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A System Analysis of LKAB Malmberget Heating System to Centralisation and Substitution of Fossil Fuels to Biofuels

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An industrial heating system connected to an iron ore mine and iron ore upgrading processing system is presented. The profitability of introducing measures for increased energy efficiency and improved waste heat utilisation has been investigated. The results show that a full centralisation of the system with increased heat recovery and densified wood based boilers is the most financial solution of a life span over twenty years. The system will be more flexible and easy to connect with external users if a centralisation is made. To minimise the risk of increased energy prices it is recommended to increase waste heat utilisation which will be most profitable if the system is centralised. Use of bio based boilers will make the system free from fossil fuels.

1. Introduction

Efficient use of energy in the energy intensive industry has grown in importance with regards to industrial competitiveness during the last decades (Lopez et.al, 2012). Among the factors behind this development are increased energy prices and increased awareness of the emissions related to the use of energy. Increased efficiency and improved utilisation of residual heat in industrial systems are becoming key factors for successful improvement of the total energy efficiency in industrial complexes (Sandberg et al., 2012).

Contemporary research holds many fields targeting increased energy efficiency in different ways. Ranging from research on molecular level to research on policies targeting consumer or industrial behaviours in regions, countries or even continents. Among the fields of research targeting a medium to large scope, the field of process integration and the different methods of the field has been successful not only among academic scholars but also in numerous industrial projects.

During the last decades process integration methods based on Mixed Integer Linear Programming (MILP) has reached industrial acceptance in studies covering many industrial branches such as but not limited to – the pulp and paper industry (Sarmveis et.al. 2003, Karlsson 2004), iron and steel industry (Larsson et.al 2006, Wang et.al 2009), petrochemical industry (Zhang et.al. 2007, Al-Sharrah et.al. 2010) and district heating (Caisisi et.al 2009, Wang et.al 2010).

In the present work an industrial heating system connected to an iron ore mine and iron ore upgrading processing system is investigated with regards to the profitability for introducing measures for increased energy efficiency and improved waste heat utilisation. With increased centralisation in the heating system oil and electricity powered utility boilers are replaced with biomass fired utility boilers located in a heat central and increased excess heat utilisation.

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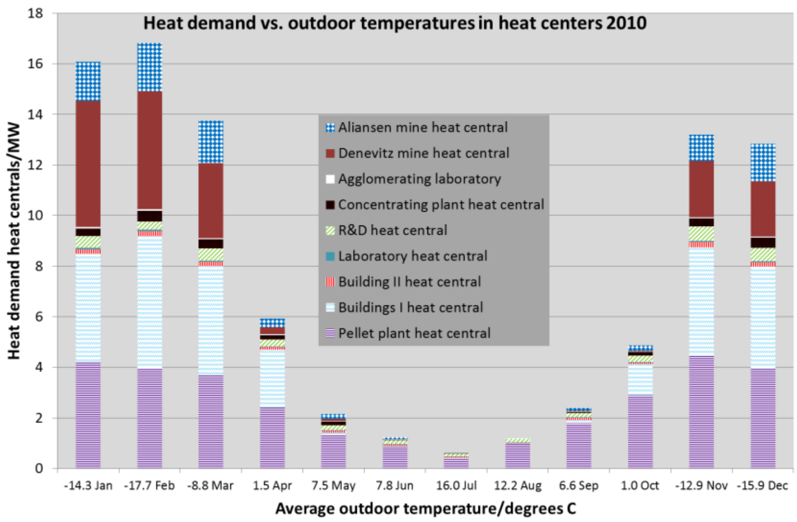
The objective of this work is to evaluate the profitability of shifting from a current decentralised and oil/electricity based heat production to a centralised system. A MILP optimisation model is applied and three predefined cases of increasing centralisation are presented.

2. Model design of LKAB Malmberget

The present heating system is a decentralised system and the model, based on a previous model (Wang et.al 2010), is stepwise modified towards a centralised solution.

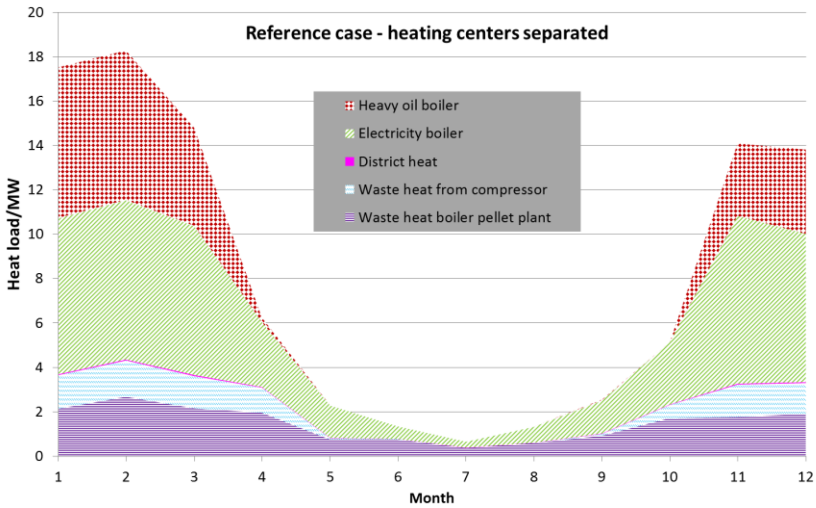


2.1 Existing system

The present heating system considered consists of eight separated heat centrals for buildings, offices, laboratories, showers and mine ventilations. The heat demand and corresponding average outdoor temperature for each month and each heating central 2010 is shown in Figure 1.

Figure 1: Heat demand and outdoor temperatures 2010

From the figure it can be deduced that heat demand is highly dependent on season and hence the outdoor temperature. Also, a few heat centrals are responsible for the major heat load. The installed capacity is only utilized a limited time of the year.



The present heat production in the system is based on heavy oil, electricity and to some extent excess heat recovery from the iron ore upgrading process. Figure 2 shows the supplied energy to the system divided by energy carrier. Electricity boilers are mainly used to heat buildings and oil boilers are used to heat air used to ventilate the underground mines.

Figure 2: Supplied energy in reference case divided by energy carrier

Excess heat recovered in the system emanates also from flue gas recovery boiler from one of the pellet plants. Heat generated from compressed air is used to preheat incoming circulating water in Building I heat central. Many of the boilers in the heating system are old and retrofit investments in different parts of the boiler centres are needed. An engineering consultancy firm estimated the cost for a retrofit of existing system to be 52 MSEK.

2.2 Mathematical model

The process integration concept has been applied for the heating system design. A mathematical optimisation model based on mixed integer linear programming (MILP) has been created. The equation editor used is called ReMIND, and the commercial software CPLEX is used as the solver.

The objective function can be simply expressed by the following mathematical term, and the objective is to minimise the total heat production cost,

$$\min\{C_{HS} = C_{Oper,HS} + C_{Inv,HS}\} \tag{1}$$

where, C: Cost; HS: Heating system; Oper: operational cost, e.g. electricity and fuel cost, energy and environmental taxes, externality cost, maintenance costs for boilers and network, etc.; Inv: investment cost, e.g. equipment cost, construction work.

2.2.1Boundary and alternative

The system studied is progressively centralised in three steps. The existing heating system and the implementation of a bio based heating central and increased heat recovery is illustrated in Figure 3.

Step 1 does not involve centralisation unit but increases the heat recovery of the waste heat boiler from 2 MW to 4 MW. The additional investment for the capacity increase is estimated to be 15 MSEK. In step 2 a heat central is implemented to which all units above ground is connected. The heat central in step 2 consists of two boilers based on densified wood and a small electrical boiler. The increased heat recovery from step 1 is also included in step 2. The estimated additional investment of step 2 is 79 MSEK compared to the reference case. In Step 3 the mine ventilation system is connected to the heat central. An additional larger densified wood boiler is implemented to cover the increasing demand in the extended system. The additional investment for Step 3 compared to the reference is estimated to 114 MSEK.

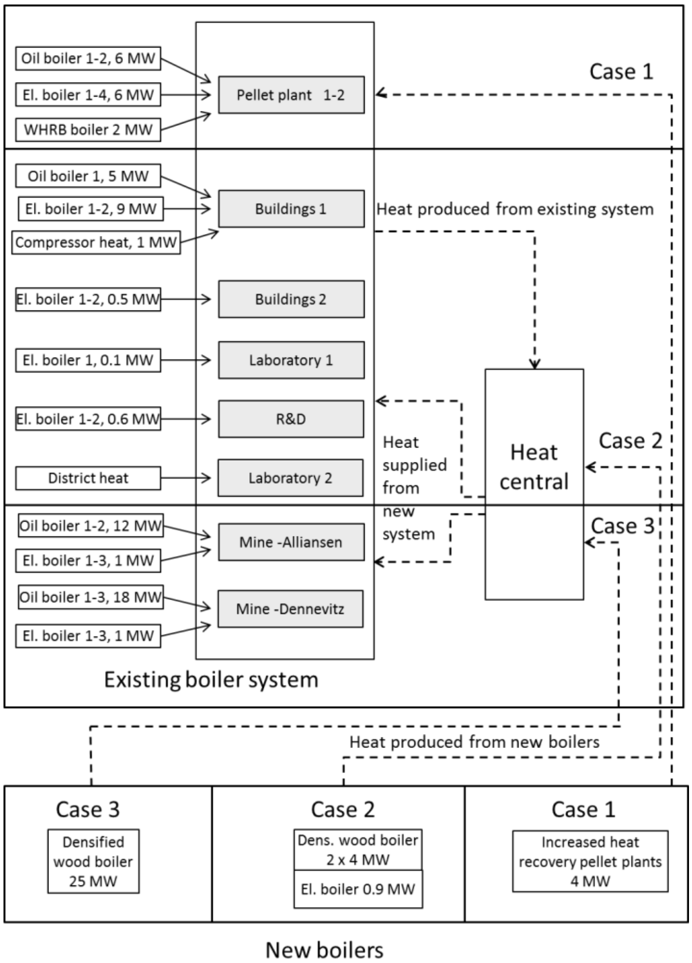


Figure 3: Present heating system and stepwise centralisation of system

Maintenance costs and efficiency parameters used in the calculations were distributed by suppliers of equipment and can be seen in Table 1.

Table 1: Maintenance costs and efficiency of boilers used in the model

Boiler (Fuel)	Maintenance costs (SEK/MWh)	Efficiency
Heavy oil	20	0.85
Electricity	10	0.95
Densified wood	50	0.85
Waste heat recovery	10	0.90

Fuel costs used is based on average numbers in Sweden 2010. The prices for fuel and CO_2 are presented in Table 2.

Table 2: Reference prices 2010 used in the model

Reference prices 2010		
Fuel	Price	Reference
Heavy oil	606 SEK/MWh	spbi.se
Densified wood	300 SEK/MWh	Swedish energy agency
Electricity	625 SEK/MWh	scb.se
District heat	707 SEK/MWh	Swedish energy agency
CO_2 emission spot price EUA	138 SEK/t	bloomberg.com
Exchange	1 € = 9.55 SEK	riksbank.se

3. Results

The objective function of the model was to minimize the heat production cost. The Investment costs, energy costs, maintenance costs and CO_2 costs for each case are summarised in Table 3.

Table 3: Investment costs, energy costs, maintenance costs and CO2 used

Costs	Reference	Case 1	Case 2	Case 3
Investment (MSEK)	52	77	131	166
Energy (MSEK/y)	33	25	18	11
Maintenance (MSEK/y)	0.8	0.8	1.2	1.9
CO_2 (MSEK/y)	0.6	0.4	0.4	0

3.1 Case 1

In case 1 the system is not centralised and the system has limited possibilities to optimise the fuel costs. The possibility to recover heat is increased but can only be used in the pellet plants. Compared to the reference case the heat recovery increases in case 1 on the expense of electricity. Oil use for the ventilation of the mine is minimised and the electricity use is maximised. The electricity price is higher but the efficiency of the electrical boiler is better which makes it more cost effective. The running costs are cut by 8 MSEK/y.

3.2 Case 2

In case 2 the heat centrals covering the demand over ground is connected. The investment is higher but the energy cost is lowered by 7 MSEK yearly compared to Case 1. Maintenance cost goes up 0.4 MSEK and the CO_2 emissions are lower but have a small influence on the total cost.

3.3 Case 3

In case 3 heat centrals for mine ventilation and heating is also connected to the centralised system. The investment costs In case 3 are more than three times higher than the reference retrofit investment. The fuel cost decreases to 1/3 of the reference case. Maintenance costs are more than doubled and the carbon emission cost is brought to zero.

3.4 Return on investment

From Table 3 it can be seen that the total running costs per year decreases when the suggested investment in the system increases. Figure 4 describes the return on investment when using the pay-back method with 10 % discount rate. Case 1 starting to gain return after the fourth year while Case 2 and Case 3 both receive positive numbers during the ninth year. In a life span of 20 years Case 3 will give most return with 58 MSEK savings compared to the reference case. Case 3 starting to be more financial than Case 1 during the 14th year after investment.

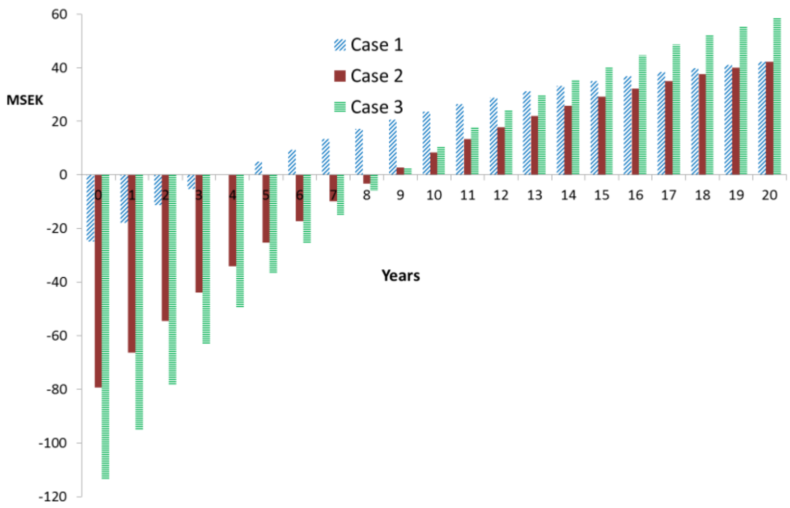


Figure 4: Return on investment pay-back net-present value with 10 % discount rate of case 1-3

4. Discussion

The objective of the work was to evaluate the profitability of shifting from a current decentralised and oil/electricity based heat production to a centralised system. From the investigation it can be deduced that existing decentralised system with upcoming retrofit investment is not efficient. However it is assumed that the new equipment in the reference case will have the same efficiency as the old which is not very likely. Some of the old boilers are from the 1970s and one can expect that the new boilers are more efficient. Anyway Case 1 which increases the heat recovery pays-back in 5 years. This shows that energy efficiency is crucial to get shorter pay-back times. It should therefore be considered to investigate if heat recovery from the pellet plants can be increased even more if a centralised system is built up as in Case 2 and Case 3. Prices on fuels have historically been volatile and to predict future prices is very difficult. The financial evaluation of this work was made considering 10 % discount rate. Sensitivity analysis should be made for a variety of energy costs and discount rates. In Malmberget the heat demand varies significantly from winter to summer. This means the system needs a high maximal capacity but only a part time of the year. The waste heat recovery can't cover for the maximum heat load in winter so extra heat capacity is required. This extra heat can be made from different sources such as electricity, oil, coal, bio mass and heat from district. Which sources to choose is dependent on many things such as direct investment costs, maintenance and expected future fuel costs but also availability of fuels and local policies for instance targets towards green energy. A centralised system will in several ways make the heat deliveries and future improvements more flexible. It will be able to increase the life time of boilers which is not needed all year around. It is easier to connect new buildings and processes to the system and control of the system will be easier when most of the heat is produced in the same building.

5. Conclusions

The present work investigates the financial profitability of introducing a centralized heating system to a mining industry heating system by applying a system analysis approach.
In general, compared to a decentralized heating system, a lower energy cost will be achieved in the centralized heating system, which makes the heat production cost low. Maximized utilization of the waste heat recovered from the industrial process is more preferable, due to the savings of the primary energy and electricity. From a long perspective, the biofuel centralized heating system can be more profitable due to its neutral carbon footprint on the system. In addition, it makes the heating system more environmentally sustainable.

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