devices;
- to do experimental testing of the elaborated computer simulation methodology;
- to evaluate the reasons of odour emissions into the outlet air from the ventilation systems of piggeries;
- to consider possible measures and ways how to avert or lessen this environmental contamination factor;
- to ensure the necessary microclimate in the animal boxes with an energy consumption as low as possible by optimizing the operation schemata of the ventilation devices.

The Scientific Novelty and Practical Application of the Promotion Work

The scientific novelty of the Promotion Work is the developed methodology for the optimization of energy consumption of the ventilation systems using the climatological data that are characteristic for Latvia, which allows complex estimation of the impact made by microclimate upon the environment, the animal productivity and consumption of energy.

Practical application of the results of the Promotion Work will give a positive economic effect: the consumption of energy will decrease; the level of welfare of the animals will rise, which determines the quality of the produced product; the sickness and death rates of piglets will diminish, and this will increase the yield of the end product; the capital investments into the equipment and systems will pay back sooner. Successful solution of this issue determines the quality of the product and, hence, sustainable economy of the farm.

A methodology has been worked out for the optimization of energy consumption using the climatological data about the repetition frequency of various combinations of the outdoor air enthalpy, temperature and relative moisture, as well as energy consumption in various combined air treatment devices. By means of the newly-developed methodology a comparison is made of energy consumption for a heating season with various operation schemata of air treatment devices.

If this methodology is applied at the designing stage of animal houses, it is possible to prognosticate the energy consumption of the ventilation systems in the boxes when planning capital investments and operating expenses for the expected new equipment. The developed methodology can be applied:

- when a comparison is made of the air treatment systems with various configuration and energy efficiency expressed by energy consumption in the heating season;
- when the duration of the operation of the system is determined by the repetition frequency of the combinations of the climatological data, then it is possible to choose optimal air treatment equipment with an optimum capacity of various components before the implementation of the project;
- when a comparison is made of the efficiency of various air treatment devices and their sets at the designing stage, before the purchase of the equipment is announced.

The methodology elaborated in this scientific work will be used by the students from the LUA and RTU in their learning process.

1. Air Parameters in Piggeries

Fluctuations in the consumption of thermal energy in agricultural production units are connected both with internal and external factors. The external factors are: the weather conditions, solar radiation, the direction of the wind, and other possible and occasional circumstances. The internal factors are variations in the amount of agricultural production, requirements for a definite microclimate at different stages of growth and life of animals. The operation of the heating-ventilation systems, depending on the meteorological parameters, varies not only by season but also during the day and night period. Fluctuations in the meteorological parameters are connected with the variations in temperature and relative moisture.

The temperature interval from 15°C to 22°C, which comprises the levels of optimum productivity and efficiency, shows the preferable designing conditions relating to the maximum result and efficiency to be achieved. Well-balanced temperature, compliance with the requirements and efficiency do not worsen the growth of pigs as long as the lowest or the highest critical temperatures are not reached, and, in the potential, worsening of the necessary conditions in the temperature interval from 10°C to 25°C might be allowed. In my work I was guided by the temperature and relative moisture parameters required for a pig utilisation group:

1) pre-farrowing/farrowed pigs with piglets up to the 21st day (piglets since their birth till they reach 7 kg weight);
2) the weaned piglets 22 – 65 days of age;
3) the breeding pigs/young fattening pigs 65 – 165 days of age.

Two microclimate areas should be provided in the farrowing box: one for the sow, the other for the piglets. The weaned piglets need the same microclimate as the piglets in the farrowing box. During the first days after weaning the temperature must not be lower than 26°C. Then, in a week’s time the temperature is gradually lowered to 22°C. In order to ensure heat for the piglets, heater lamps or heating pads are additionally used in the boxes. The fattening and the breeding pigs have similar microclimate requirements.

Table 1.1. The air parameters for different groups of pigs.

No.	Microclimate parameters/group of pigs	Sows with piglets	Weaned piglets	Fattening and breeding pigs
1.	Temperature, °C	18-20	22-26	15-18
2.	Relative moisture, %	60-70	60-70	70-80
3.	Amount of ventilation, m^3/cnt	35-60	35-60	35-70
4.	Air velocity, m/s	0.15-0.20	0.20-0.60	0.20-1.0
5.	NH_3, (mg/m^3)	up to 10	up to 10	up to 10
6.	CO_2, %	0.20	0.20	0.20
7.	H_2S, (mg/ m^3)	up to 10	up to 10	up to 10

Intensive pig breeding entails great density of animals which produce approximately known amount of manure and odour. Oxygen is consumed in breathing and carbon dioxide emitted; its concentration influences the animal welfare and safety. The gases that arise in the animal house and affect the health and productivity of animals are: ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and methane (CH).
An insufficient amount of fresh air, toxic gases and dust do harm to the animals and the personnel.

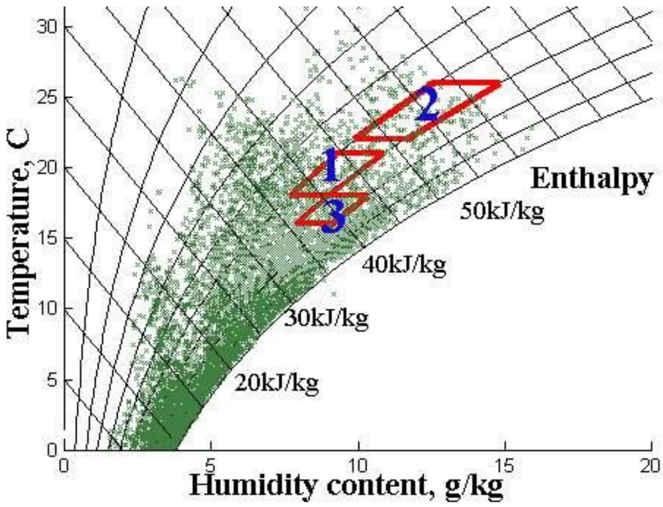


Fig.2.1. The air parameters of the outdoor air and the comfort areas of the animal house.

The main energy consumers in piggeries are the heating, ventilation and lighting systems. Fuel and electricity constitute an essential share of the end product costs; therefore energy is of great importance for the fodder conversion and production of animal products. A well-considered development of the design of the heating and ventilation systems, their operation and maintenance reduces the consumption of energy and raises the welfare of the pigs.

All the ventilation systems run according to the principle of the heat balance equation i.e. the heat emitted by the animals vs. the losses of heat through the envelopes and through the ventilation systems. As soon as the heat balance is negative, additional heat is needed to avoid lowering of temperature in the boxes or to allow the closure of the ventilation trunks. The newly-born animals need additional heat throughout the year, as well as to exclude lowering of the indoor air temperature below the minimal critical temperature. This guarantees that the forage is not used up usefully in order to maintain the heat in the animal’s body. The room temperature in itself does not always mean that the temperature of the real environment is above the lowest critical limit. The other affecting factors are: the form of the floor, thermal insulation of the building and the operation of the ventilation system.

In practice energy saving means reduced total consumption of energy. This is possible by using energy efficient technologies, i.e. a lesser amount of energy is consumed to reach the same result. The consumption of energy can be diminished also by changing the organisation (management) of operation of the equipment. Energy economy results in financial saving, conservation and safety of the environment, ensuring the animal welfare. A correctly designed and completed ventilation system raises the pigs’ welfare to the maximum and reduces the energy input, and the price. Therefore intense work is going on in the world in order to decrease the energy requirement for the microclimate ensuring systems.

2. Calculations of Energy Consumption for the Elaboration of Methodology

The annual consumption of heat is determined by the duration of the lowest outdoor air temperatures. The climatological data are summed up in the Latvian building normative LBN 003-01 “Building climatology”. Using the climatological data for Rezekne in a five-year period, the values of the intervals of the mean temperatures and relative moisture were calculated for a one-year heating season. With the help of the calculations about the outdoor air temperatures, how often and how long the combinations of temperatures and relative moisture continue in Latvia, we determined the average repetition frequency of the enthalpies of the outdoor air parameters. In this way the possible energy consumption of the air treatment devices was estimated in the animal house for a heating season. On the basis of an assumption about climate as a limited system in the h-x diagram in which every point of the outdoor air parameters has a non-uniform repetition frequency we determine the change in the enthalpies of each interval vs. the enthalpy of the working area. In the further course of investigation, using various ventilation systems and heat exchange apparatus, their application, the most economical way of ventilation systems was searched for in order to make it possible to use the obtained data in a far distant future in planning capital investments and their payback. The climatological data about the repetition frequency of the combinations of the outdoor air temperatures t and relative moisture φ are summed up in Table 2.1.

Calculations of the outdoor air parameters are based on the five years’ meteorological observations both for the warm and the cold period of the year. The outdoor air enthalpy h_O at various temperature and relative moisture combinations is calculated and summed up in Table 2.2.

Table 2.1. The repetition frequency of the combinations of the outdoor air temperatures t and relative moisture φ in τ hours during the heating season.

Temp.	**Relative moisture, φ**							
t,°C	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**	**0.8-0.9**	**0.9-1.0**
20-25			2					
15-20		7	6	8	5	4	3	3
10-15	1	18	20	24	32	29	38	39
5-10		11	23	42	65	94	185	234
0-5	4	9	26	58	105	302	358	644
-5-0			14	31	91	268	466	510
-10- -5		1	10	26	50	148	266	246
-15- -10			2	9	30	64	149	81
-20- -15			1	3	16	58	72	26
-25- -20			2	3	4	11	14	11
-30- -25					4	1	1	

Table 2.2. The outdoor air enthalpy at various temperature and relative moisture intervals.

Temperature	Temperature	**Relative moisture, % / Enthalpy of the outdoor air parameters ho (kJ/kg)**							
t °C	**t °C**	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
		25%	35%	45%	55%	65%	75%	85%	95%
20 - 25	22.5			42.07					
15 - 20	17.5		28.66	31.82	34.94	38.14	41.34	44.58	47.76
10 - 15	12.5	18.26	20.52	22.82	25.03	27.38	29.66	31.90	34.27
5 - 10	7.5		13.20	14.80	16.44	18.04	19.68	21.34	22.94
0 – 5	2.5	5.37	6.50	7.64	8.76	9.88	11.02	12.15	13.28
-5 - 0	-2.5			0.87	1.64	2.41	3.16	3.93	4.70
-10 - -5	-7.5			-5.35	-4.86	-4.36	-3.87	-3.36	-2.87
-15 - -10	-12.5		-11.5	-11,20	-10.85	-10.57	-10.24	-9.92	-9.60
-20 - -15	-17.5			-16.64	-16.54	-16.36	-16.16	-15.96	-15.75
-25 - -20	-22.5			-22.08	-21.94	-21.90	-21.68	-21.56	-21.44
-30 - -25	-27.5					-27.23	-27.14	-27.02	

The heat balance evaluates the connection between the heat emitted and flowing into the animal house, on the one hand, and the heat flowing out of the house (the lost heat), on the other.

Qdzīvn + Qpapild= Qk + Qv + Wiztv, (2.1.)

where:

Qdzīvn – the amount of the free heat emitted by the animals, W;

Qpapild – additionally delivered heat, W;

Qk – the losses of heat through the building structures of the animal house, W;

Qv – the amount of heat for heating the freshly delivered air, W;

Wiztv – the losses of heat due to the evaporation of moisture from the surfaces of the building structures, %.

The heat from the animals and from the heating devices must be equal to the losses of heat through the walls, the ceiling, the roof coverings of the animal house, and ventilation.

The basic relationship for the determination of the losses of heat through envelopes of the animal house is the following:

$$Q_k = F * U (t_I – t_O), kW, \text{ where } t_I - t_O = \Delta t, \qquad (2.2.)$$

where: U – the heat transition coefficient, $W/m^2 \cdot K$;

F – the area of the corresponding envelope, m^2;

t_I, t_O – the respective indoor and outdoor air temperatures, °C.

Depending on the keeping system, 8 – 30% should be added to the losses of heat arising from moisture W_{iztv} , kg/h which evaporates from the surfaces of the building structures of the animal house.

The amount of moisture emitted by the pigs:

$$W_p = w \cdot n, kg/s, \qquad (2.3.)$$

where: w – the moisture emitted by one pig, kg/s;

n – the number of pigs in the piggery.

The required amount of the inlet air:

$$L = m*n*l_p*1,2, kg/s, \qquad (2.4.)$$

where: m – the average weight of a pig, kg;

l_p – the required amount of fresh air per 1 kg of live weight, m^3/s;

1,2 – the mass of air, kg/m^3.

The amount of ventilation for the cold period of the year is calculated according to the removed moisture and is checked by the concentration of carbon dioxide in the air of the animal house. Calculations for the warm period of the year are made according to the amount of the surplus heat and checked by the amount of the removed moisture.

$$L_{CO2} = C/c_n – c_g , m^3/h, \qquad (2.5.)$$

where: L_{CO2} – the amount of the fresh air introduced into the house, m^3/h;

C – the amount of CO_2 emitted by the animals, l/h;

c_n – the greatest allowed amount of CO_2 according to the norms of zoohygiene, l/ m^3;

c_g – the amount of CO_2 in the outdoor air, l/m^3.

In the further course of the work, by the heat balance in the animal house in various temperature intervals, the inlet and the outlet enthalpy interval Δh, and the admissible interval of the moisture content were calculated in the working area Δx. The difference in enthalpies depends on the outdoor air temperature. If enthalpy at each temperature interval changes, then the moisture content is constant.

The difference in the enthalpies of the outlet and the inlet air:

$$\Delta h = Q/L = h_E – h_S, kJ/kg. \qquad (2.6.)$$

The enthalpies of the inlet h_S and the outlet h_E air:

$$h_S = h_I - \Delta h/2, \qquad (2.7.)$$

$$h_E = h_I + \Delta h/2, \qquad (2.8.)$$

where: h_E – the enthalpy of the outlet air, kJ/kg;

h_S – the enthalpy of the inlet air, kJ/kg;

h_I – the enthalpy of the working area, kJ/kg.

The difference in the moisture contents for the inlet and the outlet air:

$$\Delta x = W/L = x_E - x_S, g/kg. \qquad (2.9.)$$

The moisture contents of the inlet air x_S and the outlet x_E air:

$$x_S = x_I - \Delta x/2, \text{ g/kg}; \quad (2.10.)$$

$$x_E = x_I + \Delta x/2, \text{ g/kg}, \quad (2.11.)$$

where: x_E – the moisture content of the outlet air, g/kg;
x_S – the moisture content of the inlet air, g/kg;
x_I – the moisture content of the working area, g/kg.

Data were included into the calculation model of the operation of the ventilation systems and the energy consumption about the heat and moisture emitted by the animals, about the heat endurance of the envelopes, about the amount of the required air, additional moisture emissions from the surfaces of the building structures and the technological systems of keeping. The air treatment processes and their direction were considered as well.

The enthalpy of the inlet air:

$$h_S = h_I - \frac{((n \cdot q_0) - ((U \cdot F \cdot \Delta t) + W_{iztv})) \cdot 3600}{m \cdot n \cdot 0{,}01 \cdot l_p \cdot 1{,}2 \cdot 2} \quad \frac{kJ}{kg} \; . \qquad (2.12.)$$

The moisture content of the inlet air:

$$x_S = x_I - \frac{n \cdot w_0 \cdot 3600}{m \cdot n \cdot 0{,}01 \cdot l_p \cdot 1{,}2 \cdot 2} \quad \frac{g}{kg} \; . \qquad (2.13.)$$

The losses of heat through the envelopes may vary because new animal houses are built, and the heat conductive properties of the materials used in construction change. Meanwhile the old animal houses are reconstructed, they are thermally insulated, windows, doors and the roof coverings are replaced, which reduces the losses of heat through the envelopes. If an input parameters – the weight of animals, their number in the animal house, the heat and moisture emissions from animals or the surfaces of the building structures determined by other standards, the heat conduction coefficient of their materials after a possible renovation, the temperature intervals selected according to other criteria – change, then it will be possible to apply the developed methodology also by changing the value of a particular parameter. If the climatological data about the outdoor air parameters change during a year, then they can also be recalculated in the existing model, but it would be expedient to take data for a longer period. The course of calculations and the results are summed up in Table 2.3.

In the course of further investigations, using the climatological data about the outdoor air enthalpy at various temperature and relative moisture combinations and the repetition frequency τ, the energy consumption was estimated by the necessary inlet and outlet air enthalpy and by the required air exchange in the animal houses for the treatment of air within each group of animals under 3 different conditions of the ventilation systems (kWh/a). The energy consumption in the heating season G with the outdoor air heating (the 1st ventilation system) and with the outdoor air heating and moistening (the 2nd ventilation system) for each of the outdoor air combinations was determined by the formula:

$$G = \tau \cdot (h_S - h_O) \cdot L, \text{ kWh/a}; \qquad (2.14.)$$

where: τ – the frequency of the outdoor air temperature and relative moisture combination in hours/a year.

I calculated the heat utilisation of the outlet air of the ventilation system with a regenerative heat exchanger, the second heating and moistening for each of the outdoor air combinations by the formula:

$$G = \tau \cdot h_S - [h_O + 0{,}5 \cdot (h_E - h_O)] \cdot L, \text{ kWh/a}; \quad (2.15.)$$

where coefficient 0.5 stands for the efficiency of the heat exchanger at which the calculation of all the boxes were made. An example of the annual consumption is shown in Table 2.4.

Table 2.3. A model of the calculation of the heat balance in the box of sows at various outdoor air temperature intervals:
A model for various intervals of the outdoor air parameters at the range of temperatures from -27.5^{o}C to 22.5^{o}C.

Structure	**U, (W/m²*K)**	**F, (m²)**	**U·F**	**Losses of heat, Qk, (W)**	**Δt, ^{o}C**	**Q_k, (W)**	**Q_k+W_{iztv}, (kW)**	**Q = Qp - Qk, (kW)**	Δh = Q/L, (kJ/kg)	Δx=Wp/ L, g/kg L=3,94	hs=hI-Δh/2, kJ/kg	hE=hI+Δh/2, kJ/kg
					-4.5	-8619.3	-9.5	140.9	35.76		19.76	55.52
Ceiling	0.35	1296	453.6	4762.8	0.5	957.7	1.1	130.4	33.08		21.10	54.18
Floors	0.5	1296	648	6804.0	5.5	10534.7	11.6	119.8	30.41		22.44	52.85
Windows	2.5	259	647.5	6798.8	10.5	20111.7	22.1	109.3	27.74		23.77	51.51
Doors/ gates	0.43	36	15.5	162.8	15.5	29688.7	32.7	98.7	25.06		25.11	50.17
Walls		335		1583.4	20.5	39265.7	43.2	88.2	22.39	5.08	26.45	48.84
Doors/ gates	0.45		150.8		25.5	48842.7	53.7	77.7	19.71		27.79	47.5
Walls					30.5	58419.7	64.3	67.1	17.04		29.12	46.16
					35.5	67996.7	74.8	56.6	14.37		30.46	44.83
					40.5	77573.7	85.3	46.1	11.69		31.80	43.49
					45.5	87150.7	95.9	35.5	9.02		33.13	42.15
Total	x	x	**1915.4**	**20111.7**								

Table 2.4. Calculation of energy consumption for the 3rd ventilation system.
Those parameter combinations are shaded at which h is less than 0 and there is no energy requirement for heating.

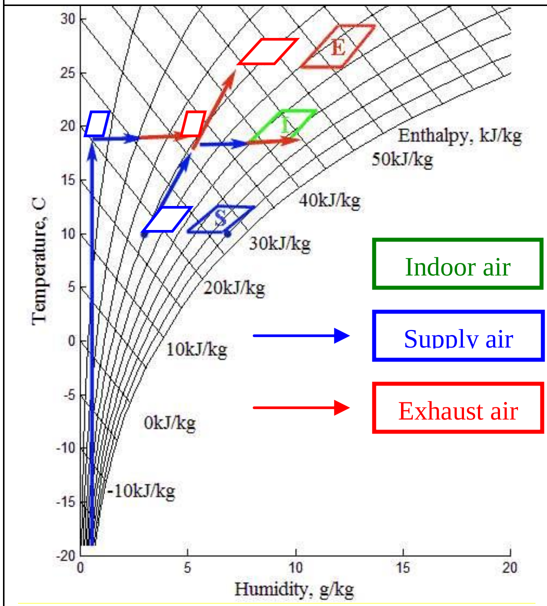
Temperature T °C	hE (kJ/kg)	Relative humidity, %								ΣG, kWh/a
		20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%	
20 - 25	55,52			-228,84						0,00
15 - 20	54,18		-560,43	-517,72	-739,46	-493,68	-420,16	-334,27	-353,06	0,00
10 - 15	52,85	-51,69	-1010,61	-1213,52	-1560,24	-2229,09	-2150,37	-2985,42	-3245,30	0,00
5 - 10	51,51		-372,29	-850,92	-1689,55	-2819,66	-4381,36	-9227,87	-12409,58	0,00
0 - 5	50,17	-41,92	-114,54	-389,27	-996,35	-2035,40	-6532,44	-8533,65	-16797,32	0,00
-5 - 0	48,84			88,26	147,79	294,00	475,16	110,16	-643,01	1 115,37
-10 - -5	47,50		15,92	264,77	662,79	1225,34	3487,06	5994,79	5311,44	16 962,11
-15 - -10	46,16			91,72	406,73	1339,21	2814,11	6457,66	3459,48	14 568,91
-20 - -15	44,83			64,50	192,90	1023,14	3686,03	4547,39	1630,84	11 144,80
-25 - -20	43,49			166,27	248,57	331,12	905,81	1149,53	900,61	3 701,91
-30 - -25	42,15					404,56	100,98	100,75		606,29
										48 099,39

3. Experimental Testing of Temperature and Moisture Conditions

In addition to the analytical description and concrete point of the climatological parameters, the optimal functioning schemes depicted and analysed in the h-x diagram allow to judge about the functioning of the air treatment devices as well as provide the necessary data about their technico-economical comparison.

By the results obtained from the h-x diagram and the calculations there were analysed the operation schemata of the ventilation systems and the air parameters in the boxes of the pigs. Figures 3.1. – 3.3. shows the air treatment processes at various combinations of the outdoor air parameters for three different combinations of the ventilation devices in the sow piggery.

<table>
<tr><td>Fig.3.1. A ventilation system with the outdoor air heating in the air heater.</td><td>Fig.3.2. A ventilation system with the outdoor air heating and adiabatic moistening.</td></tr>
<tr><td>



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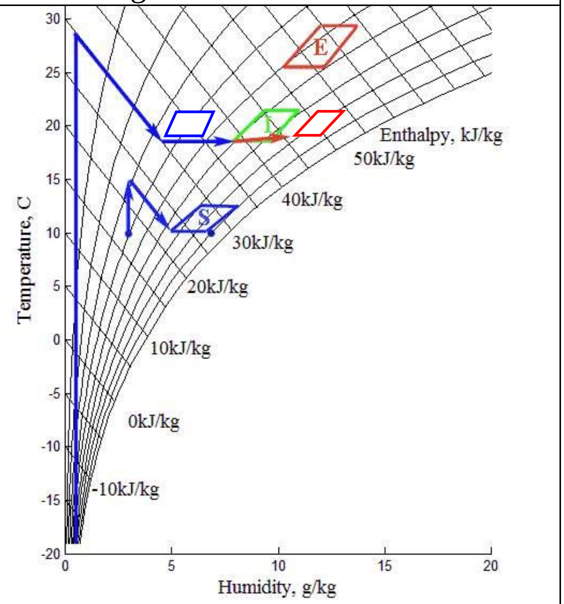
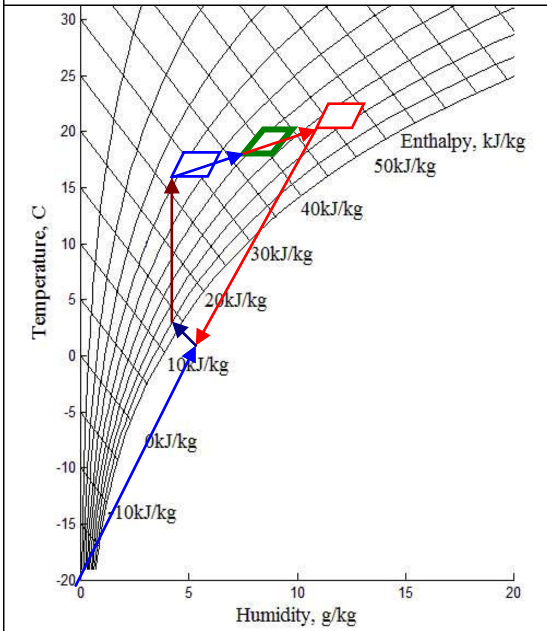


</td></tr>
<tr><td colspan="2">Figs 3.3. and 3.4. A ventilation system with regenerative air heater, air heater and moistener.</td></tr>
<tr><td>



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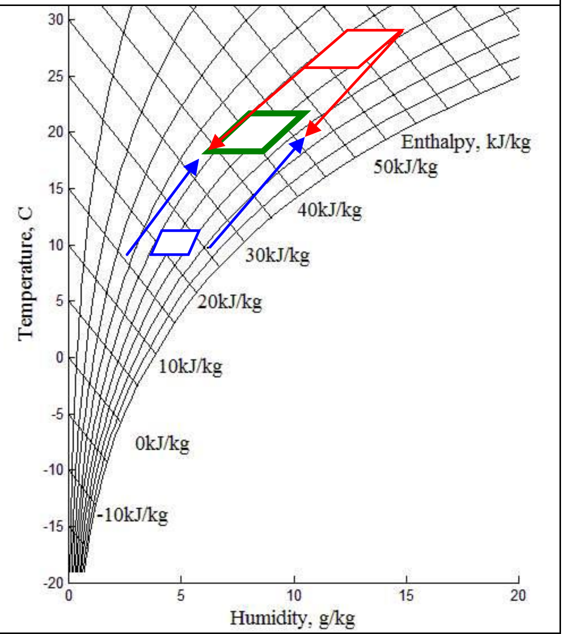

</td></tr>
</table>

In the technical documentation of their heat exchangers various producers indicate the efficiency of the heat exchanger from 0.4 to 0.75 or even 0.9. Considering the fact that rather polluted air flows from the piggeries and in winter a condensate arises on the surfaces of the heat exchanger, which may freeze (get covered with ice) when it not operated correctly, I used average values in my calculations. In a case of necessity these values in the model of calculations can be changed either to a smaller or a greater efficiency thus changing the annual consumption of energy of the equipment.

If the area of the outdoor air parameters is in the Δx interval i.e. when the moisture content of the outdoor air $x > x_S$ (g/kg), then the parameters of the inlet air are calculated for each combination of the outdoor air parameters by the values of the outdoor and the inlet air temperatures:

$$G = \tau \cdot (t_S - t_O) \cdot c_P \cdot L, \text{ kWh/a} \qquad (3.1.)$$

The values of energy consumption of the three ventilation systems are summed up in Table 3.1.

Table 3.1. Comparison of energy consumption of the ventilation systems.

No.	Group	The 1st ventilation system, kWh	The 2nd ventilation system, kWh	The 3rd ventilation system, kWh
1.	A piggery for sows with piglets	212415.67 53.7%	395415.12 100%	48099.39 12.16
2.	A piggery for the weaned piglets	234454.23 52.9%	443282.34 100%	95365.91 21.5%
3.	A piggery for the fattening and breeding pigs	680841.42 46.1%	1477592.3 100%	199995.74 13.5%

The results obtained about the energy consumption in the systems of various air treatment devices in each piggery are demonstrated in the graph (Fig.3.4.).

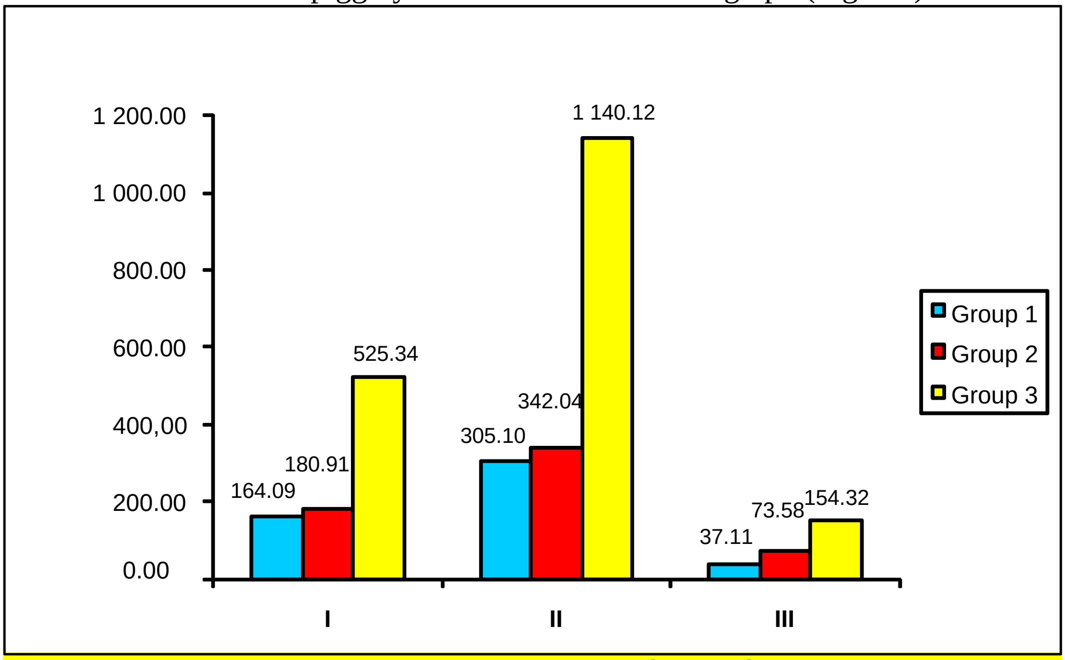

Fig.3.5. Annual consumption of energy of the 1st, 2nd and 3rd ventilation systems for each group of pigs per 1 m^2 of the floor area in the piggery during the heating period.

The air treatment devices are made and completed according to the needs of the animal houses. The set of the air treatment equipment is determined by the required parameters of the inlet air in the ventilated animal houses. The calculus of the energy consumption of the air treatment devices should include the desirable inlet air parameters, the outdoor and the outlet air parameters; the rated capacity of the heating section, the moistener section and ventilators; the data about the efficiency of the rotor and its rated capacity, the sequence of sections. The configuration of the air treatment devices in the piggery:

- heat utilisers: plate heat utilisers, regenerative heat utilisers; the type of the used energy – electricity;
- air heaters: electric or hot water air heaters; the type of the used energy – electricity;
- air moisteners: the source of energy – electricity, water;
- sorbtive air dryers;
- ventilators: the source of energy – electricity; the energy requirement depends on the characteristic curve of the ventilator, the overpowered resistance, the number of revolutions (Fig.3.6.).

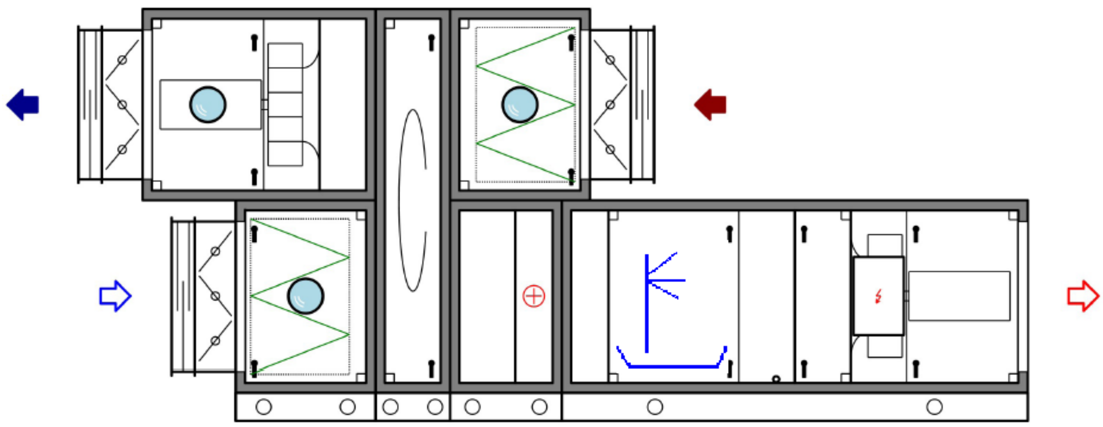

Fig.3.6. A possible configuration of the air treatment devices in a piggery.

4. Propagation of Bad Odours and Their Restriction

As a result of industrialisation of animal husbandry as well as the demographic changes, serious problems of coexistence have emerged in the rural territories. The main reasons of conflicts between the producers and their neighbours are pollution of the environment and bad odours coming from the animal houses, dung-yards and soil fertilisation. The environmental and social issues present the greatest problem now touched upon by the animal breeding complexes in Latvia as a result of which there arise conflicts in some regions between the population and the owners of pig production units.

The main reasons of bad odours in the animal houses are the great concentration of animals, evaporation from the bodies and dung. However concentration of production is a precondition for reaching good economic indicators. Only in large complexes it is possible to apply in a rational way modern technologies, mechanisation and automation. As a result of physiological processes of the pigs, carbon dioxide, sweat and specific evaporations are excreted through their skin, as well as from the dung (Fig.4.1.).

Fig. 4.1. The sources of bad odour emissions in pig breeding complexes.

The bad odours are thrown out through the ventilation system into atmosphere. The next stage where bad odours arise is dung transportation from the animal houses to the dung-yard and its emptying when the manure is spread on the field. In the piggeries the origin and propagation of bad odours is mostly affected by the behaviour of the pigs, the dung removal technology and the operation of the ventilation systems.
The methods for the minimisation of odour emission in the outlet air of the ventilation systems: chemical methods, biological purification methods, combined purification methods, air purification by means of active oxygen, mechanical methods, recycling into biogas. The costs of the air purification devices are high, which makes one weigh up the proportion between increasing the production costs, characteristic value of bad odour minimisation and environmental gains.

5. Advantages of Biogas Production in Environment Conservation and Economics

Biogas can be used in order to produce heat and electric energy. When heat is produced, biogas, like natural gas, is burned in furnaces using specially adapted, generally low-pressure or diffusion burners. There arise comparatively less harmful emissions, the nitrogen oxides of a well-equipped boiler are about 35–50 mg/MJ, which is approximately a half of that amount that arises when liquid fuel is burned. If biogas is used for burning in the furnace, it does not need any other purification but only removal of the condensate. In cases when the gas has high hydrogen sulphide content, it must be removed.

Biogas is mostly used in the cogeneration equipment which produces simultaneously electric energy and heat. The average distribution between heat and electric energy is: 35–41% electricity and 59–65% heat, and of it the total losses do not exceed 10%. There are more harmful emissions from the internal combustion engines than from the boilers but less than using liquid fuel. Before burning biogas must be dried, and usually a device is required also for the separation of hydrogen sulphide.

The main thing in the biogas production is that it is an environment-friendly, efficient waste recycling technology. Moreover, the recent sharp increase in the prices of energy resources has made biogas one of the most perspective resources of energy, also from only the energetic viewpoint. The biogas production technology or the anaerobic treatment of biomass gives the following economic effects:

1) economy of energy resources;
2) a more qualitative application effect of the fertiliser – higher crops because, when biogas is produced, a fertiliser of high quality is also obtained (of better quality than the non-fermented organic fertiliser);
3) reduced morbidity rate of the people and animals since the pathogenic microorganisms and helminths die in the process of anaerobic fermentation;

4) economy of herbicides and pesticides (e.g. the seeds of the weeds lose their germinating power in the fermented organic fertiliser);
5) reduced losses due to the pollution of nature;
6) autonomous energy provision (the effect of reliability and independence).

Conclusions

1. When a choice is made among adequate operation schemata and modes of ventilation systems, the dominating condition are the welfare (zootechnical) norms of the animals. In the area of the minimally allowed parameters it is necessary to ensure a limited “freedom of choice” among the operation schemata and modes in order to determine definite limits for the optimum energy consumption and minimum losses of the product.
2. A great deal of thermal energy and, hence, electricity can be saved by ensuring ventilation minimum through ventilators and by supplementing the system with the heat utilisation equipment. When turning to the choice of the schemata of the ventilation devices, a research in the trends of the newest technical solutions is required for the next 10 – 15 years.
3. The expedience of the heat provision processes in the production units of the farms is estimated in economic categories where the main importance is attached to non-energetic factors: saving of manpower, increase in the quality and quantity of the product.
4. The effect of individual heat provision processes cannot be determined because the non-energetic effect is much higher, e.g. heating the premises of the newly-born animals, which allows to retain essentially the number of the born piglets and ensures the growth of their live weight. According to the results of the research, ensuring optimal microclimate reduces the morbidity and loss of animals, raises productivity by 10 – 30% with simultaneous reduction in the fodder consumption by 15 – 25% per unit of the obtained product.
5. A methodology has been developed for the optimisation of energy consumption using the climatological data about the repetition frequency of various combinations of the outdoor air enthalpy, temperature and relative moisture, as well as energy consumption in various combined air treatment devices. A comparison is made according to the newly-developed methodology of the energy requirement for the heating season for various operation schemata of the air treatment devices. When applying this methodology to the piggery of a standard design, the energy consumption in the ventilation systems of different sets was reduced by 30% and 84%.
6. A correctly designed and completed ventilation system raises the pigs’ welfare to a maximum and reduces the energy input, and price. On the basis of the data about the energy consumption of the operation schemata of the air treatment devices, considering the states of the outdoor air parameters, the air treatment processes and the amount of energy required for the heating season have been estimated and graphically depicted in the h-x diagram. Graphical presentation of the air treatment processes gives a qualitative idea about the functioning of the system.
7. The developed methodology can be applied for:

- the comparison of the air treatment systems with different configurations and energy efficiency, expressed as energy consumption in the heating season;

- the estimation of the duration of operation of the system by the repetition frequency of the combinations of the climatological data allowing to choose an optimum air treatment device with an optimal capacity of the various components before the implementation of the design;
- the comparison of the efficiency of various combinations of the air treatment devices at the stage of designing.

8. The anaerobic manure fermentation during the biogas production process decreases the emission of bad odours and the content of pathogenic microorganisms in the manure. Organic waste can be additionally used increasing the output of biogas and making the production unit more profitable. Prevention or minimisation of the bad odours in order to fulfil the requirements set in the normatives of environmental protection.
9. Neither in Latvia, nor the EU is biogas sufficiently produced from the refuse products of agriculture and animal husbandry to obtain heat and electricity. Storing and using the animal manure under common conditions, a considerable amount of methane will emit; when biogas is collected by means of the gas utilisation equipment, the total methane emissions in agriculture will diminish.
10. When methane is burned, an effect occurs which is opposite to the hothouse effect as carbon dioxide is much less harmful than methane, but the energy obtained in the biogas oxidation process replaces the sources of fossil energy. Biogas production from manure gives not only cheap energy but also diminishes essentially the emission of the harmful gases from the ventilation devices into the surrounding environment.

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3. Turlajs D., Melko A., Rusovs D., Jaundalders S., Ramata A. Situation and Tendencies in Small Scale Combined Heat and Power (SSCHP) Generation in Latvia// 4th European Congress on Economics and Management of Energy in Industry. - Porto, (Portugal), 27-30. 11. 2007.- 5 p. On CD-ROM. (Referēts).
4. Kreslins A., Ramata A.. Measures of Energy Economy in Livestock Housing.// 5th European Conference „Economics and Management of Energy in Industry”. - Vilamoura, (Portugal), 14-17. 04. 2009.- 6 p. On CD ROM. (Referēts).
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6. Kreslins A., Ramata A. Energy Economy in Ventilating Systems of Livestock Housing// Proc. 10th REHVA World Congress „Sustainable Energy Use in Buildings – Clima 2010”. - Antalya, (Turkey), 9-12. 05. 2010.- 7 p. On CD ROM. (Referēts).