NON-PEER-REVIEWED PAPER

Energy efficiency in industrial surplus heat

Mr Lauri Suomalainen
Senior Consultant, Energy Efficiency in Industry
Motiva Oy
P.O. Box 489 (Urho Kekkosen katu 4–6 A)
FI-00101 Helsinki
Finland
lauri.suomalainen@motiva.fi

Ms Hille Hyytiä
Head of Unit, Energy Efficiency in Industry
Motiva Oy
P.O. Box 489 (Urho Kekkosen katu 4–6 A)
FI-00101 Helsinki
Finland
hille.hyytia@motiva.fi

Keywords
energy efficiency improvements, heat pump, dryers, surplus heat, continuos improvement

Abstract
There is a big energy savings potential in industrial surplus heat. More information and experiences about new technologies is needed in order to improve economical utilization of surplus heat. It has been estimated, that in Finland the technical potential to use surplus heat is about 19 TWh/a and the economically feasible amount about 4–5 TWh/a.

The purpose of this energy efficiency in industrial surplus heat project was to add the knowledge of industry, equipment suppliers, consultants, energy auditors etc. how surplus heat can be used more effectively by using new technology for example industrial heat pumps and ORC-technology. The purpose of the project was not only to make use of the surplus heat but also present practices how look for processes where surplus heat could found profitably and how to avoid surplus heat in the first place. The first step is to check that all current heat recovery systems are working properly.

Surplus heat cases were studied in nine industrial plants and in one combined community and industrial plant case in close co-operation with six equipment suppliers and consultants. During the project participating plants presented their surplus energy analysis case in totally ten workshops. Workshops were open to all participants. Every case was reviewed several times during the project as more material was collected and measurements were done. Along with the analysis project heat pump, ORC and drying case studies were carried out in some of the participating plants. Consultant studied cases proposed by the plants and prepared report of case's payback time, pros and cons.

The results of the project are presented in a report with four separate parts: 1) General Guidelines to Energy Efficiency in Industrial Surplus Heat; 2) Industrial surplus heat solutions using heat pumps or ORC; 3) Drying using industrial surplus heat; 4) Industrial surplus energy audits. Guide for energy auditors.

Introduction
There is a big energy savings potential in industrial surplus heat. More information and experiences about new technologies is needed in order to improve economical utilization of surplus heat. It has been estimated, that in Finland the technical potential to use surplus heat is about 19 TWh/a and the economically feasible amount about 4–5 TWh/a.

Motiva carried out the project Energy Efficiency in Industrial Surplus Heat. This project was financed by the Ministry of Employment and the Economy, Finnish Energy Industries (ET), participating industrial companies, one community and equipment suppliers. The purpose was to learn what can be done in enterprises to boost the use of secondary heat and how to use surplus heat economically. The first step in all cases is to check that all current processes and heat recovery systems are working properly.

The main targets of the project:

- Increasing the economical use of surplus heat and to improve the use of secondary heat in industry.
- To promote the use of energy efficient technology and create new business activity.
- To improve competitiveness of industrial enterprises.

- To prepare enterprises to adopt to the energy efficiency directive.
- To collect know-how and utilization cases of surplus heat.
- To improve methodology in industrial energy audits.

The project was divided into three subprojects:

- Surplus heat analysis.
- Heat pump and ORC.
- Drying of (bio)fuel.

Ten industrial companies and one community took part in this project. The companies were from energy intensive branch (metal production, paper mills, oil refinery etc.) and from energy production (power plants). The only community participant was planning to change their district heating system from natural gas to industrial surplus heat by using heat pump technology or biomass.

EQUIPMENT SUPPLIER'S ROLE

Six equipment suppliers took part in the project. Their role was to bring their know-how and experience and also budget prices for the companies to calculate cost and payback time for the investment proposals. They also play a big role in the project workshops where the companies presented their surplus heat problems and possible solutions. The equipment suppliers could during the project get acquainted with the problems and possibilities of the companies and also to get to know the key people working with energy efficiency. They gave valuable information to possibilities how to use the equipment. This made it possible for the companies to make tenders to existing problems and be also active during the years to come.

WORKSHOPS

Workshops were a key element in the project. All topics were openly and thoroughly discussed in the workshops. During the project participating plants presented their surplus energy analysis case in totally ten workshops. Workshops were open to all participants. Every case was reviewed several times during the project as more material was collected and measurements were done. Along with the analysis project heat pump, ORC and drying case studies were carried out in some of the participating plants. Consultant studied cases proposed by the plants and prepared report of case's payback time, pros and cons.

Surplus heat

DEFINITION OF SURPLUS HEAT

Surplus heat was defined to be used energy that goes to atmosphere or to water system, Figure 1.

BASIC PRINCIPLES OF UTILIZING SURPLUS HEAT

There are several factors that have to be taken into account when thinking of utilizing surplus heat. They are:

- Temperature level(s) and duration.
- Enthalpy flow (thermal power).
- Medium and phase of the flow.
- Chemical properties and purity of the medium.

Even if only one of the factors is unfavourable it may be impossible to use the surplus heat. If there is great potential in the surplus heat it may be useful to check the possibilities how to tackle the unfavourable factor.

HOW TO APPROACH SURPLUS HEAT

When planning how to make most of surplus heat it is important to look at the big picture and not to grasp the first and easiest solution.

First of all it is important to check that all the existing heat recovery systems are working properly and efficiently. Process operation values may have changed since the installation time and that may be one of the reasons why heat is wasted. This gives also possibilities to check if surplus heat can be used more efficiently by improving the current installation by for example by adding some measurements and updating the automation system. Sometimes the simplest way to use surplus heat is to make changes in pipe connections and using heat exchangers.

Heat from processes etc. can be used as secondary energy in the same or some other processes. This can simply be done for example by changing the pipe connections of the process flows or by updating the process automation.

It is useful and necessary to approach the finding and use of surplus heat in a systematic way. Pinch analysis is one way to approach this problem. Pinch analysis is a systematic method to analyze cooling and heating needs of a plant. The analysis gives answers to the following questions:

- What part of the need for energy can be covered by internal use of heating and cooling energy and how much has to be brought from outside?
- What kind of heat exchanger network is needed?
- What is the theoretical minimum for heating and cooling?

The greatest benefits of such analysis are that energy saving possibilities is found, partial optimization is avoided and knowledge of the process is improved. On the other hand the analysis very laborious and needs lot of time to perform.

Pinch analysis gives best results in plants where lots of energy is used, the process is continuous and the instrumentation is comprehensive. Pinch analysis gives poor results if any when there are batch processes, production varies a lot and instrumentation is inadequate.

If Pinch analysis does not lead to any process changes or it does not give any good alternative then next step has to be taken, Figure 2.

In order to make use of surplus heat by ORC installation process the temperature should be over 100 °C and the duration of the heat source more than 6,000 h/a. During this project the companies couldn't find such heat sources in their plants. One major reason was that the companies have done energy efficiency work for years so the easy cases have been found.

There may be need to use a heat pump or thermo compressor, or mechanical or by drying fuel material to use surplus heat economically. There are several types of heat pumps, mechanical heat pump, absorption heat pump, mechanical vapour recompression (MVR) and term compressor. They have different

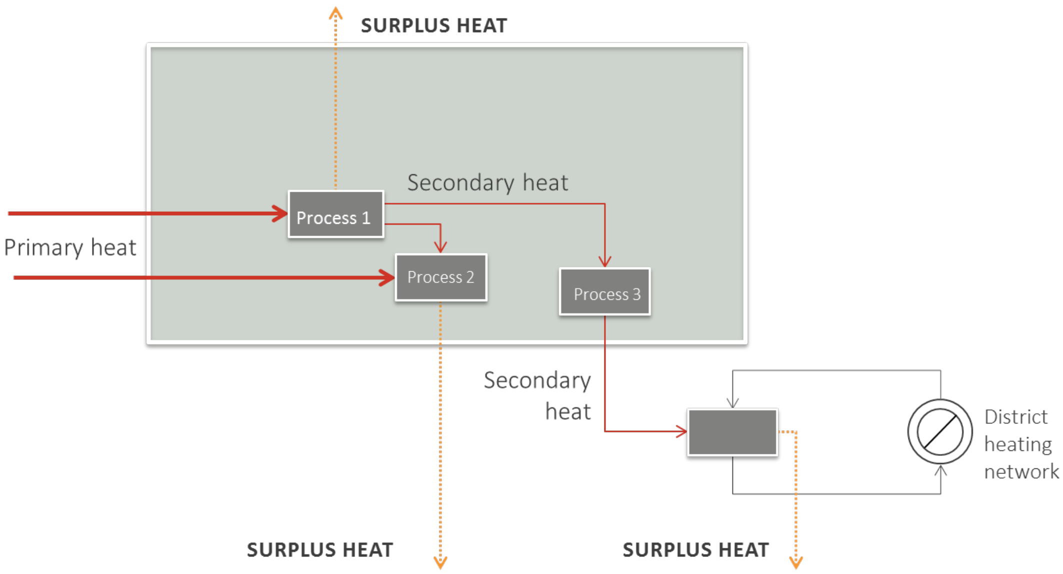

Figure 1. Definition of surplus heat.

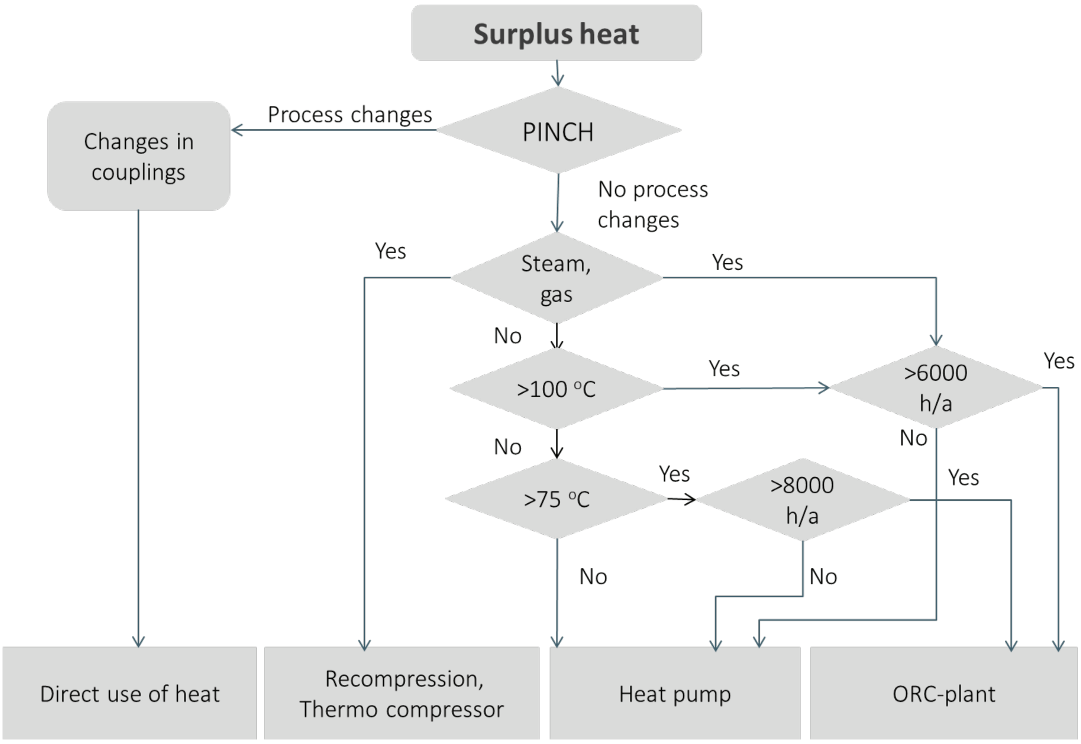

Figure 2. Possibilities to use surplus heat.

properties and areas of operation. Their typical performance factors were presented in the study so companies could compare how the equipment would fit their need.

Examples how to use surplus heat

All industrial cases are different from one another. That's why several different cases from different industrial sectors were chosen to this project. Examples give ideas and by comparing them to the situation on one's own field it is possible to get an idea if it would work under those circumstances.

EXAMPLE 1. HEAT SINKS OUTSIDE PLANT LIMITS

When a plant has plenty of surplus heat that it cannot use inside the plant limits it is usually possible to consider selling the surplus heat to neighboring company or community. There are basically three ways how to deal with this possibility, by selling the surplus heat

- as district heat to a local district heat company
- to enterprises near by
- to new business company for e.g. biofuel drying.

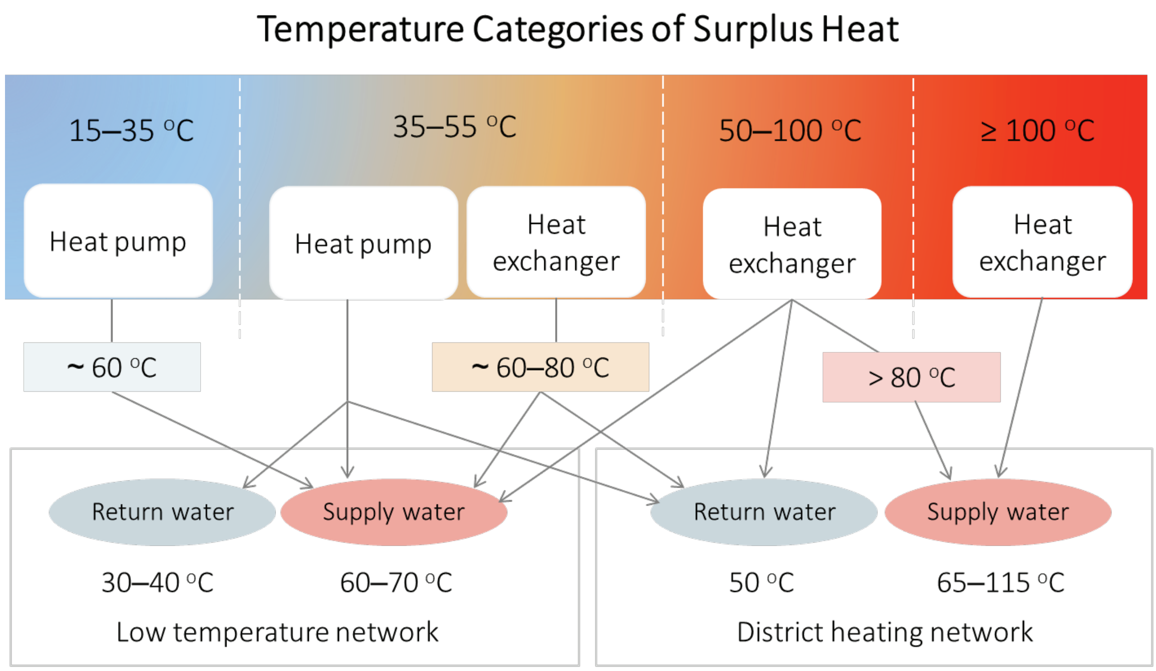

Figure 3. Temperature categories of surplus heat.

If there is no community or neighboring plants nearby it is usually not possible to sell surplus heat due to big investment cost in pipe lines. A new plant for drying biomass could then be a very lucrative possibility as biomass is becoming more and more popular fuel.

Temperature levels have to be identified so that surplus heat can be utilised properly. Temperature levels can be divided into four categories according to how the surplus heat can be used, Figure 3.

EXAMPLE 2. SELLING SURPLUS HEAT TO OTHER PARTY

It is very important that when surplus heat is sold to other party the terms and agreements are up-to-date and thoroughly checked. There are lots of technical and economical things and contractual relations that have to be considered and verified before the agreements are signed.

The most important things that have to be agreed technically are:

- Seller: Heat source, temperature levels, peak output, quantity of energy, duration, reliability of delivery and limitations.
- Byer: Heat sink, peak input, temperature levels, quantity of energy, duration and limitations.
- Distribution to customers: Temperature and pressure levels, flows.

From the economic and legal point of view there are also several things that parties have to agree on, e.g.:

- Investment cost per party (joint acquisition).
- Tariffs.
- How to change the tariffs, terms etc.
- Length of the term and dismissal.
- Maintenance etc.

All of those terms and conditions have to be thoroughly viewed and agreed which takes time, resources and money. The better this work is done fewer difficulties will arise.

EXAMPLE 3. DRYING FUEL

Surplus heat can be used as such to (pre)dry biomass fuel or products. Drying of fuel (biomass, coal etc.) not only improves the heat value of the fuel but flattens the fluctuations in the moisture content and improves the burning conditions and makes the control of the boiler much easier. Also the heat surfaces of the boiler will stay cleaner. These things are very important especially for biomass boilers.

There are several ways to dry biomass. This can be done by a drum dryer, a flash dryer or by a screen dryer etc. All the dryers have the advantages and disadvantages which have to be taken into account when choosing one for the purpose. The most frequently used dryers are drum dryers. The moisture content will drop typically from 50–60 % to 10–30 %. This can lead to 10–15 % savings in fuel cost.

EXAMPLE 4. HIGH TEMPERATURE COOLING WATER

An accumulator is attached to area heating network via a heat exchanger in an industrial plant, Figure 4. The purpose of the accumulator is to receive warm water from the process and keep the pipelines open during standstill time in winter. The heat to the heat recovery circuit originates from periodically used processes' cooling water circuits.

Accumulator was not working properly. Accumulator can be loaded when the temperature of the heat recovery system is more than 92 °C. For some unknown reason the heat recovery circuit was cooled by lower temperature water so that accumulator could not be loaded and heat was wasted to the atmosphere via cooling towers.

RECOMMENDATIONS

It was recommended that the temperature levels should be raised to the design temperature levels (120/100 °C). This would improve the efficiency of the heat recovery system, greater amount of energy could be recovered and less energy would be wasted via cooling towers. It was estimated that about 40 GWh/a could be benefitted from this arrangement. During summer time area heating network can't handle all that energy so the yearly savings will be somewhat smaller.

PROCEEDINGS

The company was instructed to start raising the temperature level of the accumulator slowly as the outside temperature starts falling in late September. This operation was considered very cost effective as no investment was needed; only temperature levels in the operation room needed to be changed by the operator.

This successful case launched another analysis in a nearby cooling network.

EXAMPLE 5 POWER PLANT

In power plants auxiliary condensers are used in order to keep the power plant running at the minimum load during disruption in production or during summer time when there is not enough load in the district heating network. By keeping the boiler running it is easy to increase the production rapidly.

In this case the steam flow through the auxiliary condenser was 4.6 barg and average temperature was about 196 °C. The maximum thermal power was 15 MW and the usage time was 1,000 h/a. About 13 GWh/a of heat has been driven through the auxiliary condenser.

Calculations were made if steam could be utilized by using ORC-process to generate electricity instead of wasting the heat. Water of the nearby river (0–22 °C) could be used as a heat sink, Figure 5. Due to environmental reasons the heat driven to the river has been limited to approximately 20 GWh/a. The main technical details are presented in Table 1.

The plant cost was estimated to be about €1.1 M. Despite proper temperature level of the heat source this case turned out not to be economically successful due to short running time.

Obstacles in utilizing surplus heat

Industrial plants have done a lot of work in energy efficiency and energy savings and benefitted from their work. The driving force behind these efforts has been especially increasing price of energy but also energy efficiency, environmental legislature and equipment development (e.g. heat pumps and automation).

Despite of this progress there is vast amount of surplus heat than can be used economically. The obstacles in surplus heat utilization can be divided in to four categories:

- economic feasibility
- lack or unreliability of proper technology
- lack of proper heat sinks
- obstacles in legislature or in politics or public opinion.

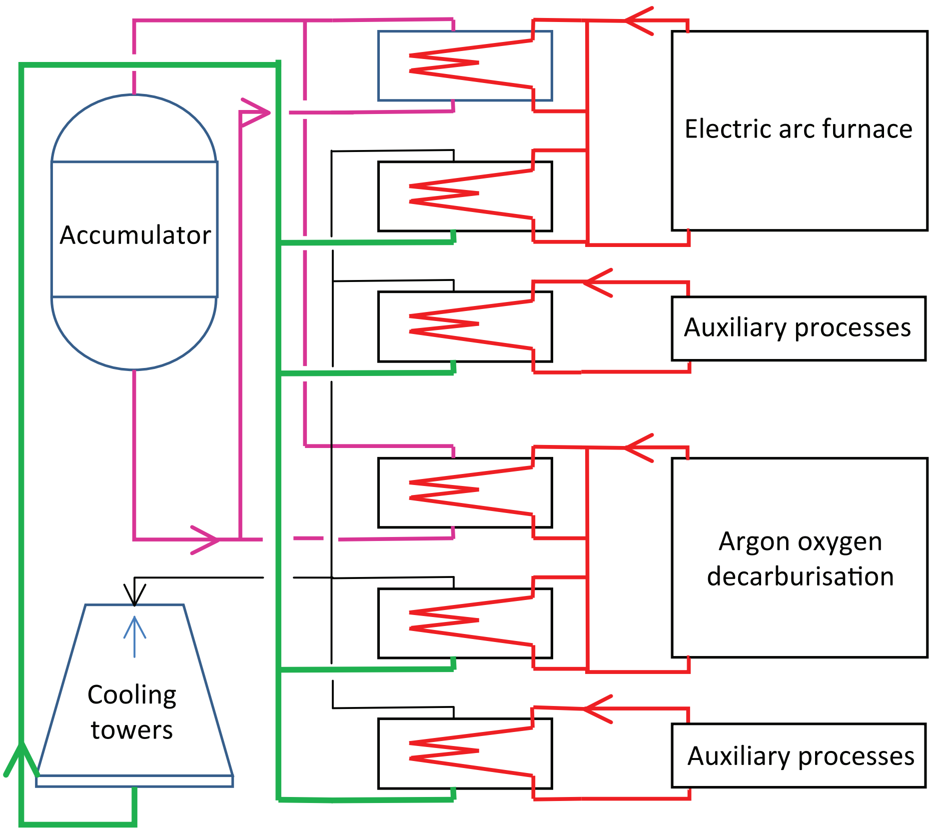

Figure 4. Principle schema of the accumulator network.

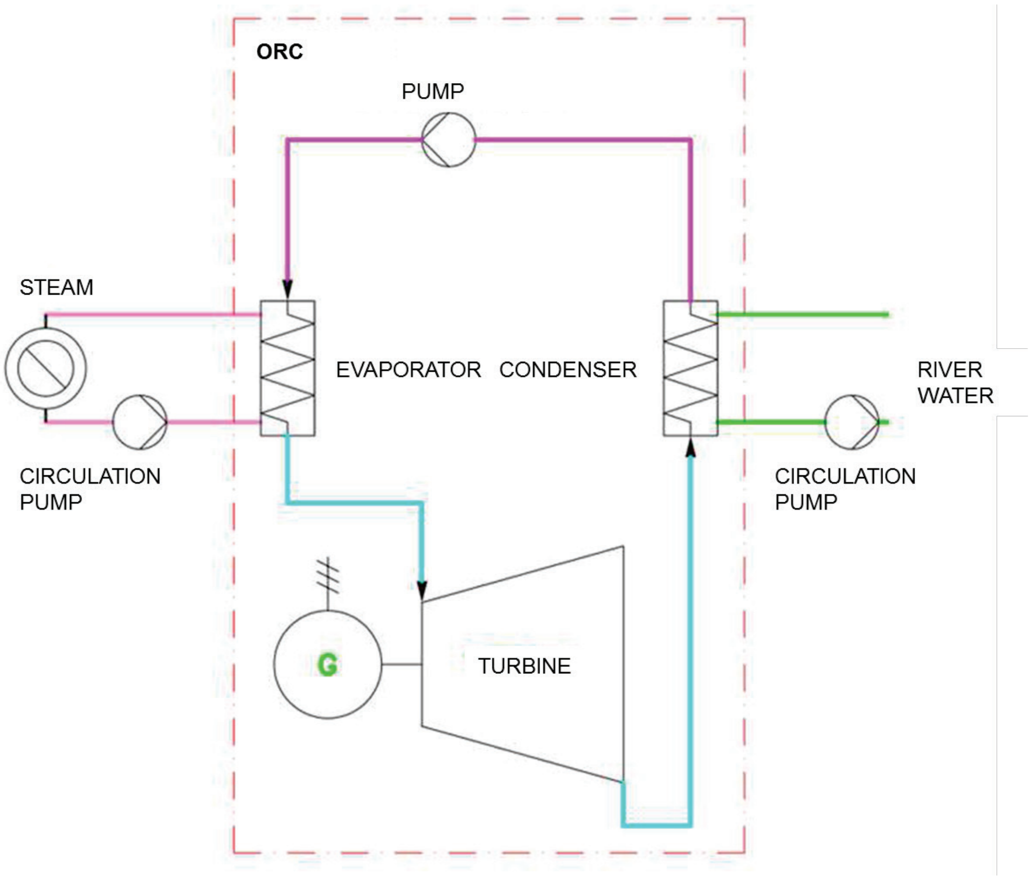

Figure 5. ORC-process.

Table 1. Technical specifications.

ORC-plant	Electricity production: • 1.9 MW_e (net) • 1.7 GWh/a
Heat source	Steam 5 bar, 196/156 °C Design 15 MW_{th}, 13 GWh/a, 5 kg/s
Heat sink	River water T_{in} average 8.6 °C, dT 16 °C Design 12 MW, 11 GWh/a, 175 kg/s

The economic feasibility is the most important factor from the company view. Companies will carry out investments that are not economically sound only if they are force to do so from e.g. environmental reasons. Very tight payback times, quarterly reports and lean organizations are seen as big obstacles in economical use of surplus heat. Energy saving projects are on the same line as production investment projects when money is concerned and due to limitation of the budget there is not always money to energy savings. Energy saving project bring money to the bottom line compared to the production which *have to sell* the goods before profits are made.

The surplus heat flow may be impossible to utilize because of the difficulties in installation. The heat flow may be so dirty that it will clog the heat exchanger totally which makes in worst cases the investment totally unprofitable. At least maintenance costs have to be calculated carefully in such cases.

All surplus heat sources must also have proper sinks, preferably nearby. The source and the sink must match in many ways (thermal power, simultaneousness, duration etc.). If these demands are not met in sufficient amount the heat recovery installation will not be feasible. One heat source may be divided to two or more sinks but this is very seldom possible.

Public opinion is mostly in favor of boosting the use of surplus heat inside the plant or selling it to the community. They see it to be good for the environment because less primary energy is used and this type of utilization can in some way be compared to renewables. The use of surplus heat has almost always positive impact on the surroundings unlike some other forms of energy production (e.g. power plant and wind mills).

Until the recent years lack or unreliability of proper technology or the high price of proper equipment has been a reason why surplus heat has not been commonly used. Now the technology of the heat pumps and ORC equipment is reliable and these equipment can be used in various installations.

Best available technique documents give some guidelines how to tackle surplus heat problems but those guide lines are sometimes too general in order to give real guidance. Despite of that those documents are worth to look into. Some companies reach out to better technology level, to BAT+ level. Such solutions can sometimes be found in discussions and negotiations with equipment suppliers or as pilot installations.

Audit guide

One of the main targets of the project was create an audit guide. This guide is aimed to the industrial enterprises with surplus energy, maintenance service companies and to energy auditors and for all those working closely with these companies. The guide gives advice how to approach the target systematically and how to recognize heat sources and sinks and list the pros and cons and estimate the feasibility of the investment. The audit guide is part of the report Energy Efficiency in Industrial Surplus Heat, General Guidelines, which is available to public as the other two publications in Motiva's internet pages, see References.

The audit guide emphasizes two important aspects in finding economically feasible surplus heat sources. They are:

- Comprehensive energy balance of the plant or processes.
- Analysis of the heat flows according to temperature levels and flow phases.

In the comprehensive energy balance both input and output energy flows are listed. Pinch analysis must be one of the options in complicated plants and processes. Energy measurements are often needed to draw up an energy balance. This may some take time and money but gives also time to think of the alternatives.

Energy balance is often yearly summary or average of the situation. To make decisions one has to know the fluctuations of the flows and temperatures and other time dependents variations in the processes in order to decide how much surplus heat can really be used economically. The auditor must have experience, professional skills and be able to communicate with the operators in order to make the right decisions and recommendations.

The easiest jobs have been done and now the auditors have to look deeper into the processes and also be aware of the progress in technology and changes in energy prices. The changes can make a previously unprofitable case to profitable.

Measurements and monitoring

Existing and accurate field measurements were found to be an extremely important part of tracking surplus heat sources. In energy intensive industry error in measurements may lead to big errors in the final estimation and wrong decisions. An error of 1 °C may lead to several MWs difference when compared to real flows.

To find out and estimate the process flows and temperatures effectively, it must also be possible to measure the flows in a reliable manner in order to see how everything is working. It must also be possible to verify changes in consumption after investments have been done.

Special attention has to be paid to balance sheets, reporting and online measurements. There must be a purpose for the measurements, such as defining efficiency or special consumption. By checking the balance sheets it is possible to narrow down the number of interesting and promising heat sources.

It is very important to choose the best meter type and the correct meter size to carry out the work. Inaccurate measurements lead the company people to look into wrong direction and perhaps to wrong conclusions.

Reliable measurements are the foundation of energy management decisions. That is why strict criteria must be followed when installing flow, temperature and pressure etc. meters. Meters must be regularly maintained and calibrated. Reliable measurements are only a part of the entire measurement process. The data transfer must also be reliable and faultless.

Communications

The surplus heat energy audit model is a new and important tool to improve energy efficiency in industry. Now that promising results have been achieved, it is very important to spread the results of the project and the auditing method to energy intensive industrial companies, especially energy managers and maintenance departments, and also to companies offering maintenance services and their personnel. The third group consists of energy auditing companies and their auditors who now have a guide to use and exploit in their work.

Benefits of the project

During this project surplus heat sources that were found and dealt with represent more than 850 GWh/a. Most of the findings were economically feasible, only the ORC-surveys turned out not to be economically feasible at the moment. One of the main reasons is that CHP is so common in Finland.

All Finnish industrial companies can adopt the principles, ideas etc. presented in the reports. Special attention to surplus heat should be paid in planning phase in new and old plants; things can be altered to be energy efficient at minimum cost.

The energy auditors are encouraged to adapt the audit guide lines in their energy audits.

The benefits of this project can be summarised as follows:

- A systematic practice for the companies to ascertain and maintain energy efficiency of the surplus heat in an industrial plant. The energy efficiency of the existing heat recovery systems can also be improved.
- The audit model presents a uniform and comprehensive way to approach and report the results of surplus heat energy audits.
- The published reports give companies many ideas, lists and examples how to locate and use surplus heat efficiently and economically.
- More attention should be paid to energy efficiency of surplus heat in industrial plants. A lot can be done to re-use it!

References

Motiva Oy, Energy Efficiency in Industrial Surplus Heat, Heat Pump and ORC Applications (Only in Finnish), 2014.

Motiva Oy, Energy Efficiency in Industrial Surplus Heat, Drying of Fuel (Only in Finnish), 2014.

Motiva Oy, Energy Efficiency in Industrial Surplus Heat, General Guidelines (Only in Finnish), 2014.