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Economic Analysis of Rotary Heat Regenerator using Waste Room Air

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Abstract: In this paper economic analysis of the rotary heat regenerator in air – conditioning systems is presented. Evaluation of heat savings, which depend on weather temperatures, was made on the basis of curve of sum of days with average daily temperatures for last ten years in central Europe. A method of net present values (NPV) was used for the calculation of investments into heat regenerator installation, including payback time and profitability coefficient. The results show us that costs are low, yielding very short payback time (6.8 month) and high profitability (7.1).

Key-Words: Rotary heat regenerator, Heat regeneration, Heating systems, Daily temperature, Net present value method

1 Introduction
Nowadays, many efforts regarding energy savings rise due to large environmental problems and declining energy sources. Among options of such renewable sources, there are also much potential to reuse the heat by applying different regeneration systems [1].

For instance, more and more rooms and halls in private, public and industrial buildings are ventilated in order to satisfy standards for healthy living space [2]. Because of this a great amount of heat is wasted, which could be reused for heating of the fresh air by application of rotary heat regenerators.

Rotary heat regenerator is a heat exchanger which consists of massive honeycomb rotating in counterflows of the warm waste and the cold fresh air [3]. It operates with laminar regime of flows to prevent fouling by dry particles while the reversal of flow direction enables self – cleaning. Filtration of the effluent air is usually not required except when it contains adhesive particles and particles larger than 300 μm.

Considering the made of heat transfer, there are two types of such regenerators: condensation and enthalpy one.

Condensation regenerators are used not only for heat regeneration but also for the regeneration of the moisture, which condenses on cold surfaces of the rotating medium in contact with waste air and then evaporates into the fresh one.

The efficiency of heat exchanger is about 70% and depends on the type and size of regenerator, the flow rate of air and the rotation speed, which is adjusted on constant value or regulated automatically according to input temperatures.

2 Climatic parameters
Heat savings in a ventilating system with regenerator depends on the temperature of outside air and are calculated from curve of sum of days with average daily temperature for appointed climatic area.

Figure 1 presents distributions of mean daily temperatures in Maribor city through the period of years 1995 to 2004.

The average daily temperature, T_a, is calculated from three measurements per day (at 7 am, 3 pm and 9 pm) [4] by following formula:

$$T_a = \frac{T_7 + T_{14} + 2T_{21}}{4} \tag{1}$$

The curve of sum of days with average daily temperatures consists of three characteristic regions.

The first part of the curve comprises the region of lowest temperatures including the interval T_a =

271K to T_a = 275K. The third part involves the region of the highest temperatures, T_a = 290K to T_a = 294K. For these regions we can use the exponential relationships:

$$z = a_1 + b_1 \cdot \exp\left[c_1 \cdot (T_a - 273\text{K}) \right] \tag{2}$$

$$z = a_3 + b_3 \cdot \exp\left[c_3 \cdot (T_a - 273\text{K}) \right] \tag{3}$$

The second part comprises linear relationship with temperatures between T_a = 275K and T_a = 294K.

$$z = a_2 + b_2 \cdot (T_a - 273\text{K}) \tag{4}$$

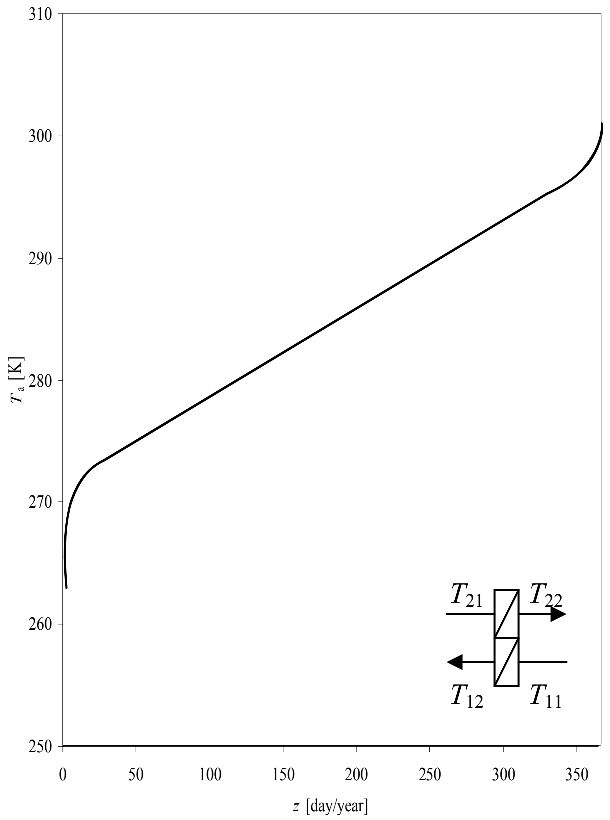

Figure 1: The curve of sum of days with average daily temperatures, T_a
T_{11} – input temperature of waste air
T_{12} – output temperature of waste air
T_{22} – output temperature of fresh air
T_{21} – input temperature of fresh air

Constants in relationships (2), (3) and (4) were determinate manually from slopes of the curve and are presented in table 1.

Table 1: Constants in equation (2), (3) and (4)

Constants	Value
a_1	1.6237
b_1	54.5679
c_1	0.4172
a_2	42.3333
b_2	13.9475
a_3	366.6783
b_3	- 2780249600
c_3	- 0.8632

3 Effectiveness of heat recovery

Degree of heat recovery for waste air is defined as:

$$\eta_1 = \frac{T_{11} - T_{12}}{T_{11} - T_{21}} \tag{5}$$

and for fresh air as:

$$\eta_2 = \frac{T_{22} - T_{21}}{T_{11} - T_{21}} \tag{6}$$

The surface S_1 on figure 2 presents heat savings achieved by the rotary heat regenerator.

Annual temperature number S_1 is the difference between the surfaces got by the integration of equations (2), (3), (4) and integration of equations (2), (3), (4) and (6) on the lower and upper borders, which are given with approximation and are presented in table 2. Surface S_2 above the curve of sum of days with average daily temperature of fresh air in the room T_{22} and an average daily temperature of waste air in the room T_{11} presents lost heat energy.

Results of the integration are given in table 3.

Table 2: Integral border

Lower border of 1st integral	261K
Upper border of 1st integral	271K
Lower border of 2nd integral	271K
Upper border of 2nd integral	295K

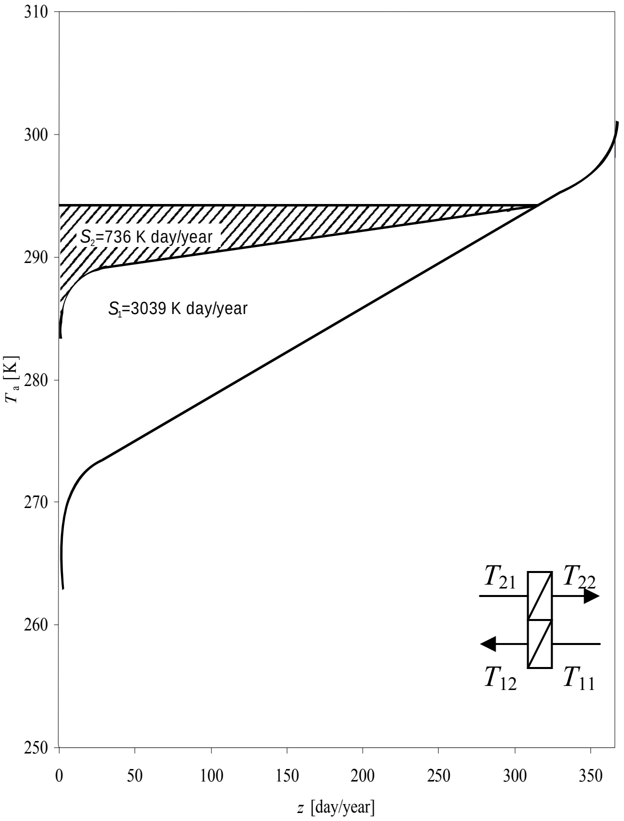

Figure 2: The curve of sum of days with average daily temperatures, T_a
S_1 - annual temperature number for 70% efficiency

Table 3: Annual operational characteristic

	Heat season	Entire year
Operating time (day/year)	192	250
Recovered energy (K day/year)	2557	3039
Lost energy (K day/year)	619	736

4 Net present value (NPV) method

Investment decisions are the most important business decisions for a company, because they influence the economy and development of the company on long term [5].

The economical profitability for the investment into heat regenerator was established with the method of net present values (NPV) considering the inflation rate. The investment is acceptable if NPV is greater than zero and not acceptable when NPV is negative.

In order to arrive at correct rotary regenerator profitability estimates it is necessary to make a clear distinction between a reconstruction and a grass – roots project which involves the costs of the entire heating and cooling systems [6].

Investment can be financed from the owned capital, loans or both. Present value of investment cost - c_1 is given with annuity discounting with equation

$$c_1 = c_o + \sum_{j=0}^{N} \frac{a_n \cdot c_{iz}}{(1+r)^j} \tag{7}$$

Where are:
c_0 - investor proper fund
c_{iz} - exchanger price
r - discount rate
a_n - annuity factor
N - regenerator operating time

Annuity factor - a_n is given with equation:

$$a_n = \frac{r_a \cdot (1+r_a)^{n_1}}{(1+r_a)^{n_1} - 1} \tag{8}$$

Where are:
r_a - annuity discount degree (must be equal or less than inflation rate, because of investment profitability)
n_1 - annuity pay time period

Maintenance costs for heat regenerator is present - c_2 are estimated up to 2% of the total investment. NPV of costs regarding inflation are given with equation.

$$c_2 = \sum_{j=0}^{N} \frac{0.02 \cdot c_{iz} \cdot (1+r_j)^j}{(1+r_j+r)^j} \tag{9}$$

Where is:
r_j - inflation rate

Electric power is consumed for fan and rotor. NPV of costs of electric power for fen - c_3 is determined by equation:

$$c_3 = \sum_{j=0}^{N} \frac{c_e \cdot (q_v p_v + q_{iz} p_{iz}) \cdot t_1 \cdot t_2 \cdot (1 + r_j)^j}{1000 \cdot \beta_v \cdot (1 + r_j + r)^j} \qquad (10)$$

Where are:
c_e - price of electric power
q_v - fresh air flow rate
q_{iz} - waist air flow rate
p_v - pressure drop of fresh air
p_{iz} - pressure drop of waist air
t_1 - operating time of regenerator in hours per day
t_2 - operating time of regenerator in days per year
β_v - fan efficiency

NPV of costs of electric power for electromotor - c_4 are defined by equation:

$$c_4 = \sum_{j=0}^{N} \frac{P_e \cdot t_1 \cdot t_2 \cdot (1 + r_j)^j}{\beta_e \cdot (1 + r_j + r)^j} \qquad (11)$$

Where are:
P_e - electromotor power
β_e - electromotor efficiency

NPV of heat savings from condensing rotary regenerator - c_5 considering inflation and annuity discounting are given with equation:

$$c_5 = \sum_{j=0}^{N} \frac{q_v \cdot \rho \cdot c_p \cdot S_1 \cdot c_t \cdot t_1 \cdot t_2 \cdot 10^{-3} \cdot (1 + r_j)^j}{365 \cdot (1 + r_j + r)^j} \qquad (12)$$

Where are:
ρ - air density
c_p - air specific heat
c_t - price of heat
S_1 - annual temperature number

NVP of heat saving regarding investment and maintenance costs; also costs for electric power - c_s are given with equation:

$$c_s = c_5 - (c_1 + c_2 + c_3 + c_4) \qquad (13)$$

Investment successfulness is estimated with profitability coefficient:

$$K = \frac{c_5}{c_1 + c_2 + c_3 + c_4} \qquad (14)$$

Profitability coefficient - K presents a ratio between NPV savings and NPV of all costs.

Investment profitability depends on operating time, on which the amount of saved energy depends. Minimum operating time of the regenerator is the time, when NPV is zero.

Another criterion for investment successfulness is payback period which presents the operating time that in which initial capital expenditure is recovered.

4.1 Economic efficiency of ventilating system

A profitability evaluation of the reconstruction of air – conditioning system by installing heat regenerator as an example of the presented NPV method is presented in this section. The following data have been used:

- fresh and waste air flow
  $q_v = q_{iz} = 2.5$ m^3/h, ($\rho = 1.2$ kg/m^3, $c_p = 1$ kJ/kgK)
- regenerator efficiency $\beta = 70\%$
- pressure drop of fresh and waste air
  $p_v = p_{iz} = 150$ Pa
- electromotor efficiency $\beta_e = 70\%$
- electromotor power $P_e = 0.4$ kW
- price of electric power $c_e = 0.07$ EUR/kWh
- heat price $c_t = 58$ EUR/MWh
- fan efficiency $\beta_v = 70\%$.

Regenerator costs $c_{iz} = 4200$ EUR (investor has $c_o = 830$ EUR of proper found, the rest he gets as bank credit, which is paid in $n_1 = 5$ years, with $r = r_a = 7\%$ discount rate and $r_j = 1.2\%$ inflation rate).

Lifetime of the rotary heat regenerator is N =15 years, maintenance costs up to 2% of total investment. The daily operating time is $t_1 = 24$ h/day, $t_2 = 250$ days/year. Calculated annual temperature number is $S_1 = 3039$ K day/year.

The results are: fan needs 648 kWh and electromotor 3428 kWh in 15 years, so 149 MWh of energy can be saved.

Costs and savings (enlarged for 1.2% inflation rate) in fifteens years are given in table 4. NPV and present values are given in table 5.

According to these result, after 15 years NPV of energy savings is 68302 EUR including all investment, maintenance and operating costs.

Profitability coefficient is 7.1. This means that NPV of savings are 7.1 times larger than NPV of all costs.

Table 4: Costs and savings in fifteens years (1.2% inflation rate)

N	c_2	c_3	c_4	c_5
0	84.0	450.0	240.0	8692.7
1	85.0	455.4	242.9	8797.0
2	86.0	460.9	245.8	8902.5
3	87.1	466.4	248.7	9009.4
4	88.1	472.0	251.7	9117.5
5	89.2	477.7	254.7	9226.9
6	90.2	483.4	257.8	9337.6
7	91.3	489.2	260.9	9449.7
8	92.4	495.1	264.0	9563.1
9	93.5	501.0	267.2	9677.8
10	94.6	807.0	270.4	9793.9
11	95.8	513.1	273.7	9911.5
12	96.9	519.3	276.9	10030.4
13	98.1	525.5	280.3	10150.8
14	99.3	531.8	283.6	10272.6
15	100.5	538.2	287.0	10395.9

Table 5: Net present values

N	c_1	c_2	c_3	c_4	c_5	c_S
0	830	0.0	0.0	0.0	0.0	-830
1	768	78.6	421	225	8130	6638
2	718	73.5	394	210	7604	6209
3	671	68.7	368	196	7112	5808
4	627	64.3	344	184	6652	5433
5	586	60.1	322	172	6221	5082
6	0.0	56.2	301	161	5819	5301
7	0.0	52.6	282	150	5443	4958
8	0.0	49.2	264	141	5091	4637
9	0.0	46.0	247	132	4761	4337
10	0.0	43.0	231	123	4453	4057
11	0.0	40.2	216	115	4165	3794
12	0.0	37.6	202	108	3896	3549
13	0.0	35.2	189	101	3644	3319
14	0.0	32.9	176	94.1	3408	3105
15	0.0	30.8	165	88.0	3188	2904
NPV	4200	769	4120	2197	79589	68302

It is necessary to take into account the operating time of regenerator, because the most of energy is saved in heating season. If regenerator operates 250 days/year and just 1.55 h/day, the payback time of investment is 6.8 month.

5 Conclusion

Heat savings depend on temperature difference between waste and fresh air. Temperature distribution of fresh outside air depends on season as well as the climatic area. Consequently, the curve of sum of days with average daily temperatures was taken as a basis for the evaluation of the investment profitability, payback time, maintenance and operating costs for the heat regenerator.

Results show that from total amount of 3775 K day/year needed for heating, regenerator saves 3039 K day/year.

The investment is economically justified. The costs for regenerator are relative low and payback time is less than one year, but it would be a little bit longer in the case that the device starts to operate out of heating season.

From NPV savings it can be seen, that the savings in fifteens years are nineteen times larger than the investment into regenerator.

The analysis has indicated that it is reasonable to use heat regenerators in ventilating systems, because much less energy is used and also as a contribution to environmental protection.

References:

[1] A. Misirlioglu, U. Gulcat, Modified displacement ventilation of rooms with chilled ceilings and ceiling mounted devices, *WSEAS Heat and Mass Transfer*, August 2004

[2] P. Karthikeyan, K. Muraldiharan, Anand Samuel, Simulation of room air conditioning strategies for hospital operation theatres, *WSEAS Heat and Mass Transfer*, January 2005

[3] O. Levenspiel, *Engineering Flow and Heat Exchange*; *Revised Ed.,* Plenum Press, 1998

[4] Hydr-ometeorologic station of Maribor, Tržaška cesta 26, Slovenia

[5] M. Kurtz, *Calculations for Engineering Economic Analysis*, McGraw Hill, New York, 1995

[6] D. L. Allen, *A guide to the economic evaluation of projects institution of chemical engineers*, Zürich, 1980