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ANALYSIS OF VENTILATION SYSTEM'S HEAT EXCHANGERS INTEGRATION POSSIBILITIES FOR HEATING SEASON

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Abstract. Ventilation systems are known as intensive energy used building engineering system. Heat exchangers are the main equipments used for energy transformation in building engineering systems as well as in ventilation systems. The conventional heat exchangers design methods do not belie the ways for efficiency energy use in building engineering system's heat exchangers.
The method of Pinch technology mostly used for industrial process integration that could be applied to analyze possibilities of process integration is first time adopted to evaluate processes integration of building engineering systems. The paper deals with analyze of integration possibilities of ventilation system.
The approach covers several possible cases of integration. Analysis is based on heat exchangers used for heat recovery and heat transfer in ventilation systems modification cases during the heating season.
As results for ventilation system integration possibilities there are represented heat exchangers modification solutions those are expressed as technical evaluation indicators of heat exchangers.

Keywords: building engineering systems, heat exchanger, heat recovery, processes integration, Pinch technology, ventilation system.

1. Introduction

The buildings consume above 40% of energy used in European Union. The major part of energy used in buildings fall to exploitation of engineering systems of building although inconsiderable part of energy falls to their manufacturing by viewpoint of life cycle.

Ventilation systems are the main engineering systems those consume quite big amount of energy in consideration with other building engineering systems. The administrative building engineering systems in comparison with residential ones use more energy in relation to bigger variety of engineering systems such as mentioned ventilation system.

The buildings and their indoor climate formatting systems still remain main area that subsists of energy saving potential in hand. Energetic systems confront with inefficient energy transformation equipments. Heat exchangers are the main equipments used for energy transformation in building engineering systems as well as in ventilation systems. The whole system efficiency depends on processes efficiency those operate in heat exchangers (Nikulshin *et al* 2002, Miseviciute and Martinaitis 2008).

As heat exchangers used for heating systems fulfil the heat generation or heat transfer function, ventilation systems use heat exchangers for heat recovery from exhaust air to preheat supply air. There also are applied conventional heat exchangers for heat exchange in ventilation systems.

The conventional heat exchangers design methods (Middleman 1998, Cornelissen and Hirs 1999, Janna 2000, Incropere and Dewitt 2002) do not belie the ways for efficiency energy use in building engineering system's heat exchangers. The processes integration (Smith 2000, Boujut and Laureillard 2002, Dincer 2002, Kemp 2007, Zhelev 2007) is invoked. The prior investigations (Schmidt 2004) had considered the ways how to integrate new, for e.g. renewable energy systems to the existing building engineering systems to strive efficient use of energy in the systems. The integration of heat generation systems quite a lot was discussed in (Puigjaner 1997, Godat and Marechal 2003) works.

This paper presents ventilation system heat exchangers formation by invoking the processes those are functioning in the other building engineering systems as heating system. The integration is assumed as search of possibilities to modification of heat exchangers by formatting new combinations of heat exchangers by streams integration and changing heat exchangers capacities for efficiency energy use in these systems as well as in other building engineering systems.

There is the lack of investigations that approach building engineering systems as a whole. This paper presents one of the ways for exploring mentioned systems as a whole.

2. Object of research

Ventilation system is chosen as the object for research in accordance with inefficient use of energy in building engineering systems. The heat exchangers of ventilation system are explored.

The relation between energy use and building engineering systems is represented in Fig 1.

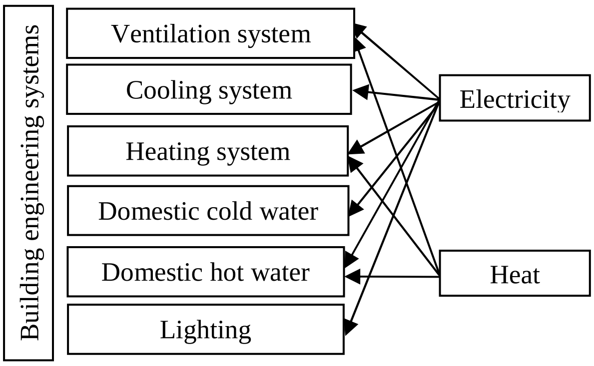


Fig 1. Energy used by building engineering systems

Ventilation system between above (Fig 1.) presented indoor climate formatting systems use both energy forms as well as heating and domestic hot water systems. Electricity is mainly used of fans for air transportation in air ducts, heat – for air heating.

As whole ventilation system could be represented as shown in Fig 2.

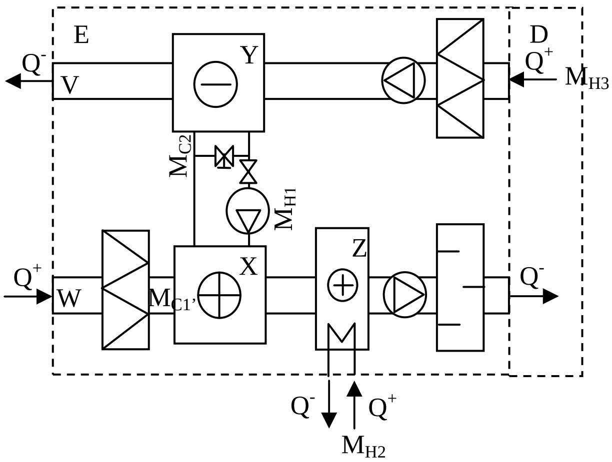


Fig 2. Schematic view of simple ventilation system

E represents air handling unit that prepare air supplied/exhausted to/from the room D. There are three (X, Y, Z) heat exchangers. The indoor climate is formatted by the air handling unit as following: the outdoor air through the air duct W flows to the room D, then exhausted air from the room is extracted by air duct V. The explored system E has the limits (dotted rectangle) those cover mentioned area. Letter Q with superscript "+" means the heat flow of stream that system E received, "-" – system E released.

Air handling unit presented in Fig 2. presents heat recovery through heat exchanger with run around loop (X and Y heat exchangers). This type of heat recovery is proper for different ventilation system heat exchangers integration possibilities. For example, the heat agent for heat transfer could be produced in several ways.

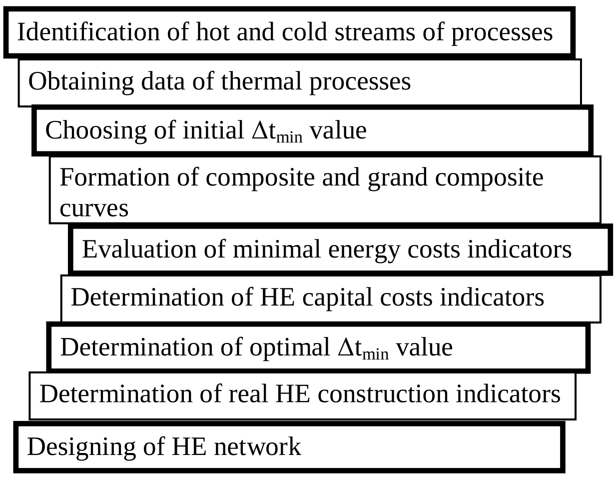
The goals of research are find out the possibilities for heat exchangers of ventilation system integration and make an analysis for heat recovery in ventilation system's modification cases during the heating season.

As was mentioned early conventional methods (Boelman and Sakulpipatsin 2004, Haseli *et al* 2007) for heat exchangers analysis could not suggest ways for efficient energy use in heat exchangers. The method of Pinch technology is proposed to use as useful tool for analysing heat exchangers by viewpoint of processes integration.

3. Methodology

Pinch technology in principle used for intensive energy industrial processes. Since building engineering systems processes also ascribable to energy intensive processes its could be explored by this method. It could be stated that thermodynamical (exergy) analysis (Ertesvag and Mielnik 2000, Ertesvag 2005, Martinaitis *et al* 2010) originated Pinch technology so this enables use this for thermodinamical processes of building engineering system.

Pinch technology (analysis) is used for new or existing heat exchangers network formation. According to Pinch technology the steps presented in Fig 3. should be realized.



Note: HE – heat exchanger

Fig 3. Pinch technology steps

Some of these 9 steps are quite difficult to reach. The first is obtaining the data about streams those appear in processes is quite difficult of reliability of data those will be used will influence the results of calculation. The main data needed for analysis are presented in Fig 4.

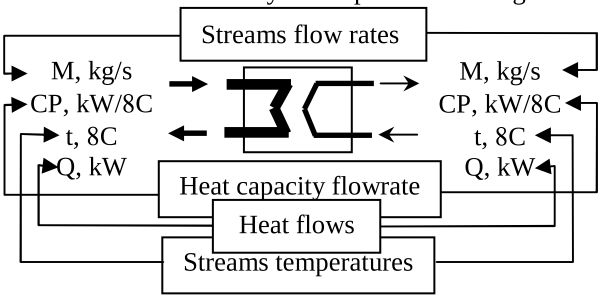


Fig 4. Data for analysis

The data about streams those attending in the processes of building engineering systems are obtained from Building Energy Management System (BEMS). Then the streams in processes are indentified i.e. hot or cold.

As the biggest part of energy is used by ventilation system during the heating season this period is chosen for research. The heating season is divided into three periods. The beginning/end of heating season is examined. The heating season begins and stops when outdoor temperature sets +10 ºC. Periods when temperature reaches about 0 ºC marks the average heating season temperature and -23 ºC (heating and ventilation systems rated temperature) are discussed. These three temperatures were selected for further heat exchangers of ventilation system's analysis.

The basic different between heat exchangers those are used for heating systems and ventilation systems is quite large temperature differences between inlet and outlet streams into the heat exchangers.

Data that can not be directly obtained from BEMS is estimated according to the heat and mass balances. Formula (1) represents heat balance equation.

$$Q = M_i \cdot c_{p_i} \cdot \Delta t = CP \cdot \Delta t \qquad (1)$$

Where: Q – heat flow, kW; M_i – mass flow rate of i stream, kg/s; c_{pi} – heat capacity of i stream, kJ/kg8C; Δt – the temperature difference between inlet and outlet to/from the heat exchanger stream, ºC; CP – heat capacity flowrate, kW/8C.

Another significant quantity is minimal temperature difference that directly depends on the stream physical state. (Kemp 2007) recommends use 15 ºC for liquids and gases.

Further calculations are based on formulas presented below.

$$Q = \int_{t_s}^{t_t} CPdt = CP\left(t_t - t_s\right) = \Delta H \qquad (2)$$

Where: Q – heat flow, kW; CP – heat capacity flowrate, kW/8C; dt – differential temperature difference, 8C; t_s – supply temperature, 8C, t_t – target temperature, 8C; ΔH – enthalpy change of stream, kW.

Knowing the streams population in each i temperature interval enthalpy change of stream balances could be calculated according formula (3).

$$\Delta H_i = \left(t_i^{'} - t_{i+1}^{'}\right) \cdot \left(\sum CP_H - \sum CP_C\right)_i \qquad (3)$$

Where: $t^{'}_i$ – shifted by $1/2\Delta t_{min}$ i interval temperature, 8C; $t^{'}_{i+1}$ – shifted by $1/2\Delta t_{min}$ i+1 interval temperature, 8C; ΣCP_H – total of hot streams heat capacity flowrates of i interval, kW/8C; ΣCP_C – total of cold streams heat capacity flowrates of i interval, kW/8C.

Data for calculation if Δt_{min}=15 8C is presented in table 1. Shifted temperatures (t'_s, t'_t) are calculated respectively by adding or subtracting from supply/target temperatures quantity $1/2\Delta t_{min}$.

Table 1. Data of streams those attend in ventilation system's heat exchangers (the coldest period of heating season)

Stream	t_s, 8C	t_t, 8C	t'_s, 8C	t'_t, 8C
Hot I (H1)	12.04	3.52	4.54	-3.98
Hot II (H2)	81.68	50.98	74.18	43.48
Hot III (H3)	23.63	15.11	16.13	7.61
Cold I (C1)	-23.00	-14.48	-15.50	-6.98
Cold II (C2)	3.52	12.04	11.02	19.54
Cold III (C3)	-14.48	24.10	-6.98	31.60

As seen in table 1, the stream that is cooled during the process is called hot, contrariwise – cold stream. Streams (C1 and C3) could be considered as one stream (C1').

Two schemes of ventilation system air handling units were explored. The first presented before in Fig 2. presents conventional one used for heat recovery. Another scheme (Fig 5.) deals with the opportunity to use additional heat/cool source of one of building engineering systems – heating system.

The notations in Fig 5. are the same as in Fig 2. The main difference is the position of Z heat exchanger. The stream functioning in heating system is used for ventilation system for heat recovery by run around loop heat exchanger.

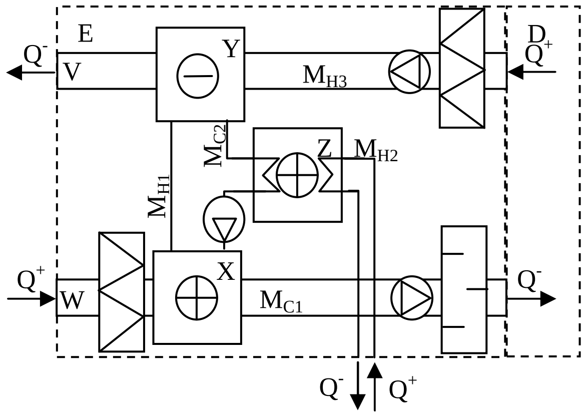


Fig 5. Schematic view of improved ventilation system

Data presented in tables 1 and 2 are used in Excel spreadsheet to further calculations needed for Pinch analysis performance.

Table 2. Additional data of streams those attend in ventilation system's heat exchangers (the coldest period of heating season)

Stream	CP, kW/8C	Δt, 8C	Q, kW	ΣQ, kW
H1	16.70	8.52	142.28	928.85
H2	20.99	30.70	644.29	
H3	16.70	8.52	142.28	
C1	16.70	8.52	142.28	928.85
C2	16.70	8.52	142.28	
C3	16.70	38.58	644.29	
or				
C1' (C1+C3)	16.70	47.10	786.56	

The aim of Pinch analysis is designing of new or modification of existing heat exchangers network. First of all carry out the separation of ventilation system heat exchangers by extracting data about streams and make a synthesis of them later by combining new heat exchangers from separated streams before.

Separation covers the stream data extraction from existing heat exchangers network. The situation seems like presented in Fig 6.

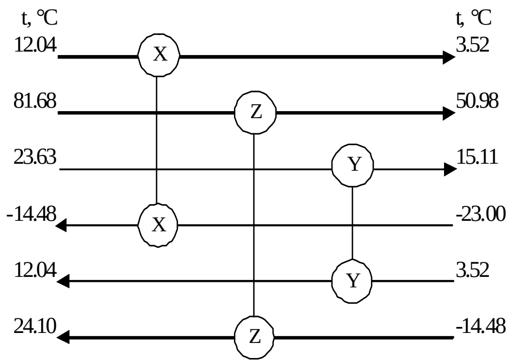


Fig 6. Separated heat exchangers network according to the simple ventilation scheme

The horizontal lines in Fig 6. present all hot streams (covered by upper circles) and cold streams (bottom circles). The joined by line upper and bottom circles means heat exchanger.

Scheme (Fig 7.) explains the algorithm for the heat exchangers formation.

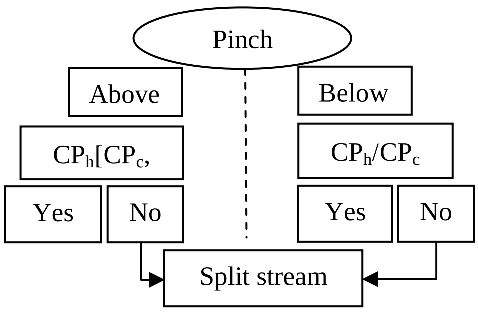


Fig 7. Algorithm for heat exchangers network design

Shortly Pinch analysis could be defined as a tool for identification of maximal heat recovery, minimal hot and cold utilities to heat or cool streams. Fig 8. presents the positions where to design mentioned devices.

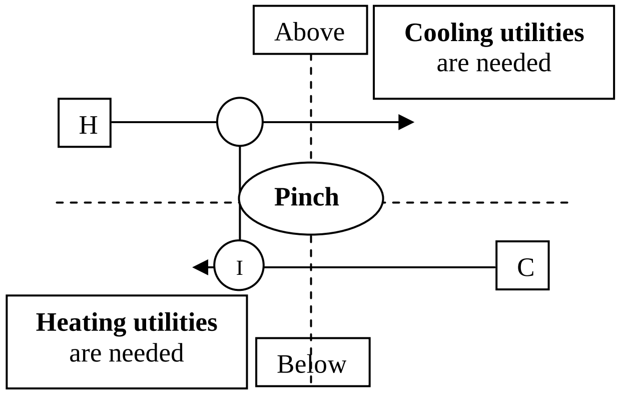


Fig 8. Pinch and division of Pinch area

Pinch divides area for heat exchangers network design into four sections. The left side is designed for hot streams, the right – cold streams. The hot streams are drawn from the left side to the right above Pinch. The cold streams – in opposite order. The circles join by line present heat exchanger.

Pinch is described by Pinch temperatures for hot and cold streams those respectively are equal:

$$t_{Pinch\_H} = t_{Pinch} + \frac{\Delta t_{min}}{2} \tag{4}$$

$$t_{Pinch\_C} = t_{Pinch} - \frac{\Delta t_{min}}{2} \tag{5}$$

Pinch temperature can be estimated by series of calculations. First of all is carrying out the calculation of heat flows in i temperature intervals, as the result of this calculation is produced composite curves of cold and hot streams separately and then add and put them together on general graph. The graph presents the overall view of cold and hot composite curves distribution.

The so called "Problem table" must be produced to represent the position where is heat surplus or heat deficit in temperature interval i. This table must present shifted temperatures of streams at each temperature interval i, temperature differences between intervals, the difference between total hot and cold streams heat capacity flowrates and also heat flow or enthalpy change of stream in temperature interval i.

According to the problem table can be formatted heat cascades. Exactly these heat cascades show where the Pinch is and what are the minimal capacities of required hot and cold utilities.

Hot and cold utilities can be added only in the places remarked in the Fig 8. Heat can be supplied from these hot utilities: thermal fluid, exhausted heat from refrigeration systems and heat pumps condensers or electrical heating. Cool respectively can be supplied using these cold utilities: cooling water systems, air coolers, refrigeration systems and heat pumps evaporators.

The next step is designing of heat exchangers network what is one of the aims of this research. The results are presented in next chapter.

4. Results

The heat exchangers network is design according to algorithm presented in Fig 7. Various cases those differ by the specific temperature of the heating season are explored.

Analysing the case of the beginning or the end of the heating season, the outdoor air temperature is equal to 10 ºC. Figures 9 and 10 present the heat exchangers (boxes) of ventilation system, numbers in scheme mark inlet and outlet to/from the heat exchanger stream temperatures. Ventilation system form indoor climate for the room presented by dotted line (the right side). The schemes differ by position of Z heat exchanger.

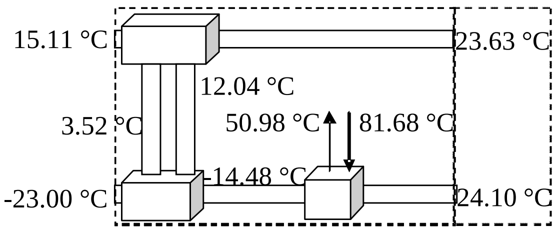


Fig 9. Scheme for standard (simple) ventilation system

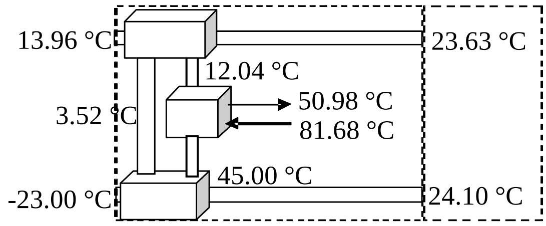


Fig 10. Scheme for improved ventilation system

The bottom temperature in the left side means the inlet temperature of outdoor air and also defines the one of specific points of the research. Fig 9. and Fig 10. are missing some ventilation system elements: fans, filters and silencer. It is assumed that these elements do not have impact for the heat exchangers performance.

The results for one of cases are presented in Fig 11. Figure 11 shows the case of extreme conditions – the coldest period of heating season. The simple ventilation system explored according Pinch technology seems like presented in Fig 11. The numbers in the Fig 11. present temperatures except in the circles. The numerical values in the circles mean the capacity of heat exchanger (I, II, III).

The vertical (dotted) line presents the Pinch temperatures for hot (upper value) and cold (bottom value) streams.

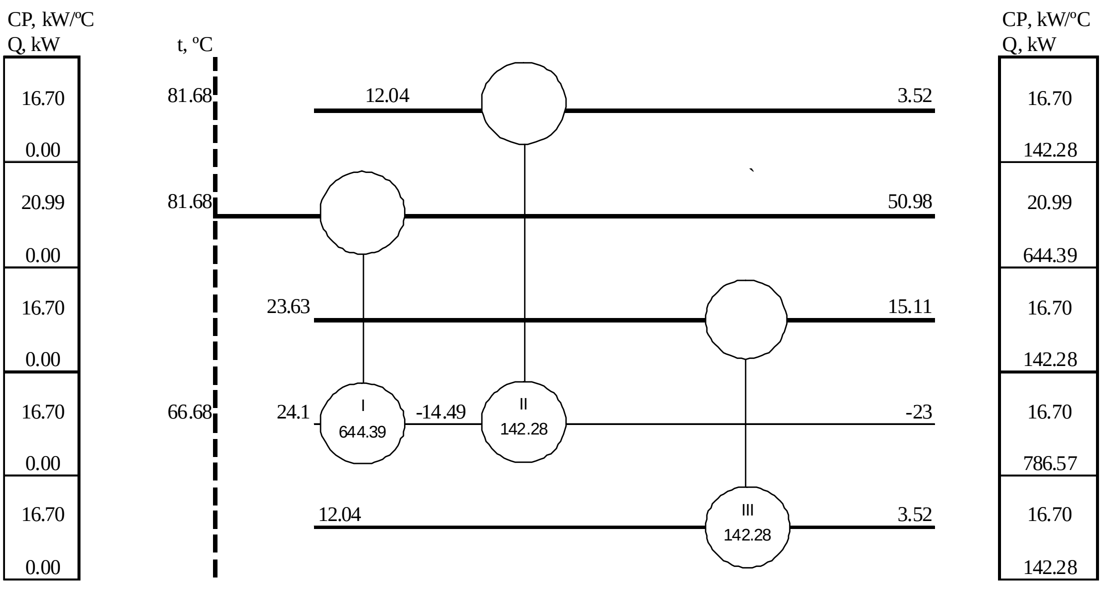


Fig 11. Heat exchangers network for simple ventilation system (analyzed according to Pinch technology)

The obtained results for the new ventilation system are mainly the same as the previous situation presented in figure 6. The heat exchanger (II) previously preheats the outdoor air (X heat exchanger in former system) then I (Z) and III (Y) heat exchangers perform ing heat transfer. It is possible to optimise the heat exchangers network by finding destination from one external utility to another or the closed circuit. The optimization depends on number of heat exchangers and external utilities. Here is not presented optimization.

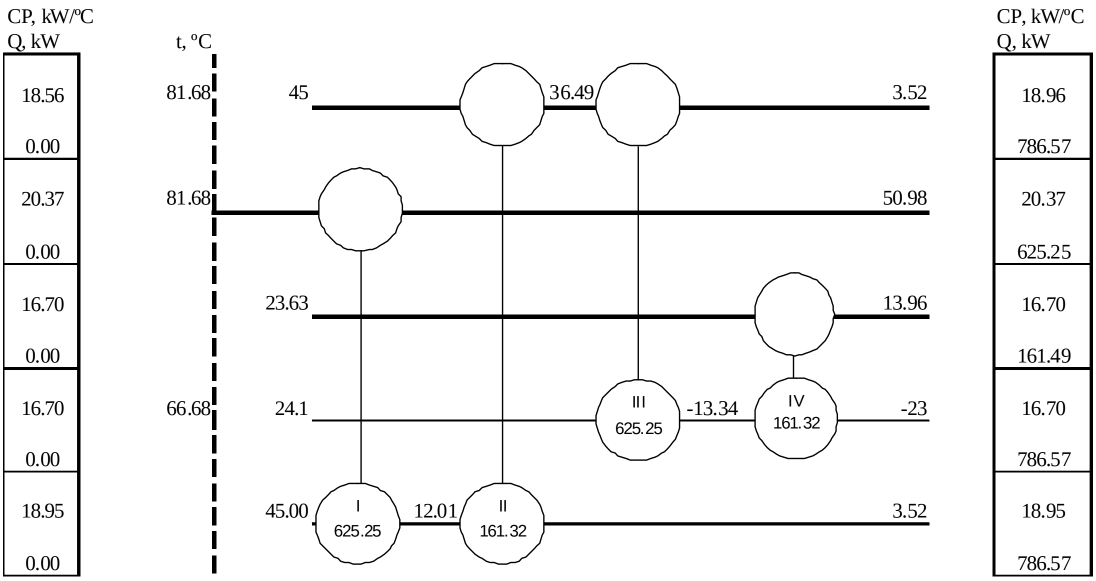


Fig 12. Heat exchangers network for improved ventilation system (analyzed according to Pinch technology)

The heat exchanges network (Fig 12.) differ from the former heat exchanger network (Fig 5.) by the number of heat exchangers. The number of heat exchangers increases from three to four. Both figures (Fig 11. and Fig 12.) show the positions of new designed heat exchangers by changing the way of integrating streams of processes. Instead of using one heat exchanger (Z) to heat C2 stream here is used two heat exchangers (I, II). The same situation is obtained with X and Y heat exchangers. Table 3 presents the comparison of results for estimated cases.

Table 3. Comparison of the results

	t, 8C	Number of HE/ maximal recovered heat, Q_R, kW	Number of external utilities/ total capacity, kW		Number of HE/ maximal recovered heat, Q_R, kW	Number of external utilities/ total capacity, kW	
			Hot	Cold		Hot	Cold
Scheme / Case	I				II		
Non optimised HE network	-23	4/928.88	0	0	4/1573.48	0	0
	0	3/303.10	1/110.71	1/110.71	6/455.39	2/150.70	1/150.70
	+10	2/118.07	2/126.92	2/126.92	3/198.94	2/164.06	2/164.06
Optimised HE network	-23	4/928.88	0	0	4/1573.48	0	0
	0	3/303.10	1/110.71	1/110.71	5/438.69	2/167.49	2/167.49
	+10	2/118.07	2/126.92	2/126.92	3/198.94	2/164.06	2/164.06
Non optimised HE network*	-23	3/928.88	0	0	4/1573.48	0	0
	0	2/303.10	1/110.71	1/110.71	5/426.03	1/180.06	1/180.06
	+10	2/118.07	1/126.92	2/126.92	3/198.94	1/164.06	2/164.06
Optimised HE network*	-23	3/928.88	0	0	4/1573.48	0	0
	0	2/303.10	1/110.71	1/110.71	3/409.34	1/196.75	1/196.75
	+10	2/118.07	1/126.92	2/126.92	2/181.53	1/181.47	2/181.47

Notes: I – simple ventilation system, II – improved ventilation system, minimal temperature difference is 15 8C, * – used two cold streams instead of three

The results subjected in table 3 show that the optimization of heat exchangers network if it is possible gives opportunity to eliminate non useful heat exchanger (minimal capacity heat exchanger that can not influence the network of heat exchangers) from the network.

As the prior investigators calculations have shown the Pinch technology used for processes integration also remarks that the better heat recovery from exhaust air can be reached during the coldest period of heating season (corresponding shaded rows in table 3). The capacity of recovered heat increases by 69 percent in case of improved ventilation system if specific temperature is -23 ºC, increases by 50 percent if the specific temperature is equal to 0 ºC in case of improved ventilation system.

In comparison with the bigger minimal temperature difference, for e.g. Δt_{min}=30 8C, the recovered heat respectively decreases by 7 percent in simple ventilation system scheme and 37 percent in improved scheme for the coldest period of heating season.

5. Conclusions

As the paper has shown the presented method of Pinch technology for processes integration can be used to the building engineering systems as well as to energy intensive industrial processes.

The suggested method gives some answers for properly design heat exchangers network by striving to use as many as possible various thermal processes streams. The results have shown how to install heat exchangers those could increase efficient use of energy in building engineering systems.

The increasing of heat recovery during the optimization process could be influenced by such factors as equal capacity of external utility. So the effect of this can influence decreasing or disappearing of external utilities (capacities or units).

The better heat exchanger network could be obtained by using as smaller as possible temperature difference between the hot or cold streams in viewpoint of efficient energy use in building engineering systems.

The variation of heat exchangers number in various explored cases could be explained by the different parameters of climate during the heating season. The colder the period is the higher parameters of streams are needed to satisfy the indoor climate conditions.

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