INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr 6/2008, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 51–61
Komisja Technicznej Infrastruktury Wsi
Commission of Technical Infrastructure of the Polish Academy of Sciences-Cracow Branch

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VERIFICATION OF THE EFFECTS OF THE SECONDARY HEAT RECOVERY FROM VENTILATION AIR IN AN ANIMAL HOUSE FOR THE FATTENING OF BROILER CHICKENS

Summary

This paper presents results of the verification of a heat exchanger composed of gravitation thermal pipes installed in a broiler chicken feeding facility. The objective of the study was to verify the possibility of the application of a power management system including a heat recovery system in a heavy-duty environment of a broiler chicken fattening facility and to specify effects of the system upon the specific consumption of energy for space heating and ventilation of the animal house.

The calculation of the thermal balance of the animal house documents that the power management system that includes a heat recovery exchanger unit may reduce the thermal capacity of external sources of heat in the animal house by 26.5% even when subject to extreme conditions and at the atmospheric temperature of -12°C and the age of chickens being 1 day.

The results of the metering and calculations of the efficiency have proven that the heat exchanger reaches the operational efficiency of 10–47% and thermal efficiency of 20–80% even during the most demanding operational first twenty days of the breeding cycle of broiler chickens.

The specific consumption of energy for space heating and ventilation related to 1 kg of the live weight of chicken in the animal house facility *A* provided with a heat recovery exchanger unit at the average atmospheric temperature during the cycle being 4.3°C amounted to 278.5 Wh. In the animal house *B* as not provided with the heat recovery exchanger units hosting the same number of chickens and provided with the same process and thermal loss due heat transmission through peripheral structures being one half compared to the animal house *A*, the specific consumption of energy per 1 kg of the live weight of chicken was 420.5 Wh.

Key words: animal house; broiler chicken; recovery heat exchanger; gravitation thermal pipe; exchanger efficiency; thermal balance; specific energy consumption

INTRODUCTION

The importance of power management systems for the recovery of heat from ventilation air in animal houses resides in a reduction of the consumption energy needed for heating, improvement of the quality of the animal house environment and protection of peripheral civil structures against their impairment due to condensation of air humidity on cold surfaces.

What is subject to operational testing abroad are first of all systems implemented in animal houses for mammals breeding (including pigs and beef-cattle). The reason is a high relative humidity of air and resulting possibility to make use of condensation heat contained in steam and also a less dusty environment compared to poultry breeding facilities

Plate counter-flow heat exchangers in animal houses for various pig categories were verified by staffs of Agricultural Engineering Department, North Dakota State University, U.S.A. What they metered was the efficiency of the heat exchanger of up to 49%. Higher efficiency was found at condensation of water steam from the extracted air. High level of dustiness in the suckling pig after-breeding section caused that the heat transmission coefficient used to drop on a polluted plate of the heat exchanger from 6.87 $W \cdot m^{-2} \cdot K^{-1}$ to 5.90 $W \cdot m^{-2} \cdot K^{-1}$. The heat transmission coefficient in the sow farrowing house dropped from 4.88 $W \cdot m^{-2} \cdot K^{-1}$ to 2.84 $W \cdot m^{-2} \cdot K^{-1}$ (Vassilakis, Lindley, 1993) after the deactivation of a fan supplying atmospheric air.

Staffs of Latvia University of Agriculture checked a plastic plate exchanger with the heat transmission area of 100 m^2 in an animal house for the fattening of 500 pigs. They proved the operability of the system and a reduction of the consumption of energy up to the atmospheric air temperature of -20°C [Ilsters, Kancevica, Ziemelis 2006].

Experience with the application of a cross-current plate exchanger in a pig breeding facility was published by staffs of Les Consultans BPR, Province of Quebec, Canada. The study concentrated first of all on the efficiency of the production. The daily increments grew by 5% [Lord, Dutil, Chagnon 1989] in the pig breeding house thanks to a better quality of the environment.

A plate exchanger with a PVC heat transmission surface was checked by staffs of Department of Agricultural Engineering, University of Alberta, Canada, in a broiler chicken breeding facility [Kennedy, Leonard, Feddes 1991]. The average inflow of air was 0.565 $m^3 \cdot s^{-1}$ and the average efficiency of the plate exchanger was 38 %. According to an economic analysis, the return of the investment was three years given the local conditions.

An important and inevitable condition of the analysis of the technical, organizational and other measures aimed at reducing costs of heating is the knowledge of the specific consumption of energy. We are missing such knowledge for broiler chicken breeding facilities despite the broiler chicken breeding business belongs to the most energy demanding operations among poultry industry activities in terms of energy and ventilation. As to foreign literature, we have found only a publication of Harold and Jones [1983] where the authors specify the specific consumption of energy of the fattening of broiler chickens in natural animal facilities implemented in north and north-west regions of the U.S.A. within the range of 2,106 – 2,178 Wh/chicken. However, the publication does not specify any technological lines and climatic conditions of such facilities. In a publication by Adamovský *et al*. [1999], we presented results of the metering of specific consumption of energy in a standard animal house and a natural facility of the type of LUISIANA. The mean consumption of energy as needed for the heating in 6 monitored cycles amounted to 2,950 Wh/chicken in the standard animal house and 2,277.78 Wh/chicken in the natural facility.

A low level of the knowledge of the possibility of the application of quality recovery heat exchanger units in such facilities and the impossibility of an unbiased assessment of their effects inspired us to specify the objectives of this study: To verify the possibility of the use of a heat recovery power management system in a demanding operational environment of broiler chicken fattening facilities and to specify effects of the system upon the specific consumption of heat for heating and ventilation of the animal houses.

METHODS

Our metering took place in an animal house for the fattening of 13,000 broiler chickens with the floor plan 58 x 10.8 m and the gable height of 3.2 m. The calculation atmospheric temperature in this region is -12°C. The temperature, humidity and concentration of pollutants in the interior of the animal house matched in the course of individual phases of the breeding cycle of broiler chickens to the values specified by Ross Breeders UK and Xaverov, a.s. Prague. For the flow chart of the ventilation and heating system see the fig. 1. Air heated in recovery exchangers (1) was distributed to the animal house by a perforated sleeve (2) with the diameter of 800 mm. Air was extracted from the animal house by two fans installed in the bottom part of the exchanger (5). Axial fans (3) and closable openings (4) made it possible to upgrade the intensity of the ventilation of the animal house inn summer time.

Both heat recovery exchangers were set up of aluminum lamella gravitation thermal pipes of the diameter of 35 mm (lamella diameter being 62 mm) and of the length of 1960 mm filled with ammonia. The heat exchanger consisted of 100 thermal pipes configured in 10 rows. What was installed at the side of the extraction or air from the animal house upstream heat exchanger surfaces of the evaporation element of thermal pipes, were unwoven cloth filters, thickness 3 mm. The filters were supposed to protect the heat exchanger surfaces against formation of dust scales coming from dry feed, small feather particles and wooden chips from the bedding. 15 electrical infra-radiators were installed in the animal house with the capacity of 600 W·ks^{-1} and one gas-fired warm-air set with the capacity of 20 kW. These sources used to create comfortable ambience conditions for small chickens and work as peak hour or substitute sources of heat. At the beginning of the cycle, chickens were bred on 45% of the area of the animal house that was separated by a curtain from the rest of the house. This way, a significant reduction of thermal losses due to heat transmission through civil structures was achieved. Both heat recovery exchangers were used in the beginning of the breeding cycle, too.

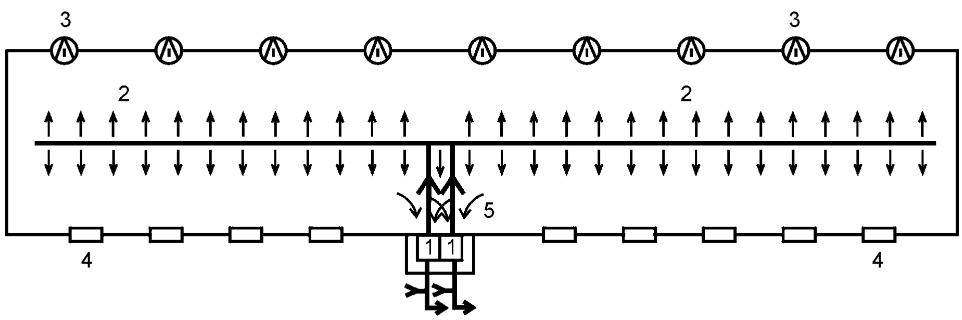

Figure 1. Animal house HVAC system flow chart: 1. Heat recovery exchanger of gravitation thermal pipes; 2. Foil sleeve for the distribution of heated outside air; 3. Axial fan; 4. Closable openings for the supply of atmospheric air; 5. Extraction of air from the animal house

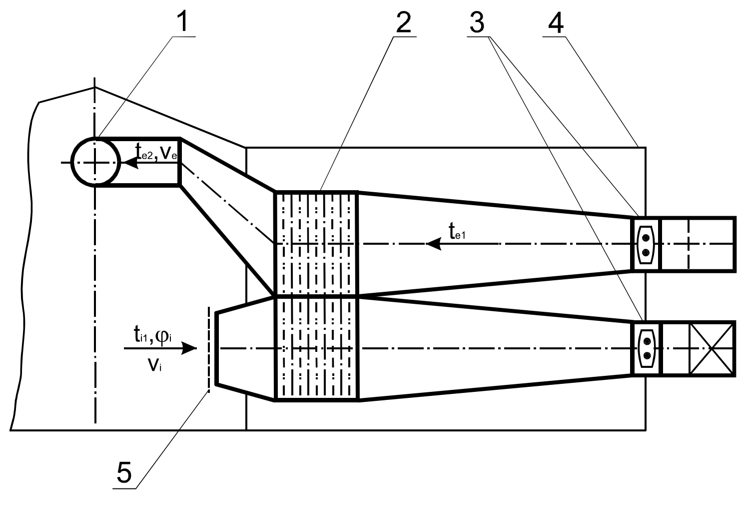

Figure 2. Drawing of the installation of the heat recovery exchanger and meters: 1. Foil sleeve for the distribution of heated atmospheric air; 2. Heat recovery exchanger consisting of thermal gravitation pipes; 3. Axial fan; 4. Annex for the heat recovery exchanger; 5. Filter

What was measured according to the flow chart 2 for the efficiency calculation of the heat recovery exchanger was:

- Temperatures t_{i1}, t_{e1}, t_{e2},
- Flow rates v_i, v_e,
- Relative humidity of extracted air φ_{i1}.

The layout design of the HVAC distribution systems did not make it possible to measure the air temperature t_{i2} behind the evaporation section of the exchanger.

The efficiency of heat recovery exchangers was thoroughly analyzed first of all in the first ten days of the breeding cycle when the volume flows of air through the exchanger were limited and the air contained lots of dust and fluff. At the beginning of the metering process, the average weight of the chickens was 35 g·ks^{-1}, at the end it was 510 g·ks^{-1}. The thermal balance was established using the following equation (ČSN 02 0210, ČSN 73 0543-2):

$$Q_p + Q_v - Q_c - Q_t = 0 \quad [W] \tag{1}$$

where:

Q_p – thermal loss by the transmission of heat through peripheral civil structures [W],
Q_v – thermal loss due to forced ventilation [W],
Q_c – thermal gains generated by animals (after the deduction of the power needed to evaporate water) [W],
Q_t – thermal capacity of the external source [W].

Thermal power Q_R recovered from the extracted animal house air and reused for the warming of the atmospheric air, so called recovered thermal power was calculated based on the following equation:

$$Q_R = V_e \left[\left(\rho_{e2} \cdot c_{pe2} \cdot t_{e2} \right) - \left(\rho_{e1} \cdot c_{pe1} \cdot t_{e1} \right) \right] \quad [W] \tag{2}$$

If the following equation applies:

$$Q_R > Q_{i,r} = V_i \cdot c_{pi1} \cdot \rho_{i1} \left(t_{i1} - t_{i1,r} \right) \quad [W] \tag{3}$$

at

$$V_i > V_e \quad \left[m^3 \cdot s^{-1} \right] \tag{4}$$

Air extracted from the animal house is cooled bellow the animal house air dew point temperature $t_{i1,r}$ and partial condensation of water in extracted animal house air starts on the exchanger surface. Then we calculated the efficiency of the heat exchange using the following equation (Adamovský *et al.*, 1996):

$$\eta_{R,h} = \frac{h_{e2} - h_{e1}}{\frac{V_i \cdot \rho_{i1}}{(1 + x_{i1})} \cdot \frac{(1 + x_{e1})}{V_e \cdot \rho_{e1}} \cdot h_{i1} - h_{e1}} \quad [-] \tag{5}$$

If the equation $Q_R < Q_{i,r}$ at $V_i > V_e$ applies, we calculated the fictive temperature t_{i2} from the equation:

$$V_i \cdot \rho_{i1} \cdot c_{pi1}(t_{i1} - t_{i2}) = V_e \cdot \rho_{e1} \cdot c_{pe1}(t_{e2} - t_{e1}) \quad [W] \tag{6}$$

We compared the calculated temperature t_{i2} to the temperature $t_{i1,r}$. If $t_{i2} > t_{i1,r}$ was valid, we presumed that extracted animal house air was not cooled below the dew point temperature $t_{i1,r}$ and we calculated the efficiency of the exchanger using the equation (Adamovský *et al.*, 1996):

$$\eta_{R,t} = \frac{t_{e2} - t_{e1}}{\frac{V_i \cdot \rho_{i1} \cdot c_{pi1}}{V_e \cdot \rho_{e1} \cdot c_{pe1}} \cdot t_{i1} - t_{e1}} \quad [-] \tag{7}$$

In the equations (2) through (7):

V – is the volume flow of air [$m^3 \cdot s^{-1}$],

ρ – is the specific weight of air [$kg \cdot m^{-3}$],

c – is the specific thermal capacity of air at a constant pressure [$J \cdot kg^{-1} \cdot K^{-1}$],

h – is the specific air enthalpy [$J \cdot kg^{-1}{}_{da}$],

x – is the specific air humidity [$kg \cdot kg^{-1}{}_{da}$].

Values of condition and other thermodynamic quantities of wet air used in the calculations were established using the publication Vitázek (2006).

The consumption of electrical energy of the building was measured continuously by calibrated instruments in the course of breeding cycles.

RESULTS AND DISCUSSION

1. *Animal house thermal balance*

a) One-day old chickens, required ambience temperature in the animal house t_i = 26°C, calculated atmospheric temperature t_e = -12°C; 45 % of the area of the animal house.

Calculations executed subject to ČSN 06 0210 and ČSN 73 0543-2 suggest that Q_p = 17715 W; Q_c = 12901 W; Q_v = 12101 W. Then, the equation (1) Q_t = 16915 W applies.

What corresponds to the volume flow V_i = 0.26 $m^3 \cdot s^{-1}$ as needed for the removal of CO_2 according to laboratory metering (Adamovský et al., 2005) is the efficiency of the gravitation thermal pipe heat recovery exchanger η_R = 0.37. Then, the recovered power $Q_R = \eta_R \cdot Q_v$ = 4477 W. The thermal loss due to forced ventilation using the heat recovery exchanger $Q_{v,R} = Q_v - Q_R = 7624$ W. The required thermal power of external sources of heat, using recovery heat exchangers will drop to $Q_{t,R} = 12438$ W. The thermal power of installed external sources is $Q_{t,z} = 9000$ W (electrical infra radiators) and $Q_{t,a} = 20000$ W (gas-fired warm air set). The above thermal balance documents that even in extreme conditions, subject to an extraordinarily low atmospheric temperature and one day old chickens, the power management system with a heat recovery exchanger will reduce the thermal power of external sources of energy by 26.5 %. At the same time, the results of the calculations confirmed the necessity of the installation of external peak heat sources.

b) 20-day old chickens $t_i = 23$°C, $t_e = -12$°C, the entire area of the animal house.

The calculations based on ČSN 06 0210 and ČSN 73 0543-2 suggest that $Q_p = 34085$ W; $Q_c = 89708$ W; $Q_v = 74195$ W. Then, the equation (1) $Q_t = 22259$ W applies.

The volume flow for the removal of CO_2 at the average weight of chickens 0.51 $kg \cdot ks^{-1}$ is 1.34 $m^3 \cdot s^{-1}$. What corresponds to this volume flow is the efficiency of the heat recovery exchanger measured in the laboratory $\eta_R = 0.27$. What stems from the previous sentences is that $Q_{t,R} < 0$ given this weight of chickens and the anticipated efficiency of the exchanger. Thus, the external sources of heat need not be used.

2. *Efficiency of the heat recovery exchanger*

Table 1 shows results of the metering of the heat recovery exchanger made of gravitation thermal pipes during the most demanding first days of the breeding cycle of broiler chickens. Moreover, there are operational efficiency values of the exchanger η_R calculated based on measured values and the recovered thermal power Q_R. What applies to the metering values No. 1 through No. 18 is $Q_R > Q_{i,r}$. Thus, air extracted from the animal house is cooled below its dew point temperature and a partial steam condensation takes place. The efficiency of the exchanger may be calculated using the equation (5). What applies in the metering values No. 19 and 20 is $Q_R < Q_{i,r}$. Air from the animal house is cooled down in the heat exchanger above the dew point temperature. The efficiency of the exchanger may be calculated using the equation (7). The sudden rise in the efficiency of the heat exchanger in the days 6, 11 and 18 of the operation was due to cleaning of the filter of air extracted from the animal house. The fouling of the filter significantly affected the efficiency of the exchanger. In the first 5 days, the efficiency of the exchanger used to drop by 4.4 % per 24 hours due to the fouled filter.

Table 1. Results of the metering of the gravitation thermal pipe heat recovery exchanger

Operation day	t_{i1} [°C]	φ_{i1} [-]	t_{e1} [°C]	t_{i2} [°C]	V_i [$m^3 \cdot s^{-1}$]	V_e [$m^3 \cdot s^{-1}$]	η_R [-]	Q_R [W]
1	24.5	0.62	22.8	4.5	0.18	0.17	0.47	3752
2	24.2	0.68	20.2	2.7	0.18	0.17	0.40	3547
3	25.0	0.58	19.2	6.5	0.18	0.17	0.36	2604
4	25.4	0.61	16.7	4.6	0.18	0.17	0.30	2481
5	25.2	0.64	15.7	5.4	0.18	0.17	0.25	2112
6	25.0	0.68	18.6	1.9	0.18	0.17	0.36	3424
7	25.7	0.70	14.8	0.6	0.27	0.23	0.25	3939
8	25.3	0.68	15.2	2.8	0.27	0.23	0.24	3440
9	26.1	0.67	17.6	1.8	0.40	0.28	0.23	5335
10	25.4	0.68	13.7	2.1	0.40	0.28	0.17	3917
11	25.5	0.61	15.2	2.4	0.40	0.28	0.20	4322
12	24.0	0.72	14.7	3.7	0.52	0.34	0.16	4510
13	24.4	0.74	14.5	5.2	0.52	0.34	0.14	3813
14	23.9	0.76	12.8	4.0	0.64	0.47	0.14	4988
15	23.9	0.72	10.4	2.6	0.79	0.59	0.13	5550
16	22.8	0.74	6.3	-1.7	0.79	0.59	0.13	5692
17	23.1	0.76	8.0	-0.3	0.79	0.59	0.13	5906
18	25.2	0.70	11.7	1.4	0.79	0.59	0.16	7329
19	24.1	0.72	9.4	3.1	1.13	0.75	0.20	5698
20	24.3	0.77	9.7	7.6	1.13	0.75	0.10	1899

The measured values of the average daily efficiency of the heat exchanger (η_R = 0.10 – 0.47) are relatively low. However, they match the values given in foreign publications. At the broiler chicken fattening station VEB KIM Königs – Wüsterhausen, an exchanger of 48 gravitation thermal pipes 2 m long configured in 8 rows was subjected to a study [Hettwer, Bath 1982]. Given the air velocity of 3 $m \cdot s^{-1}$, the measured thermal capacity was 43%. Our metering monitored the actual operational efficiency that is lower than the thermal efficiency in particular if $V_i/V_e > 1$ applies. The thermal efficiency of the heat exchanger we verified ranged from 20 to 80%. Higher levels of the operational efficiency were achieved when verifying the exchanger of gravitation thermal pipes in an animal house used for the breeding of porkers up to the weight of 30 kg [Kára, Šulc 1989]. The heat exchanger worked at $V_i = V_e$ and temperature differences $t_{i1} - t_{e1}$ = 4.4 – 6.3 K. These facts resulting from the nature of the operation and climatic conditions significantly affected the values of the operational efficiency that used to range from 43 to 48 %. An analysis of the results of the verification indicates that any higher values of the operational efficiency cannot be achieved at high differences of the ambience and atmospheric temperature and high quotient of V_i/V_e.

3. *Specific energy consumption*

The specific consumption of energy for the heating and ventilation of animal houses were monitored in two cycles lasting from February 27 to April 9 (42 days) and from April 28 to June 12 (46 days). Compared were the specific consumption values of energy in the facility *A* on the ground floor with installed recovery heat exchangers and in the facility *B* on the floor 1 operated without any such heat recovery exchangers. The thermal losses due to heat transmission through peripheral civil structures in the facility *B* amounted to 50% of the thermal loss due to heat transmission in the facility *A*. The numbers of chickens in both facilities were identical as well as the feeding technology and quantities of feed given to chickens. The mutual confrontation of the specific energy consumptions in the facilities *A* and *B* is not relevant, it is just an informative value. The Table 2 shows processed results of the monitoring of specific consumption of energy for heating and ventilation converted to 1 kg of live weight of chicken and 1 chicken at the conclusion of the breeding cycle.

Table 2. Specific consumption of energy for the heating of the animal house

	Cycle I		Cycle II	
	A	*B*	*A*	*B*
Chicken age [day]	42	42	46	46
Average weight input/output [g]	35/1600	35/1320	42/1770	42/1770
Average atmospheric temperature during the cycle [°C]	4.3	4.3	12.8	12.8
Average consumption of electrical energy per 1 chicken [Wh]	377.8	491.7	408.3	538.9
Average consumption of gas per 1 chicken [Wh]	63.9	63.9	63.9	0
Average consumption of total energy per 1 chicken [Wh]	441.7	555.6	472.2	538.9
Average consumption of electric energy per 1 kg of live weight of chicken [Wh]	236.1	372.2	230.5	297.2
Average consumption of gas per 1 kg of live weight of chicken [Wh]	39.7	48.3	35.8	0
Average consumption of total energy per 1 kg of live weight of chicken [Wh]	275.8	420.5	266.3	297.2

A confirmative quantity showing the specific consumption of energy for the fattening of broiler chickens is in particular he consumption per 1 kg of live weight of chickens at the conclusion of the cycle. Given the average atmospheric air temperature of 4.3°C during the breeding cycle in the facility *A,* the specific consumption of energy for heating and ventilation of the facility *A* was 275.8 Wh·kg^{-1}. That equals to 65.6% of the specific consumption of energy for the facility *B*. Given the atmospheric temperature of 12.8°C, the specific consumption for heating in the facility *A* is 89.6% of the specific consumption of energy in the facility *B*. A lower energy saving value at higher atmospheric temperatures is given mainly by a lower thermal loss due to forced ventilation and, therefore, a lower recovered thermal power Q_R.

The values of specific consumption measured are lower than the values given in literature. For instance, the paper by Harold and Jones [1983], gives the specific consumption of energy for heating and ventilation of a broiler chicken fattening facility in southern regions of the U.S.A. of 881 Wh·kg^{-1} and in northern regions of the U.S.A. of 1348 Wh·kg^{-1}. Unfortunately, the respective studies do not specify prevailing climatic conditions. In the paper [Adamovský and Neuberger 1999], we specify the specific consumption as for heating and ventilation of a broiler chicken fattening station that is 1772 Wh·kg^{-1} for a region with the calculation atmospheric temperature of -15°C.

Lower specific consumption values are affected in that case by higher atmospheric air temperatures during the breeding cycle. Still, the results of the verification documented a significant positive influence of heat recovery exchangers upon the specific consumption of energy.

CONCLUSION

The results of the verification of the heat recovery exchanger of gravitation thermal pipes confirmed realistic opportunities for their application in the demanding environment of broiler chicken fattening facilities.

Evaluation proved reduction of the installed capacity of external sources of thermal energy, the operational efficiency of the heat exchanger and the need of filters installation of extracted air from the animal house. Moreover, the study verified positive impact of the application of the heat recovery exchanger upon the specific consumption of energy for heating and ventilation of the animal house. It would be interesting and important for the practical operation to verify the operation of the power management system with heat recovery exchangers at low atmospheric air temperatures.

This paper has been developed with support of the research project GACR 103/08/P358: Efficiency evaluation method of heat recovery equipments in ventilation systems concerning the method based on exergy of heat flows.

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