# Process integration applied to a papermaking site

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## Abstract

In France, energy consumption in the paper industry represents 10 % of the final energy consumed by the industrial sector, of which 70 % is used for heat purposes. Both environmental and competitiveness issues are pushing the sector to reach more energy savings.

In this context, this paper presents the application of an energy integration methodology inspired by the so-called pinch analysis to a papermaking site of the North of France: instead of focusing only on the utilities or on the major energy-consuming equipment of the process, the energy integration considers simultaneously all the heating and cooling needs of the process and optimizes heat recovery and heat pumping at the whole site scale.

After a first step of data collection and data reconciliation, the composite curves of the site are built to set the maximum target for internal heat recovery, which represents 14 % of the current hot utility consumption. Then, the heat exchanger network is optimized to reach minimal energy requirement and utilities are integrated with a particular concern to high temperature heat pumps that can supply process needs above 90 °C. Last but not least, the heat recovery solutions are selected and prioritized regarding their practical feasibility and their internal rate of return.

As a result, the efficiency of existing heat recovery is challenged, and new realistic heat recovery equipments are proposed, which involve both mature technologies and equipments under development that will be commercially available in a short future. Those results can be applied not only to the studied site, but also to other papermaking sites with similar processes.

## Introduction

This paper presents the application of an energy integration methodology inspired by the so-called "pinch analysis" (Kemp, 2007) to a French papermaking site. The study was conducted through a partnership between Arjowiggins Graphic, a paper manufacturer, the EPFL, an academic partner bringing the methodology and the optimization tool (Bolliger, 2009), and EDF, the main French electricity producer and supplier.

The choice of this papermaking site was motivated by several reasons: first, the paper industry in general is one of the most energy intensive industries, more and more constrained by environmental regulations and wishing to decrease its energy consumption also because of the rise of energy prices and the search of competitiveness. Then, Arjowiggins Graphic is strongly involved in sustainable development actions and is continuously in search of improving the energy efficiency of its production sites: thus, they were interested to go further and to find new energy savings opportunities by applying process integration methodology.

The global and systematic process integration methodology applied in this study has already been presented in a previous paper (Salgueiro, 2011). In the present article, we will more particularly focus on the technical feasibility of the solutions proposed by the optimization tool.

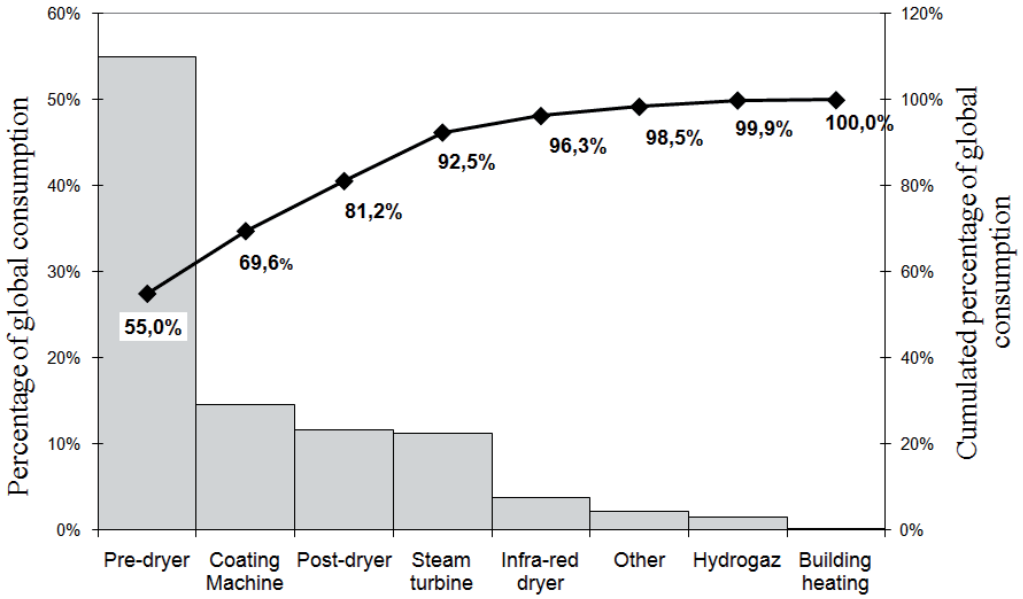



*Figure 1: Percentage of heat consumption of the main equipments of the site.*

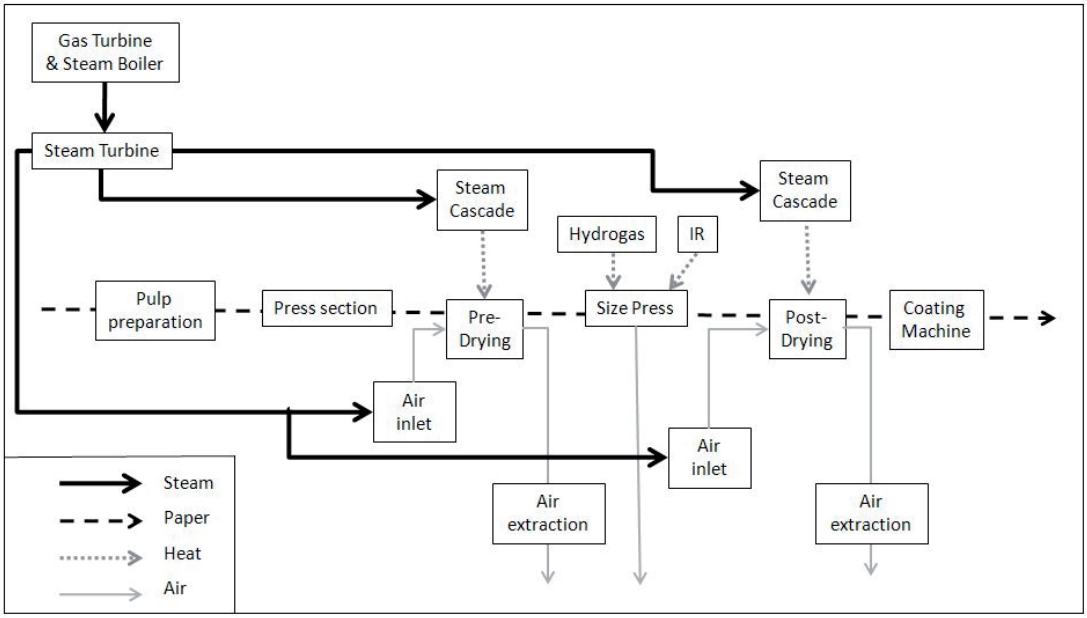



*Figure 2: Modules of the papermaking process model developed with Belsim Vali-Modeller software.*

## Modelling of the papermaking site

We chose to study a strict papermaking site, where pulp enters as a raw material to produce paper – by opposition to an integrated papermaking site where both pulp and paper are produced.

The site consumes gas and steam for heating purposes: the repartition of heat consumption among the process units on site is illustrated on Figure 1.

The main energy consumer is the paper machine constituted of the pre-dryer and the post-dryer. This equipment, together with the coating machine and the steam turbine that produces electricity auto-consumed by the site, reach more than 90 % of the site heat consumption.

Considering the high complexity of the process and the incomplete data from existing report or current on-site energy monitoring, it was necessary to build a model of the process, so as to establish its mass and energy balances. This process modelling was conducted using the Vali-Modeller software developed by Belsim, chosen especially because of its data-reconciliation capabilities. Thus, based on data filled with a given level of accuracy and on equations linking the different variables, this software solves a constrained non-linear programming problem so as to deduce missing data and to correct inaccurate data.

As a result, we get a complete and consistent set of data. The structure of the model and its different modules are presented on Figure 2.

The papermaking process begins with the "stock" preparation, where dry pulp, water and additives are mixed together. Then, the stock enters the paper machine and undergoes me-

chanical drying followed by a thermal drying section: this section is composed of a pre-dryer, a "Size Press" (where the paper receives some additives and is dried by infra-red rays) and a post-dryer. At the end, the paper receives a final coating.

In order to get practical results, we decided to model the existing energy supplying technology. In particular, we entered in the detail of the paper machine, where heat is provided to paper through cylinders linked together by a steam cascade as schematized below:

Steam from the network enters a first group of cylinder represented by "Cylinder 1". Once heat has been supplied to the paper, the mixture of steam and condensates that exits "Cylinder 1" is flashed: the resulting steam at a lower temperature is sent to the next group of cylinders represented by "Cylinder 2", whereas the remaining condensates – as well as potential excess flash steam – is available for heat recovery.

At the end of the steam cascade, all the condensates are gathered in a tank and sent back to the boiler at 85 °C. A condenser is needed to evacuate the remaining latent heat so as to ensure the vacuum in the last cylinders.

The paper runs at counter-current of this cascade, being in contact first with "Cylinder 2" at a lower temperature, then with "Cylinder 1" at a higher temperature.

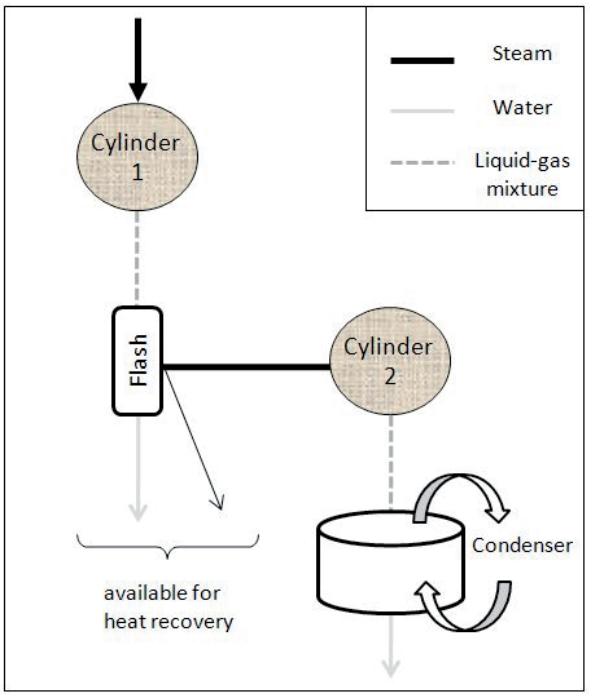



*Figure 3: schematic representation of two-level steam cascade.*

## Composite Curves and internal heat recovery potential

Once this reconciled model has been established, we were able to characterize the thermal power and temperature of the heating and cooling needs of the process, in other words to define the hot and cold streams of the process, which is the starting point of a process integration analysis.

This information is entered in the optimization tool that solves the heat cascade between process streams and utilities (Maréchal, 1998): as a result, the hot and cold composite curves of the site are drawn, aggregating respectively the hot and cold needs of the process. Those curves are presented on Figure 4 and are labelled to ease their interpretation.

This representation enables to see the direct heat recovery potential of the process, given by the overlap of the hot composite over the cold composite curve: this shows a maximal recovery potential of 5.5 MW, which corresponds to a minimal hot utility requirement of 15.6 MW.

Currently, the hot utility consumption of the site is about 18 MW: thus, we deduce that 3 MW of this potential is already recovered through existing heat exchangers that preheat the hot air entering the paper machine with the humid air extracted from the paper machine hood and with the steam condensates from the cylinders.

As a consequence, the direct heat recovery potential of the site is 2.5 MW, which represents 14 % of the current utility consumption.

## Utilities optimization

The specificity of the methodology is that it optimizes simultaneously internal heat recovery and external utilities integration.

When dealing with utilities, the most adapted representation of the process needs is the Grand Composite curve which plots the heat deficit and heat excess as a function of temperature (illustrated in Figure 5). This curve is particularly interesting to determine at which temperature level the utilities are needed, and enables us to see some heat pump potentials as cooling needs under pinch point match heating needs above pinch.

Thus, we decided to simulate the following utility scenarios:

- Scenario 1: existing utilities (reference case)
- Scenario 2: existing utilities with integration of a "small" heat pump with a cold source at 97 °C and a hot source at 107 °C.
- Scenario 3: existing utilities with integration of a "medium" heat pump (77 °C cold source -110 °C hot source)
- Scenario 4: existing utilities with integration of a "large" heat pump (50 °C cold source -120 °C hot source)

The integrated grand composite curve for the Scenario 1, showing both process needs and integrated utilities, illustrates the current utility system that consists in a Gas Turbine supplying heat to a 40-bar steam generator. Steam enters a steam turbine to produce electricity and the outlet 4-bar steam is supplied to the process.

For each of the three heat pump scenarios, we entered the temperature levels as input data of the optimization tool that returns the optimal thermal power to be supplied by each heat pump as output data. The heat pump size resulting from the optimization is presented in the Table 1.

The estimated Coefficient Of Performance (COP) is the Carnot efficiency of the heat pump by an isentropic efficiency factor of 0.55.

As a last step, once the complete hot and cold streams list of both process and utilities is defined, a second optimization is conducted to define the heat load distribution (HLD which defines the process and utility hot stream – cold stream heat exchanges needed to reach the heat recovery and utility targets (Maréchal, 1999): those HLD results are the base of the following discussion.

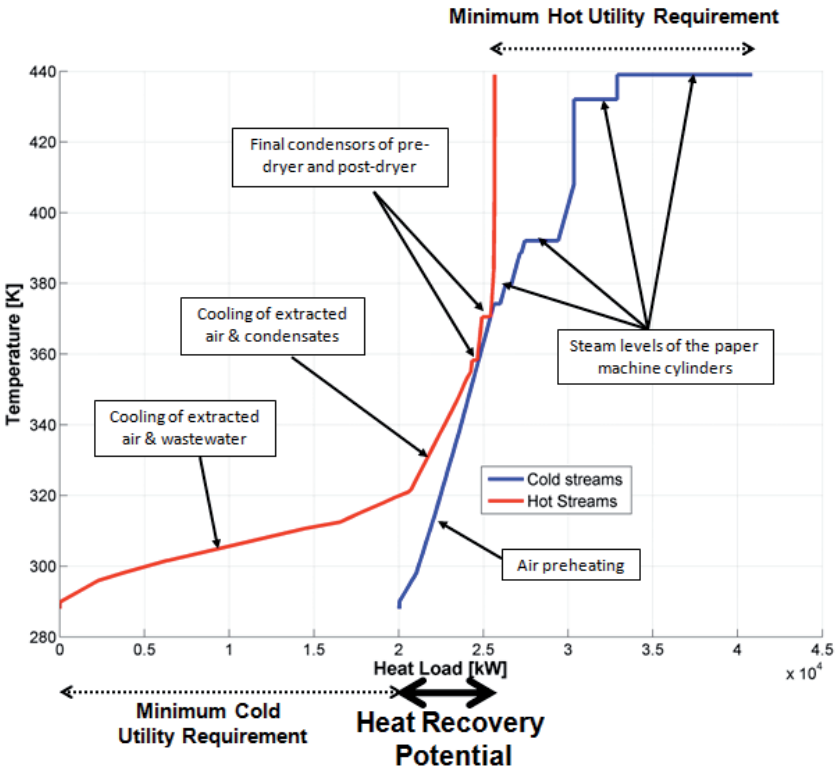



*Figure 4: Hot (left) and cold (right) composite curves of the papermaking site.*

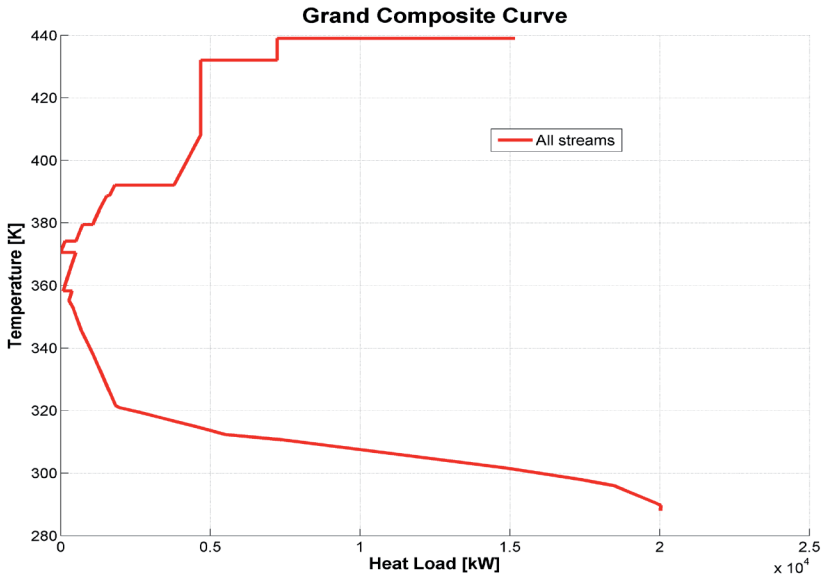



*Figure 5: Grand composite curve representation.*

## Detailed interpretation of heat load distribution results

The main heat sources potentially available for heat recovery are presented in the Table 2.

The flow B gathers all the condensates and flash steam excess available between the cylinders of the paper machine. The flow C represents the energy lost at the final condenser of the pre-dryer section, and the flow D the one of the post-dryer section.

The rough HLD optimization results were not applicable directly and needed to be refined:

- some of the recommended heat exchangers were too small to be realistic so we focused only on the heat exchangers that got a sufficient size
- some of the recommended heat exchangers were infeasible because of the distance between equipments, so we ignored them
- as 4 different utility scenarios were simulated, we got 4 different HLD results and had to make the synthesis of those 4 results for each of the main hot source

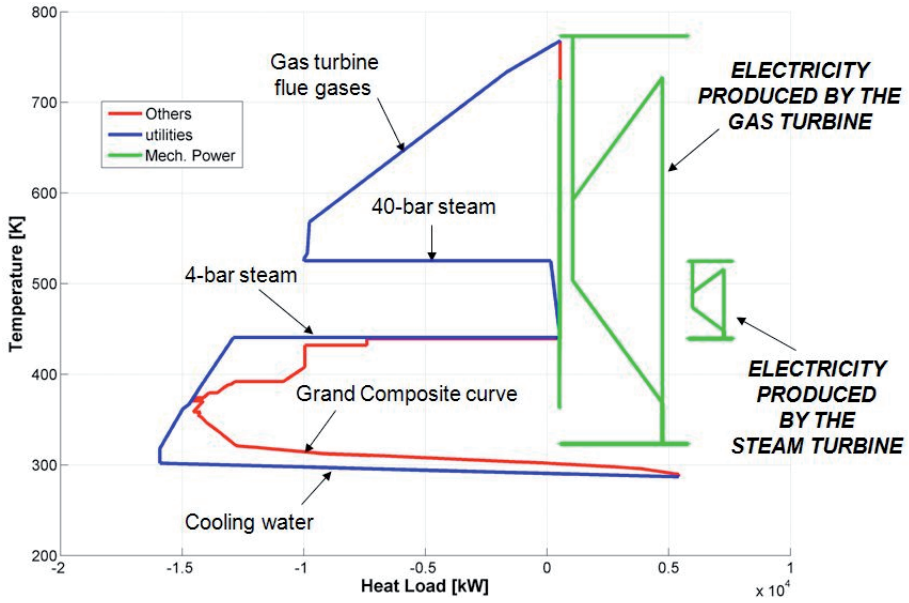



*Figure 6: Integrated grand composite curve.*

**Table 1: Characteristics of heat pump optimization in the different scenarios.**

| Scenario | Cold Source (°C) | Hot Source (°C) | Heat available at hot source (kW) | Current utility savings (%) | Estimated COP |
|---|---|---|---|---|---|
| HP of Scenario 2 | 93 | 107 | 430 kW | 2.5% | 14.9 |
| HP of Scenario 3 | 77 | 110 | 880 kW | 5% | 6.4 |
| HP of Scenario 4 | 50 | 120 | 3900 kW | 22% | 3.1 |

**Table 2: Main hot streams of the papermaking site.**

| | Maximum available thermal power | Initial temperature | Final temperature |
|---|---|---|---|
| A-Flue gases from Gas Turbine | 1,600 kW | 160 °C | 100 °C |
| B-Steam condensates of pre & post-dryer | 540 kW | 115 °C | 85 °C |
| C-Final condensation of pre-dryer steam cascade | 300 kW | 86 °C | 85 °C |
| D-Final condensation of post-dryer steam cascade | 500 kW | 98 °C | 85 °C |
| E-Humid Air extracted from the dryer hood | 4,000 kW | 87 °C | 45 °C |
| F-Wastewater | 6,400 kW | 40 °C | 25 °C |

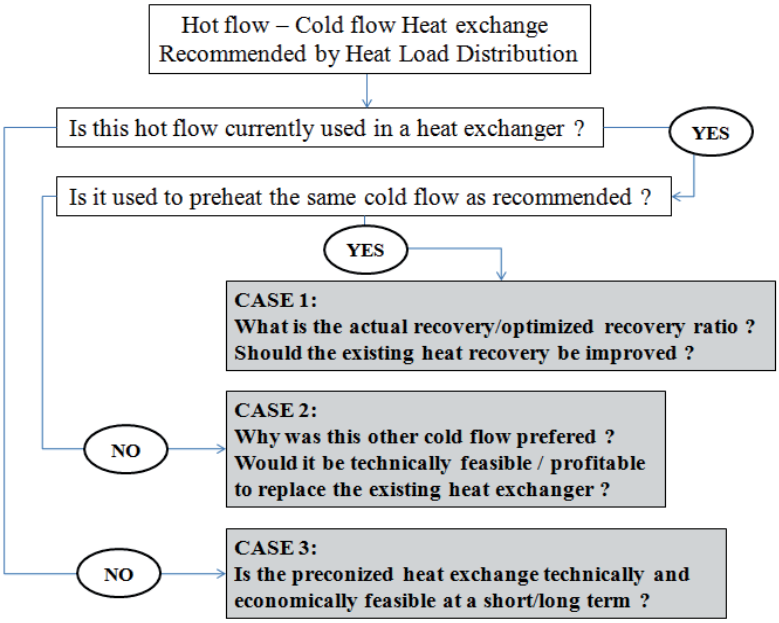



*Figure 7: The relevance of the proposed hot flow–cold flow heat exchange.*

Once this preliminary sorting was made, we applied the following methodology to assess the relevance of each of the proposed hot-flow-cold flow heat exchange.

The solutions that were selected through this process are presented in the Table 3.

We based our analysis of the technical feasibility of heat pumps on the ongoing developments at EDF R&D on high temperature heat pumps working with water as refrigerant fluid (Chamoun, 2012).

We identified 4 types of solutions:

- some necessary **preliminary actions** that are not a direct result of the HLD but need to be done before putting a heat recovery solution in application
- the **short-term solutions** refer to heat recovery action that require mature technologies available on the market. The expected payback time of these solutions is small (< 3 years)
- the **mid-term solutions** refer to heat recovery action that require innovative technologies that are already available on the market or should be available soon. Because of higher investment costs of those solutions by unit of saved energy, the expected payback time of these solutions is higher (3 to 5 years)
- the **long-term solutions** refer to heat recovery actions that require technologies that are still under development – a heat pump condensing above 120 °C – and will probably need more time to be available on the market. Due to the innovative character of the technology combined with a lower energy performance, we expect a higher payback time for these solutions.

As a synthesis, the priority is to minimize the heat needs of the paper machine – in particular by improving the air tightness of the hood so as to decrease the parasite air flow which seems too high – and to carry out an evaluation of the existing heat recovery on stream B.

Once those preliminary actions are taken, new heat recovery can be considered.

The remaining heat in the gas turbine flue gases match with air preheating needs: however, in the technical and economic study has to take into account the seasonality of this recovery, as the gas turbine only works during winter.

The heat available at the condensers of pre and post-dryer (C ad D) lead to two incompatible solutions: direct use through hot water generation for size press additives or heat pumping. The recovered heat is higher with heat pumping but it generates a higher investment cost and some supplementary operating costs linked with the electricity consumption of the heat pump.

Considering the temperature level of the hot source, it is more relevant to use the heat at the pre-dryer condenser to generate hot water: this should be sufficient to cover the whole hot water needs and to suppress the "Hydrogaz" boiler that currently generates this hot water.

Then, the heat at the condenser of the post-dryer would be recovered by a heat pump: if the temperature difference of the heat pump is small (under 10 °C), we would use mature technology like mechanical vapour recompression or thermocompressor. For higher temperature difference, some innovative compressors would be needed. A huge amount of energy is available by condensing the exhaust humid air: however, the water content is low and so is the temperature level. By direct exchange, it is possible to produce warm water.

The integration of a heat pump to higher the temperature level is theoretically possible, but the temperature difference achieved by such heat pump would need some innovative compressing technology, and the coefficient of performance would be low. This solution is neither technically realistic nor profitable unless increasing the water content of exhaust air so as to increase its temperature.

Finally, no heat recovery solution is proposed for wastewater, as other waste heat flows at a higher temperature are available on site.

**Table 3: Synthesis of the heat recovery solutions given by the energy integration analysis.**

| HEAT SOURCE | Immediate Action | Short-term solution | Mid-term solution | Long-term solution | Expected savings (kW – yearly tons of steam) | Expected payback time |
|---|---|---|---|---|---|---|
| **A** | Improve the air tightness of the hood to decrease the flow of parasite air and control the air extraction by variable frequency drive motor | Preheating of drying air entering the paper machine | | | 1,600 kW<br>315,000 t/y | < 3 years |
| **B** | Check the efficiency of existing heat recovery | If necessary, improve the existing recovery | | | Depends on the existing recovery | |
| **C** | | Generation of hot water at 75 °C for size press additives | | | 230 kW<br>45,000 t/y | < 3 years |
| | | | *Install a high temperature heat pump on the condenser to higher the temperature and reuse the heat in the low pressure cylinders* | | 300 kW<br>59,000 t/y | 3 < P < 5 years |
| **D** | | *Generation of hot water at 75 °C for size press additives* | | | 230 kW<br>45,000 t/y | < 3 years |
| | | | Install a high temperature heat pump on the condenser to higher the temperature and reuse the heat in the low pressure cylinders | | 400 kW<br>79,000 t/y | 3 < P < 5 years |
| **E** | Improve the air tightness of the hood to decrease the flow of parasite air and control the air extraction by variable frequency drive motor | Generation of warm water at 45 °C for additive preparations | | | 1,000 kW<br>197,000 t/y | < 3 years |
| | | | | Put a very high temperature heat pump to higher the temperature level of humid air so as to preheat inlet air | 2,000 kW<br>394,000 t/y | > 5 years |
| **F** | No Heat Recovery Opportunity | | | | | |

## Conclusion

We applied the energy integration methodology on a site that had already substantial heat recovery in place.

Despite this fact, we found a direct heat recovery potential of 2.5 MW, almost equal to the existing heat recovery, as well as indirect heat recovery potentials through heat pumps.

In practice, all recommended direct or indirect heat exchanges were not achievable: after selecting the most relevant results we were able to draw a road-map of solutions that should be explored by the manufacturer at shorter or longer term. Today, the proposed immediate actions and short-term solutions are still under review.

This study also showed that the inapplicability of the optimization results could be lowered by taking into account industrial constraints at the modelling stage: for instance, in many industrial sites, direct heat exchange can be impossible due to safety or product quality issues, long distances or non-simultaneous process operations.

In light of this observation, new functionalities of the optimization tool were developed (Becker, 2011): in particular, it is now possible to divide the process and/or utilities models into sub-systems. Inside a sub-system, direct heat exchange can occur, whereas it is not allowed between sub-systems: as a consequence, heat exchanges inside sub-systems are prioritized, and an indirect heat transfer system is needed for heat exchanges between sub-systems.

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