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Cost Effective Heat Exchangers Network of Total Site Heat Integration

Stanislav Boldyryev, Goran Krajačić, Neven Duić

Department of Energy, Power Engineering and Environment, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, 10000 Zagreb, Croatia
stas.boldyryev@fsb.hr

This paper deals with selection of optimum amount heat to be recovered during Total Site integration and utility targets for external heating, cooling, refrigerating etc. The methodology provides the calculation of minimum capital investment during heat integration of industrial site. It uses heat transfer area targets, utility distribution with overall cost of retrofit. Heat transfer area is calculated for different regions with use of intermediate utility and direct heating and cooling. Minimal temperature difference between Total Site profiles is analysed. Minimum of total heat transfer area for Total Site recovery is calculated for array of minimal temperature differences. The utility consumption, numbers of units and material of equipment are analysed too and minimum total cost for retrofit project of site recovery system is calculated. The case study shows heat recovery improvement on 1.94 MW. Site heating demands is reduced on 37.3 % and cooling capacity reduction is 39.6 %. The implementation of retrofit EUR 777,474 and payback time is 11.96 months.

1. Introduction

The energy efficiency improvement is one of the key goals for future sustainable development (EC Climate Action). As reported by IEA the industrial energy consumption in 2012 was 28 % of overall world energy balance.

Energy saving potential in industry is still huge despite the last time there are a lot of researches and applications that allowed reducing energy consumption considerably. Most of them are based on pinch analysis, mathematical programming and life cycle assessment as well as combinations and modifications of these methods as reported by Klemeš et al. (2014). For example, Čuček et al. (2014) proposed the multi-period synthesis of an optimally integrated regional biomass and bioenergy supply network through a Mixed-Integer Linear Programming (MILP) approach. They obtained solutions with optimal selection of raw materials, technologies, intermediate and final product flows, and reduced greenhouse-gas emissions. Čuček et al. (2011) presented combination of mathematical programming and life cycle assessment for biomass and bioenergy supply chain. Boldyryev and Varbanov delivered the application of Pinch Analysis for chemical plant and shown energy consumption reduction on 45 %.

Last time a big progress in energy efficiency improvement of individual industrial processes was reached and more attention should be paid to industrial sites. Firstly, it allows reducing energy consumption of industrial regions and decreasing pollution reduction considerably, secondly, it provides the possibility to utilise the industrial heat for residential and commercial sectors that are still big energy consumers. From the other hand, it makes appropriate background to implement alternative energy sources including renewables that leads additional reduction of energy costs and improves environmental impact.

These measures need well developed approaches that solve this type of system objectives. To utilise the waste industrial heat for different needs on site level the Total Site Analysis (TSA) should be used as was reported by Klemeš et al. (1997). More recent developments shown, that it could be based on different approaches. Karimkashi and Amidpour proposed a method for analysis an industrial energy system. It is based on the development and modifications of the R-curve concept, which was previously developed by Kimura and Zhu (2000) and later updated by Varbanov et al. (2004). It was also used by Boldyryev et al.

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(2013) to estimate the investments of Total Site power cogeneration. Hackl et al. (2011) analysed large chemical site with use of TSA and proposed retrofit shown 50 % energy saving. However, for low potential industrial heat utilisation the Total Site heat recovery can be used. Nemet et al. (2012) proposed the intermediate utility use. This method was later updated by Boldyryev et al. (2014) and provided a methodology for minimisation of heat transfer area of Total Site heat recovery systems. Last time the authors were concentrated on development of methodology which allow minimise the heat transfer area of heat recovery on Total Site level.

In this paper proposed the methodology to estimate minimum cost for retrofit of Total Site heat recovery systems including energy and investments. The methodology was previously described by Boldyryev et al. (2015). The case study is presented in this paper and show the results and applicability of the offered method.

2. Case study

2.1 Initial data

The case study uses the stream data of three individual processes. These processes were integrated by pinch methodology and streams are accounted for when plotting Total Site Profile described Nemet et al. (2012). There are eight process streams collected to the Table 1 with specific phase and thermo-physical properties.

Table 1: Stream data for Site Profiles

Stream	Type	TS (°C)	TT (°C)	CP (MW/°C)	ΔH (kW)	*h* (MW/(m^2 C))
Process A – liquid 1	hot	100	60	0.05	2.0	0.0007
Process B – Gas 1	hot	180	130	0.03	1.5	0.0001
Process C – liquid 1	hot	80	40	0.02	0.8	0.0005
Process D – liquid 1	hot	145	85	0.01	0.6	0.0006
Process A – liquid 2	cold	70	120	0.03	1.5	0.0005
Process B – liquid 1	cold	100	140	0.04	1.6	0.0009
Process B – Gas 2	cold	150	240	0.02	1.8	0.0002
Process D – liquid 2	cold	130	160	0.01	0.3	0.0007

Hot utility of site is a steam with temperature 250 °C that is produced by boiler house, cold utility is cooling water with temperatures 28 to 35 °C before and after cooling tower respectively. Film heat transfer coefficients for hot and cold utilities are 0.001 and 0.0079 MW/(m^2·°C). The cost of hot utility is 366 EUR/kWy that corresponds to prices of natural gas for Croatia in 2014 and 10 % losses, the cost of cold utility is 36 EUR/kWy.

Specific price of heat transfer area is taken equal to 800 EUR/m^2. It is a price of plate heat exchangers with high corrosion resistance. The coefficient of nonlinearity of heat transfer area price is 0.87. Installation costs with revamp of 1 heat exchanger are 10,000 EUR. Calculations are made for 5 y plant life and return on investment employed of 10 %.

2.2 Calculation results

The Total Site Cost Curves were built (see Figure 1) with use of data in Table 1 varying the minimum temperature approach for Total Site Profiles and temperature of each intermediate utility. Minimum total cost is 2,107,800 EUR and it is localised for minimum temperature approach 31 °C (Figure 1(c)).

The Total Site Profiles was built for optimal Total Site temperature approach and it is as shown in Figure 2. The overlapping part representing the heat recovery was distributed by enthalpy intervals. Sink and Source Profile temperatures limit the temperature range of intermediate utility and utility Pinch appear between Site Profiles and intermediate utility.

The Source Profile requires 2.96 MW of the external cooling capacity and hot utility target is 3.26 MW of middle-pressure steam. There are several kinks on the Sink and Source Profiles on heat recovery of this case study. These breakpoints create three enthalpy intervals as presented in Figures 2 and 3 intermediate utilities are used. The heat transfer area for each enthalpy interval is calculated varying the temperature of intermediate utility from low to upper bound. Optimum levels of intermediate utilities were defined. The results of calculation of heat transfer area for Total Site heat recovery and intermediate utilities characteristics are shown in Table 2.

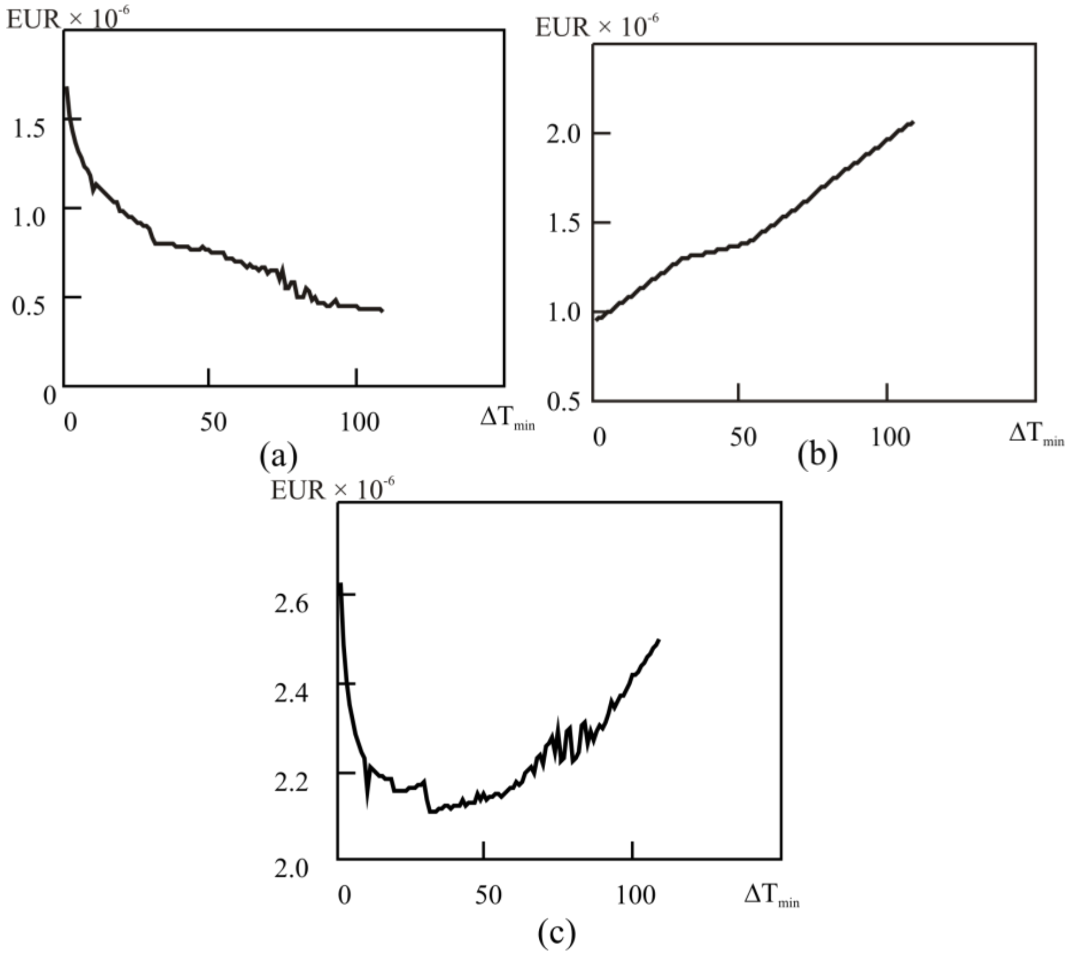

Figure 1: Total Site Cost Curves. (a) – reduced capital costs; (b) – reduced operating costs; (c) – total costs

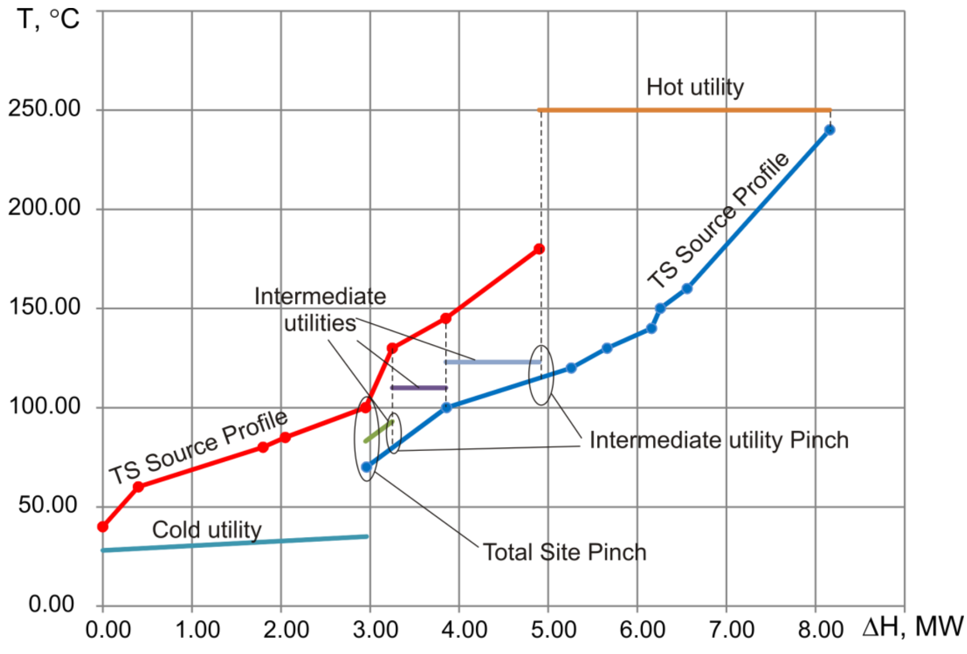

Figure 2: Site Profiles for minimum temperature approach 31 °C

The intermediate Utility Pinches are located at utility 1 and 3, the minimum temperature approach is 8 °C (see Figure 2). The heat exchangers network is presented in Figure 3 and total number of units is 8. In this case study, the heat recovery is increased on 1.94 MW, wherein hot utility is reduced from on 37.3 % and cold utility reduction is 39.6 %.

Table 2: Calculation results of heat transfer area of Total Site heat recovery

Enthalpy interval	ΔH, MW	TS, °C	TT, °C	ΔT_{min}, °C	h_{IM1}, MW/(m^2·°C)	h_{IM2}, MW/(m^2·°C)	S, m^2	N_{HR}
#1	0.30	83	93	8	0.00011	0.00012	786.16	2
#2	0.60	110	110	10	0.0080	0.0054	273.17	3
#3	1.05	123	123	8	0.0079	0.0053	408.87	3

The implementation of retrofit project of site heat recovery requires additionally 1,468 m^2 of heat transfer area of 8 heat plate exchangers. The installation of additional heat exchangers leads to annual economy of 779,880 EUR and 777,474 EUR of capital investments are needed. The simple payback period of proposed retrofit is 11.96 month. The economic results of case study implementation are presented in Table 3.

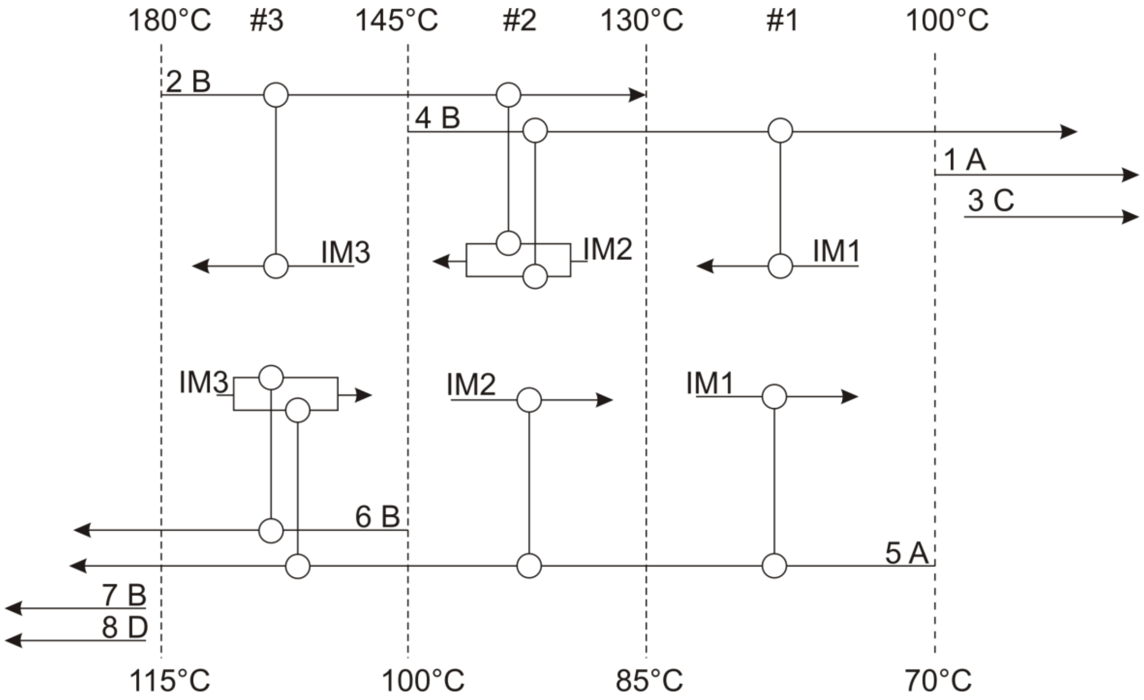

Figure 3: The heat exchangers network of Total Site recovery

Table 3: Economic results of Total Site integration

	Hot utility (MW)	Cold utility (MW)	Recovery (MW)	Investment (EUR)	Saving (EUR/y)	Payback time (months)
Existing Site	5.20	4.90	0	–	–	–
Retrofit	3.26	2.96	1.94	777,474	779,880	11.96

3. Discussion

The paper is a step ahead to application the Total Heat Site heat recovery methodology to real cases and providing the decision making tool for the managers during retrofit and new projects. However, there are some things are still needed deeper discussion and investigation.

The heat exchangers network for Total Site heat recovery is consisted of multiple steam boilers, condensers, water heaters and coolers. This equipment proposed to be placed for each enthalpy interval but it is still the possibility to simplification of heat exchangers network and finding the most profitable way between numbers of units and heat transfer area. The number of heat exchangers heat transfer area is increased comparison to

individual process heat recovery due to heat transfer via intermediate utility. From the other hand heat transfer coefficient for phase change is much higher than for heating and cooling of liquids and gases. In this case, the heat transfer area has to be minimized as mentioned above and combined with numbers of units.
Calculating the total cost of heat recovery integration on Total Site the trade-off is determined. Energy costs have a big influence on this and using of different energy sources will be researched here. Low price energy sources move the retrofit project for low heat recovery to bigger energy consumption. It will decrease even realization of retrofit project which is so important for industrial site operation mode. This retrofit can be done during short time scheduled maintenance. To reduce this energy prices the renewables can be integrated into the Total Site but this should be well analysed from scheduling point of view and appropriate placement into the Site.
The additional analysis of Total Site heat recovery systems should be delivered in future work with attention to capital cost reduction by use the methodology of selection of optimal level of intermediate utility and possibility for cogeneration of heat and power. The design of Total Site heat exchangers network deserves further attention as well as revamp. The summer operation mode should be analysed additionally. During this period, the heating and cooling demands will be changed and operation of heat exchangers network has to be updated as well.

4. Conclusion

The presented methodology allows to estimating minimum total cost for retrofit of Site heat recovery systems. It provides the selection of numbers of heat exchangers, numbers and levels of intermediate utility, hot and cold utility consumption on Total Site level. The case study has shown the considerable potential for energy saving on Total Site level. The use of excess heat provides a way to reduce the use of primary energy and to contribute to global CO_2 mitigation. The heat recovery is increased on 1.94 MW. Total Site heating demands were reduced on 37.3 % and cooling demands on 39.6 %, the estimated capital costs of retrofit project requires 777,474 EUR and payback time is 11.96 months.

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Nomenclature

CP – stream heat capacity, MW/°C;
h – film heat transfer coefficient of process stream, W/(m^2 °C);
h_{IM1} – film heat transfer coefficient of intermediate utility on source side, W/(m^2 °C);
h_{IM2} – film heat transfer coefficient of intermediate utility on sink side, W/(m^2 °C);
ΔH – enthalpy, kW;
S – heat transfer area, m^2;
N_{HR} – number of heat exchangers for heat recovery;
TS – temperature, °C;
TT – target temperature, °C;
ΔT_{min} – minimal temperature difference between two process streams, °C;

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