Solutions for optimizing the operation of energy recovery in ventilation systems

Soluții pentru optimizarea funcționării recuperării energiei în sistemele de ventilație

Marius Adam[1], Adriana Tokar[1], Alexandru Dorca[1], Dănuț Tokar[1], Daniel Muntean[1], Vera Guțul[2]

[1]Universitatea Politehnica Timișoara,
Piata Victoriei Nr.2, 300006 Timisoara, Romania
[2]Universitatea Tehnică a Moldovei,
Bd. Ștefan cel Mare, 168, Chișinău, Moldova, MD-2004
E-mail: marius.adam@upt.ro, adriana.tokar@upt.ro, alexandru.dorca@upt.ro, danut.tokar@upt.ro,, daniel-beniamin.muntean@student.upt.ro, vera.gutul@acagpm.utm.md

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Abstract. *Energy efficiency norms require effective insulation techniques for buildings in order to minimize energy consumption. The paper presents simulations, carried out throughout the year, regarding the efficiency of energy recovery units (ER) to ensure the quality of fresh indoor air. Indoor air energy recovery calculations were performed using plate and rotary heat exchangers in different operating scenarios. The evaluated parameters led to the stability of the optimization solutions in order to obtain a higher energy efficiency on the equipment. By comparing the obtained results, optimal measures and solutions were identified for energy efficiency in the operation of ER.*

Key words: outside air, ventilation, air conditioning, energy efficiency, energy recovery

1. Introduction

Due to the high consumption of primary energy for which the construction sector is responsible, which also has a negative impact on the environment (average annual increase in carbon emissions of approximately 2% [1]), the member states of the European Union have been obliged to adopt measures to energy efficiency of buildings. The gradual reduction of energy consumption has as its target the percentage of 11.7% until 2030, in relation to the year 2020 [2], [3]. A considerable percentage of energy consumption (around 50%), of total consumption in buildings, both in the residential and non-residential sectors, is due to HVAC (heating, ventilation and air conditioning) systems due to the high demand for thermal comfort. Of this percentage, ventilation accounts for 30% to 60% of energy consumption in buildings [1], [4], [5], [6], [7].

The new energy efficiency norms require construction techniques that insulate buildings better and better. Efficient buildings have very good thermal insulation and NZEB or passive buildings minimize primary energy consumption for heating/cooling and ventilation needs. Regarding the ventilation systems, which provide fresh air in buildings, the ventilation rates must be correctly set because insufficient ventilation is a critical factor that causes severe dissatisfaction in indoor environments. In the context of reducing energy consumption per building surface, which must be achieved through the objectives imposed by the EU, an important role is played by the recovery of the heat lost through the air exhausted by the ventilation systems. Heat recovery ventilation is known to be effective in saving energy and maintaining required ventilation rates. In this sense, an important aspect is the type of energy recovery capable of contributing to the reduction of energy consumption for heating and cooling spaces in buildings [8], [9], [10].

2. Efficiency of energy recovery

The contribution of heat recovery to energy savings should be studied depending on the destination of the building and the type of ventilation system. Therefore, the paper makes an analysis of the efficiency of energy recovery on energy savings considering several operating scenarios.

The heat recovery efficiency represents the use of waste heat for preheating fresh cold air and can take values between 0 and 100%. Achievable heat recovery efficiencies for common air handling equipment are estimated to be somewhere between 30 and 90%, while efficiencies above 60% are considered good and above 80% excellent [11].

The heat recovery efficiency η_t depending on the temperatures, (temperature differences) is calculated with the relation [12], [13]:

$$\eta_t = (t''_2 - t'_2) / (t'_1 - t'_2) \quad (1)$$

where:
t'_1 - extracted air temperature at the entrance;;
t'_2 - fresh air temperature at the entrance;
t''_2 - fresh air temperature at the exit.

This is where the efficiency grade (EG) comes in, where the fresh air heating is placed in relation to the required temperature and is calculated with the relation:

$$EG = (t''_2 - t'_2) / (t_{2N} - t'_2) \quad (2)$$

where:
t_{2N} - the required (maximum) temperature of the air introduced;
t'_2 - fresh air temperature at the entrance;
t''_2 - fresh air temperature at the exit.

The grade of efficiency is therefore important, especially in rooms with technological processes, where the temperature of the extracted air is often clearly higher than the required temperature of the input air. The degree of efficiency (EG) is higher than the recovery efficiency (ηt). Over the course of a year, significant differences appear between the annual degree of efficiency and the heat recovery efficiency depending on the temperature of the extracted/input air. So, it can be concluded that:

- the influence of the temperature difference between the extracted and introduced air with the energy used is considerable;
- for an extracted air temperature of 20ºC (input air temperature), as expected, the annual efficiency is the same as the heat recovery efficiency;
- the degree of annual efficiency increases with the exhaust air temperature and that the efficiency decreases at high values of heat recovery. The temperature of the air to be introduced would otherwise be too high.

Regarding the cost effectiveness of projects (high investment and high pressure loss) with high heat recovery efficiency, it is appreciated that they are not always advantageous.

3. Ventilation systems with heat recovery for a residential building. Case Study

The study carried out presents simulations regarding the efficiency of ER in order to ensure the quality of fresh indoor air. Indoor air heat recovery calculations using plate and rotary heat exchangers were performed, depending on the air flow rate and the number of operating hours of the ventilation system, and the feasibility of using heat exchangers was analyzed. Several operating scenarios were presented in which the parameters, which influence the energy efficiency of the energy recovery, were modified. In order to determine the optimization solutions in order to obtain a higher energy efficiency on the equipment, the following parameters were evaluated: the air speed in the free section and the pressure loss on the filter material. The scenarios were designed for different types of energy recovery and in different HVAC constructiv systems. For the case study, the realization of a separate installation was considered, which would provide fresh air all year round. Obviously, in winter, the outside air must be heated, either by an electric battery or by a battery supplied with hot water from the building's central heating boiler. In summer the fresh air can be cooled, either with a separate coil with direct expansion, or with a coil with water received by a water cooler (chiller), so that the rooms do not heat up undesirably. The actual cooling of the rooms is done with separate fresh air installation equipment either with direct expansion equipment ("splits") or using an installation with fan coils and the central water cooler.

The article analyzes only the air circulation produced by the installation that permanently introduces fresh air into a building intended as a residential building, and is composed of the following rooms: living room (29 m^2, 87 m^3); adult bedroom 1 (19 m^2, 57 m^3); adult bedroom 2 (18 m^2, 54 m^3); child's bedroom (17 m^2, 51 m^3); office

(17 m^2, 51 m^3); kitchen (14 m^2, 42 m^3); bathroom (9 m^2, 27 m^3); service bathroom (4 m^2, 12 m^3); entrance hall (6 m^2, 18 m^3); interior hall (9 m^2, 27 m^3).

Ensuring correct air circulation is done according to the following rules:

- rooms with continuous introduction of fresh air: living room, office, the three bedrooms which have a total area of 100 m^2 and a volume of 300 m^3;
- rooms with periodic evacuations of stale air: kitchen, bathroom and service bathroom;
- buffer rooms, for variable exhaust of stale air: hall and entrance.

The total flow of fresh air introduced is 900 m^3/h, distributed as follows: living room→260 m^3/h, bedroom 1 adults→170 m^3/h, bedroom 2 adults→160 m^3/h, children's bedroom→155 m^3/h, office →155 m^3/h.

At the same time, there are rooms from which stale air is evacuated depending on the period of their use. In these cases, the exhaust air flows can be variable: from everything to nothing. Thus, from the kitchen, through the hood (placed above the stove), either the maximum air flow of 210 m^3/h or nothing when the hood is not working. Either 135 m^3/h or nothing (fan off) can be evacuated from the bathroom, and 60 m^3/h or nothing (fan off) can be evacuated from the service bathroom. Under these conditions, everything that is not evacuated through the kitchen and/or bathroom and/or service bathroom will be evacuated through the suction holes located in the central hall and in the entrance, thus maintaining a continuous ventilation of the apartment.

To perform the calculations, the following climatic parameters were taken into account:

- Winter:
  - Outside air: temperature: -15°C; humidity: 70%;
  - Indoor air: temperature: 22°C; humidity: 50%;
- Summer:
  - Outside air: temperature: 36°C; humidity: 2570%;
  - Indoor air: temperature: 26°C; humidity: 50%;

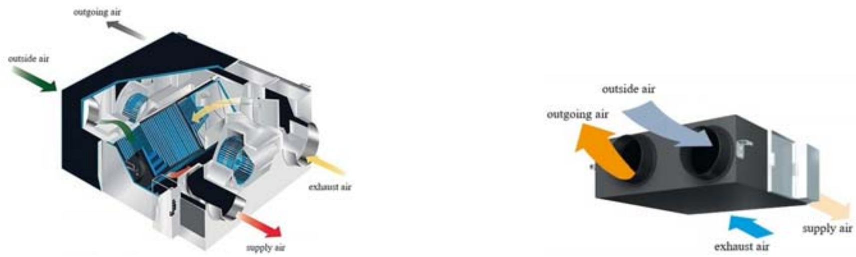
Following the simplified calculation, the results were obtained:

- Winter → the introduction of fresh air into the building requires a thermal energy consumption of approx. 11.5 kW;
- Summer → the introduction of fresh air into the building requires a refrigeration energy consumption of approx. 3.5 kW.

To be able to make an accurate analysis of the electrical consumption of the ventilation equipment, it is necessary to know their technical characteristics. The comparison was made for a fresh air flow rate of 900 m^3/h. The simulation was carried out considering two ER types with plates, especially used for residential buildings:

- air-air ER Lossnay with plates LGH-100RVX (Fig. 1 a);
- air-air ER VAM1000FC with plates (Fig. 1 b).

The air flows circulation related to the two ER types of considered for the case study are shown in Fig. 1.



a) b)

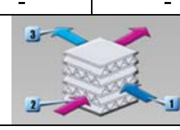
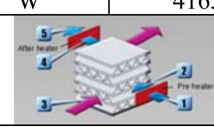
Fig. 1 Types of energy recovery
a) Lossnay (https://torn-climatizare.ro/), b) VAM (https://c-control.com.ua/)

4. Results and discussion

- The results obtained were compared and optimal measures and solutions were identified for energy efficiency in the operation of ER. The simulations were carried out throughout the year, there being a difference between the winter and summer periods regarding the efficiency of the ER, and as well the investment recovery period was also taken into account. The simulations were carried out for the two types of ER, for the summer and winter periods, as follows:
- *for the type air-to-air ER with Lossnay LGH-100RVX plates,* the simulation of the efficiency of the ER was done with the help of the Lossnay Selection calculation program in which the calculation parameters were entered. For the summer/winter period, the results shown in Table 1 were obtained.

Table 1

Results obtained for the ER Lossnay LGH-100RVX

No.	Characteristic	Unit	Value	Unit	Value
		Summer		Winter	
1.	Selected Lossnay model & Fan Speed: LGH-100RVX x 1 unit				
	Heat exchange efficiency	%	68	%	80
	Enthalpy exchange efficiency	%	71	%	72.5
	Sound level	dB	47	dB	47
2.	*Selection Conditions*				
	Total supply air	m^3/h	900	m^3/h	900
	Power Supply	Hz	50	Hz	50
	External static pressure	Pa	150	Pa	150
	Pre heater(W)	-	-	W	4165
	After heater(W)	-	-	W	4165
3.	*Psychrometric Points*				
	Outdoor air (OA)-Summer (1) and Winter (1)				
	Dry bulb temperature	°C	36	°C	-15
	Relative humidity	%	25	%	70
	Absolute humidity	g/kg	9.3	g/kg	0.7
	Enthalpy	kJ/kg	60	kJ/kg	-13.2
	Outdoor air after Pre heater (OA')-Winter (2)				
	Dry bulb temperature	-	-	°C	-2.9
	Relative humidity	-	-	%	24
	Absolute humidity	-	-	g/kg	0.7

No.	Characteristic	Unit	Value	Unit	Value
		Summer		Winter	
	Enthalpy	-	-	kJ/kg	-1
	Room air (RA) - Summer (2) and Winter (3)				
	Dry bulb temperature	°C	26	°C	22
	Relative humidity	%	50	%	50
	Absolute humidity	g/kg	10.5	g/kg	8.2
	Enthalpy	kJ/kg	52.9	kJ/kg	43
	Supply air (SA) - Summer (3) and Winter (4)				
	Dry bulb temperature	°C	29.2	°C	17
	Relative humidity	%	40	%	45
	Absolute humidity	g/kg	10	g/kg	5.4
	Enthalpy	kJ/kg	54.9	kJ/kg	30.9
	Supply air after After heater (SA') - Winter (5)				
	Dry bulb temperature	-	-	°C	29
	Relative humidity	-	-	%	22
	Absolute humidity	-	-	g/kg	5.4
	Enthalpy	-	-	kJ/kg	43.1

- *for the type air-to-air ER with VAM1000FC plates,* the simulation of the efficiency of the ER was done with the help of the Daikin calculation program. The selection software uses data according to the JIS B 8628-2017 standard and shows the result for the specific air flow, ESP and temperature conditions. For the summer/winter period, the air flow characteristics in the rooms are shown in Table 2, the air conditioning characteristics in the rooms are shown in Table 3, the results obtained are shown in Table 4, The Psychrometric Points, for both cooling and heating are presented in Table 5. For the selection data it was considered: exhaust / Supply ratio – 1, additional resistance: supply side - 4.5Pa and exhaust side - 4.5Pa.

Tabel 2

Characteristics of air flow in rooms

Characteristic	Unit	**Value**
Room Airflow Conditions		
Total supply air	m³/h	900
Total exhaust air	m³/h	900
External Static Pressure (ESP)		
Design supply ESP	Pa	150
Altitude Selection		
Altitude	m	0

Tabel 3

Parametrii aerului condiționat în încăperi

No.	Characteristic	Unit	Value	Unit	Value
		Cooling		Heating	
1.	*Room Air Conditions (RA)*				
	Dry bulb temperature	°C	26	°C	22
	Wet bulb temperature	°C	18.6	-	-
	Relative humidity	-	-	%	50
2	*Ambient Air Conditions (OA)*				
	Dry bulb temperature	°C	36.0	°C	-15.0
	Relative humidity	%	25	%	70
3.	*Discharge* Temperature Setting				
	Temperature	°C	18	°C	25

No.	Characteristic	Unit	Value	Unit	Value
		Cooling		Heating	
4.	*Electric Heaters*				
	Inlet heater	kW	5.000	-	-
	Supply Temperature	-	-	°C	20.0
	Supply heater	-	-	kW	3.000

Tabel 4

Results obtained for the ER VAM1000FC

No.	**Characteristic**	**Unit**	**Value**	**Unit**	**Value**
		Cooling		**Heating**	
1.	**Efficiencies**				
	Temperature exchange efficiency	%	79.2	%	79.2
	Enthalpy exchange efficiency	%	65.2	%	70.4
2.	**Savings over Heat Exchanger**				
	Latent heat savings	kW	1.220	kW	3.382
	Sensible heat savings	kW	3.593	kW	6.321
	Total heat savings	kW	4.813	kW	9.703
3.	**Heaters**				
	Switch on inlet heater above	°C	59.5	-	-
	Switch on inlet heater below	-	-	°C	1.0
	Inlet heater (user settings)	kW	1.500	kW	3.788
	Inlet heater (calculated minimum)	kW	0.000	kW	3.788
	Supply heater (user settings)	-	-	kW	3.000

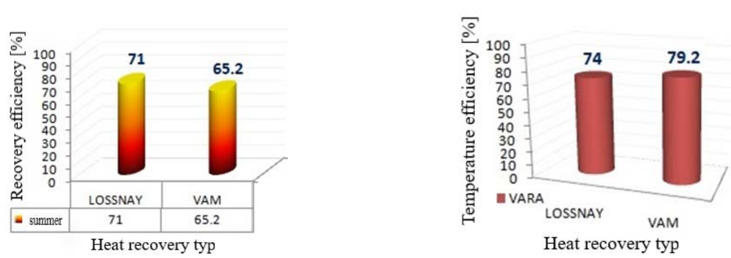
Table 5

Psychrometric Points

No.	Characteristic	Unit	Value	Unit	Value
		Cooling		Heating	
1.	Room Air (RA)				
	Dry bulb temperature	°C	26.0	°C	22.0
	Wet bulb temperature	°C	18.6	°C	15.4
	Relative humidity	%	49.8	%	50.0
	Absolute humidity	kg/kg	0.0104	kg/kg	0.0082
	Enthalpy	kJ/kg	52.8	kJ/kg	43.0
2.	*Exhaust Air (EA)*				
	Dry bulb temperature	°C	38.0	°C	1.4
	Wet bulb temperature	°C	21.0	°C	1.0
	Relative humidity	%	21.4	%	93.5
	Absolute humidity	kg/kg	0.0088	kg/kg	0.0039
	Enthalpy	kJ/kg	60.9	kJ/kg	11.2
3	*Outdoor Air (OA)*				
	Dry bulb temperature	°C	36.0	°C	-15.0
	Wet bulb temperature	°C	20.7	°C	-15.6
	Relative humidity	%	25.0	%	70.0

No.	Characteristic	Unit	Value	Unit	Value
		Cooling		Heating	
	Absolute humidity	kg/kg	0.0093	kg/kg	0.0007
	Enthalpy	kJ/kg	60.0	kJ/kg	-13.3
4.	*Supply Air (SA)*				
	Dry bulb temperature	°C	29.1	°C	25.2
	Wet bulb temperature	°C	19.9	°C	13.7
	Relative humidity	%	43.1	%	25.6
	Absolute humidity	kg/kg	0.0109	kg/kg	0.0051
	Enthalpy	kJ/kg	57.1	kJ/kg	38.4
5.	*Ventilation In (VI)*				
	Dry bulb temperature	°C	41.1	°C	-4.0
	Wet bulb temperature	°C	22.2	°C	-7.3
	Relative humidity	%	19.0	%	26.4
	Absolute humidity	kg/kg	0.0093	kg/kg	0.0007
	Enthalpy	kJ/kg	65.2	kJ/kg	-2.3
6.	*Ventilation Out (VO)*				
	Dry bulb temperature	°C	29.1	°C	16.6
	Wet bulb temperature	°C	19.9	°C	10.1
	Relative humidity	%	43.1	%	43.6
	Absolute humidity	kg/kg	0.0109	kg/kg	0.0051
	Enthalpy	kJ/kg	57.1	kJ/kg	29.6

Based on the results obtained, a comparative evaluation was made between the two types of ER, during the summer, in terms of the efficiency of the ER (Fig. 2 a) and the efficiency of the temperature exchange (Fig. 2 b).



a) b)

Fig. 2 Comparative evaluation for summer period - ER Lossnay vs. VAM

a) ER efficiency, b) temperature exchange efficiency

According to the graph in Fig. 4 it can be seen that the ER Lossnay will have a much lower energy consumption than the ER VAM.

In order to evaluate the yield during the winter, the internal temperature of 22°C was considered. Comparative graphs between the two ER types, in winter, the efficiency of the ER (Fig. 3 a) and the temperature exchange efficiency (Fig. 3 b).

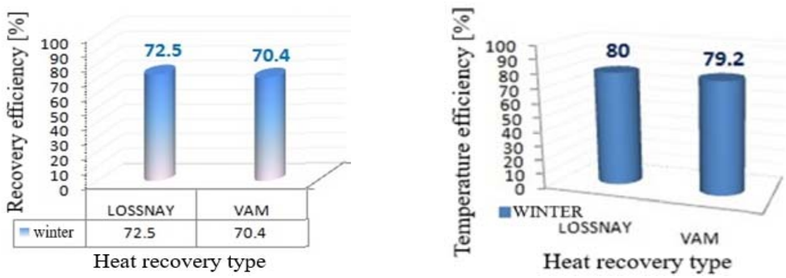


Fig. 3 Comparative evaluation for winter period - ER Lossnay vs. VAM
a) ER efficiency, b) temperature exchange efficiency

The investment cost calculation showed that the installation with ER Lossnay is 3780 Euros, and the one with ER VAM is 3655 Euros, resulting in a price difference of only 125 Euros. So, it can be said that the efficiency of the ER is proportional to its investment cost.

Another important indicator in the choice of the ER is the payback period of the investment, which was determined as the ratio between the cost of the equipment in lei and the cost of the energy saved in a year, in lei/year. For the two ER types , in Fig. 4 compares the payback of the investment in months.

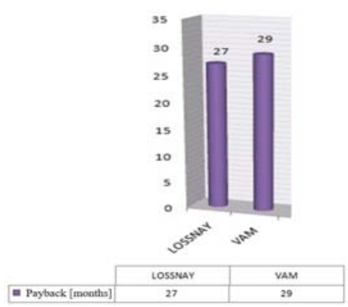


Fig. 4 Payback of investment- ER Lossnay vs. VAM

5. Conclusions

With the increasing demand for thermal comfort, HVAC systems and their related consumption have grown considerably, accounting for around 50% of energy consumption in buildings and around 10–20% of total energy consumption in developed countries, a trend that will . continues to rise in line with the expansion of built-up areas and related energy needs. From the analysis of the payback of the investment, it was found that a better heat recovery is done with the help of the ER Lossnay over the period of 27 months, this also takes into account its efficiency. The lower the efficiency of the equipment, the longer the payback period of the entire investment. The use of ER leads to the uninterrupted supply of clean air in buildings (especially residences, offices, commercial premises, etc.) which means maintaining a high standard of health. The continuous change of the contaminated air in the premises drastically reduces the development of airborne germs.

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