Case Study – Heat Recovery in a Food Company

By Bo Kuraa, BKU Consult

Star Food Ltd. is a modern food producer, which stands for the contemporary-style cooking - with roots in the Danish food culture.

Star Food produces pâté for the Danish, Swedish and German market - a flow chart describing the main processes and the kind of the energy supplied is shown in figure 1. The company is operating 24 hours a day from Sunday evening to Friday evening.

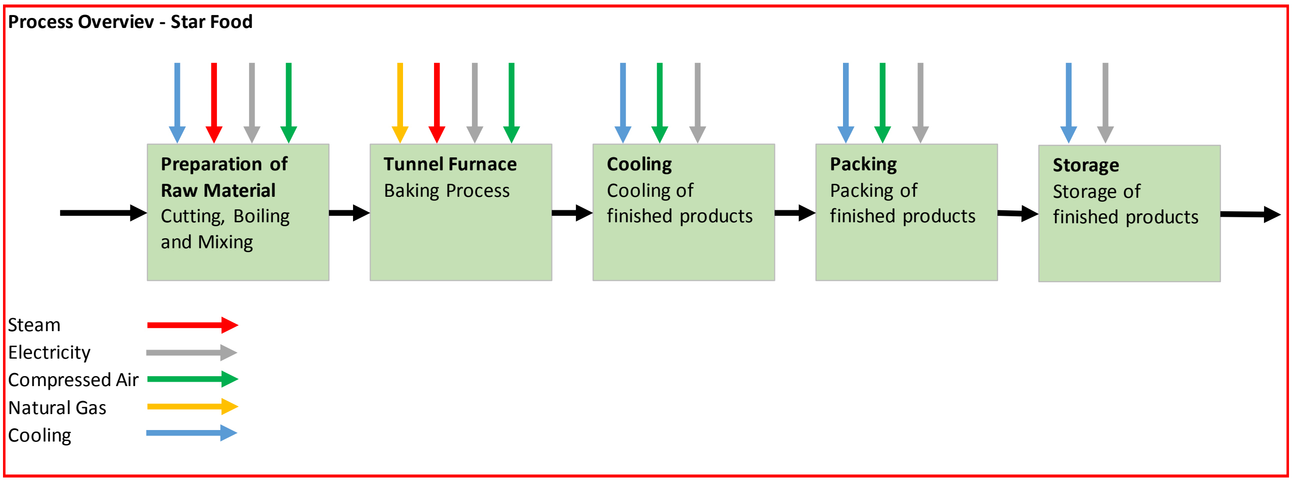


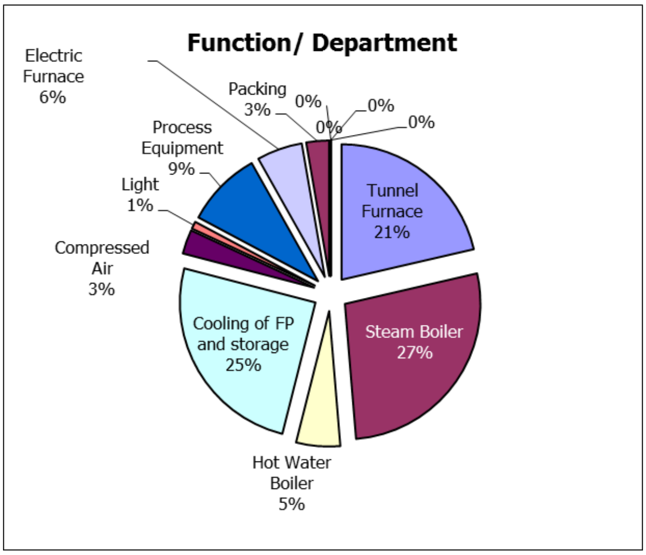
Figure 1. The flow chart describes the main processes and the kind of the energy supplied.

Initially the company did not have an effective energy management system in place; only limited information on energy-using equipment (which is common practice for many companies!). The energy consumption data of the company for the year 2012 are reported in figure 2.

Year 2012			
	El [kWh]	Natural Gas [m3]	Production [kg]
Jan	349.586	37.648	598.717
Feb	312.078	33.560	614.210
Mar	359.133	37.120	898.853
Apr	312.309	30.928	582.451
May	341.802	28.620	547.244
Jun	328.737	26.671	642.004
Jul	364.577	29.006	549.999
Aug	386.875	30.218	620.775
Sep	363.339	30.628	797.771
Oct	363.519	32.282	601.346
Nov	354.852	34.427	619.775
Dec	340.305	37.389	785.523

Figure 2. Energy and production data from Star Food, 2012.

A mapping of the energy consumption (natural gas and electricity) was initially implemented by using the Excel tool "Energy Mapping". The charts in figures 3, 4 provide a breakdown of energy consumption by different users within the company, while figure 5 show the correlation between gas consumption (steam boiler) and the degree days (driving factor).



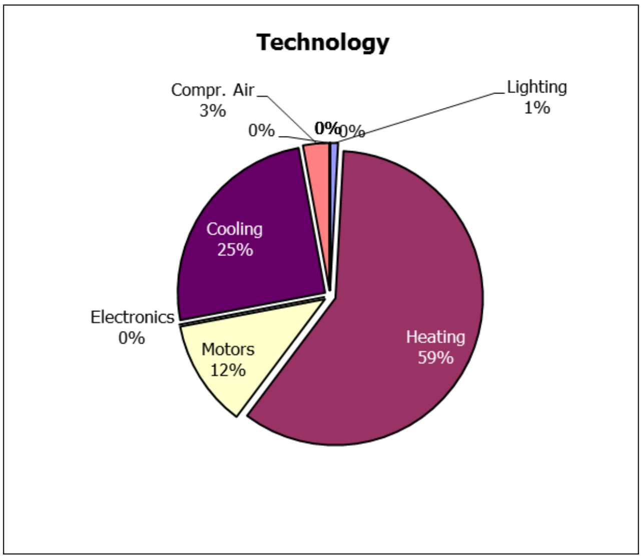


Figure 3 and 4. Presentation of data from the energy mapping/energy screening (Excel Tool).

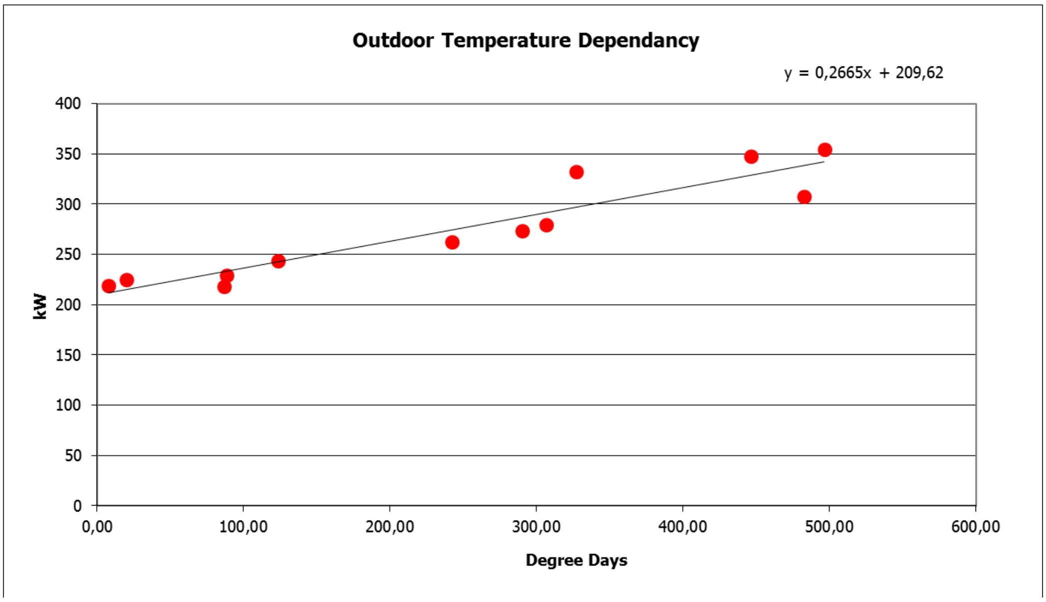


Figure 5. During the screening of the energy consumption – contrary to expectation – it was uncovered that the gas consumption of the steam boiler was related to the number of degree-days rather than to the production.

The following highlights emerged after the energy mapping:

- The steam boiler is close to full load only during cleaning, since in this period of time (4 hours) large quantities of water are needed – hot water storage is only 10 m^3 – the rest of the time the steam boiler is very low loaded with a resulting poor efficiency.
- Only two main consumers need steam – hot water for cleaning purposes and boiling (preparation of raw material).
- About 73% of the natural gas consumed by the steam boiler is used for heating of water for cleaning purposes (temperature: 62° C) - see calculation, figure 9.

- There are two possible sources for heat recovery – the tunnel furnaces and the refrigeration plant (cooling compressors, R717).

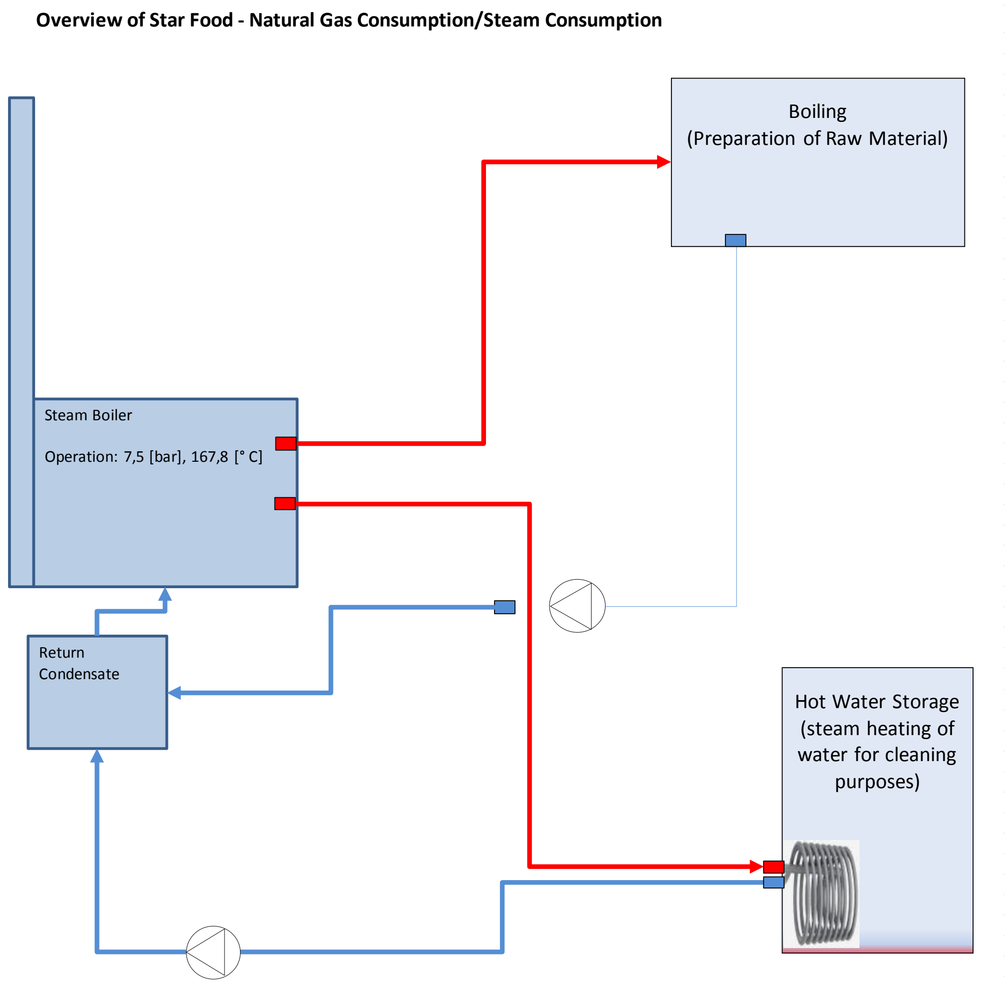


Figure 6. Overview of the steam consumers at Star Food.

Water Consumption for Cleaning Purposes			
Water Consumption:		80	[m³/day]
Cleaning:	Peak Load:	21	[m³/h]
	Average:	14	[m³/h]
	Start Temp.:	8	[° C]
	End Temp.:	62	[° C]
	Start Time:	16:30	(weekdays)
	End Time:	22:30	(weekdays)

Figure 7. Information about the cleaning process, water consumption and temperature levels.

Data - Natural Gas:		
Net Calorific Value	39,548	[MJ/nm³]
Combustion Air (stoichiometric combustion):	10,56	[nm³/nm³ gas]
Flue Gas (dry) (stoichiometric combustion):	9,5	[nm³/nm³ gas]
Properties of Water:		
Specific Heat Capacity:	4,178	[kJ/kg °K] (40 [° C])
Density:	992,2	[kg/m³] (40 [° C])

Figure 8. Natural gas and water properties.

Natural Gas consumption (calculated) - Water for cleaning purposes:			
Efficiency (boiler)	75%		
N Gas consumption:	17.908.178	[kJ]	$Q=m*cp*\Delta T$
	17.908	[MJ]	
	453	[nm^3/day] (stoichiometric combustion)	
η=75 [%]	604	[nm^3/day]	
Production days per month:			
	22	[days/month]	
Estimated consumption per month:			
	13.282,8	[nm^3/month]	
Annualized average N Gas consumption (steam boiler):			
	18.242,0	[nm^3/month]	
Water for cleaning purposes - % of Steam Boiler N Gas consumption:			
	72,81%		

Figure 9. Calculation - percentage of the gas consumption used for heating of water for cleaning purposes.

Resource Efficiency Measures

A) Water and Energy Conservation in Cleaning

The first identified measure was to contact the sub-contractor in charge of cleaning. Close cooperation was established and a study was initiated with regard to minimum consumption of water and chemicals for cleaning without compromising the quality of the cleaning.

Note!
As the cleaning company did not pay for water (water + heating + drainage of sewage) according to the old contract, they had no incentive to save on the water. Example: The employees left all the hoses lying on the floor with running hot water while they applied cleaning agent - then the staff did not have to open and close the water supply, saving them time!

A new plan for cleaning was prepared and certain routines were changed, including training of cleaning staff. This initiative saved 15-20% of water, including energy for heating (N Gas: 438.000 kWh/year).

B) Heat Recovery

<u>OPTION 1 (first stage)</u>

The next initiative was to investigate the possibility of heat recovery and decommission of the old steam boiler, which most of the time has too large capacity compared to the process needs. In this context, it soon became clear that large hot water storage will be an important component as cleaning and production do not take place at the same time. In Star Food there are two possible sources for heat recovery, one is the flue gas from the tunnel furnaces and the other is the refrigeration system (R717).

The flue gas from the furnaces is extraordinarily fat (sticky stuff); this will require frequent cleaning of any heat exchanger, otherwise it is flammable and gives poor heat transfer. Furthermore, the furnaces are only in operation for about 8 hours per day.

The refrigeration plant is a more interesting source of heat; it is always in operation, since it also supplies the cold store for finished products. Furthermore, it is well-known technology, which needs a minimum of maintenance.

For that reason it was initially decided to keep the steam boiler, install hot water storage in the size of 60 m^3 and a de-superheating heat exchanger at the refrigeration plant. The investment cost for this option would be in the order of 180,000 euro.

On screw compressors the two main sources of heat losses are the discharge gas and the cooling of compressor oil via an oil cooling process. On reciprocating compressors heat is rejected primarily via the discharge gas. If left unexploited, these quantities of heat are rejected to the main heat rejection devices of the plant, i.e. the condensers.

Figure 10. Hot water storage.

Energy used to heat water, whether it is electricity, gas or other fuel, can be reduced by using heat recovery to preheat water between 50° C and 60° C. This provides a considerable saving in energy consumption. Ammonia based chillers using reciprocating or screw compressors generally allow recovery of 10-20% of the total condensing heat in the form of useful heat, i.e. at temperature higher than 50° C.

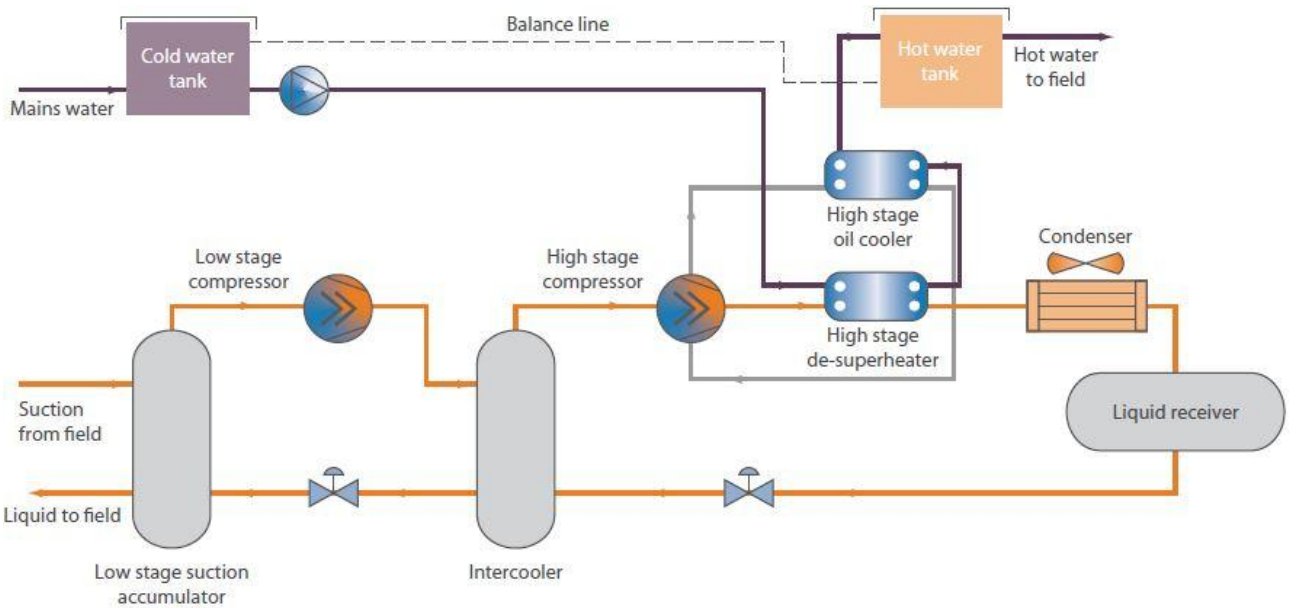


Figure 11. Schematic of heat recovery system with high stage de-superheater.

The saving potential associated to option 1 are summarized in the below figures 12 and 13.

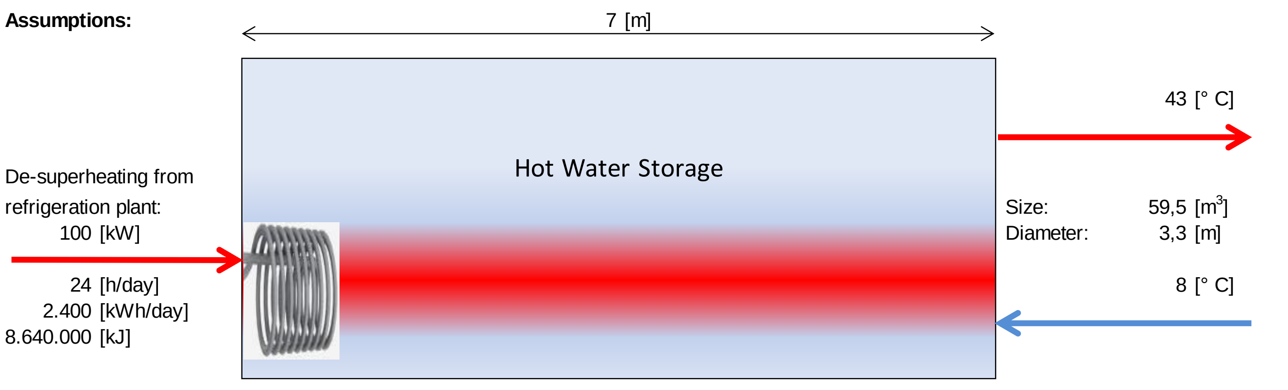


Figure 12. Calculation – Hot Water Storage.

Saving Potential		218,5 [nm^3 N Gas/day]	
Boiler η= 0,75	*)	6.408,4 [nm^3 N Gas/month]	
N Gas Cost:	4 [DKK/nm^3]	307.604 [DKK/year]	(22 days/month)

Figure 13. Calculation – Saving Potential.

OPTION 2 (second stage)

Heat pumps extract heat from a variety of sources and convert the heat to higher temperatures for use in many industrial applications. The advanced compression capabilities of single screw technology have contributed to the development of heat pumps for industrial applications, providing higher capacities and a greater range of temperatures than prior generations of heat pump compressors.

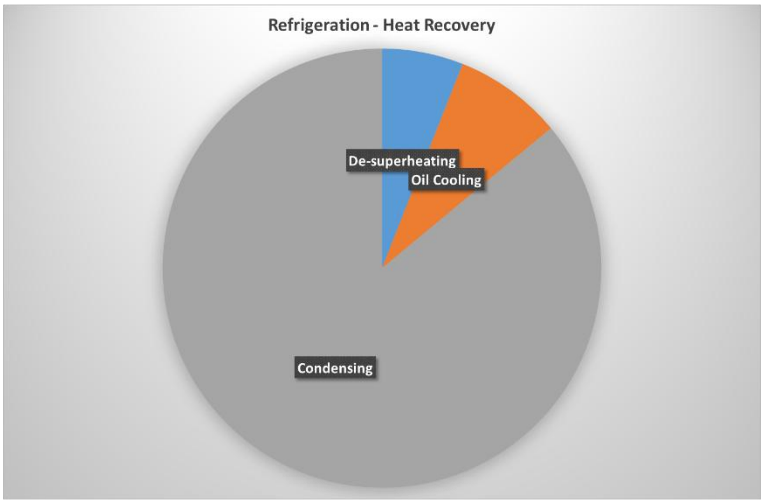


Figure 14. Available heat from a refrigeration plant.

In the second stage of the project, it was initially planned to implement heat pump technology. There is plenty of energy available for the total consumption of hot water and space heating, but the temperature has to be increased.

Figure 14 shows the breakdown of heat that can be recovered by the various methods: De-superheating, Oil Cooling and Condensing.

Again, the hot water storage is an important element of the project as the heat builds up during the day.

Quotations from suppliers of heat pumps have shown that one can estimate approximately 350 USD per kW heating capacity of a heat pump in the magnitude of 400 kW, which is expected to be a suitable choice in this case; see figure 15.

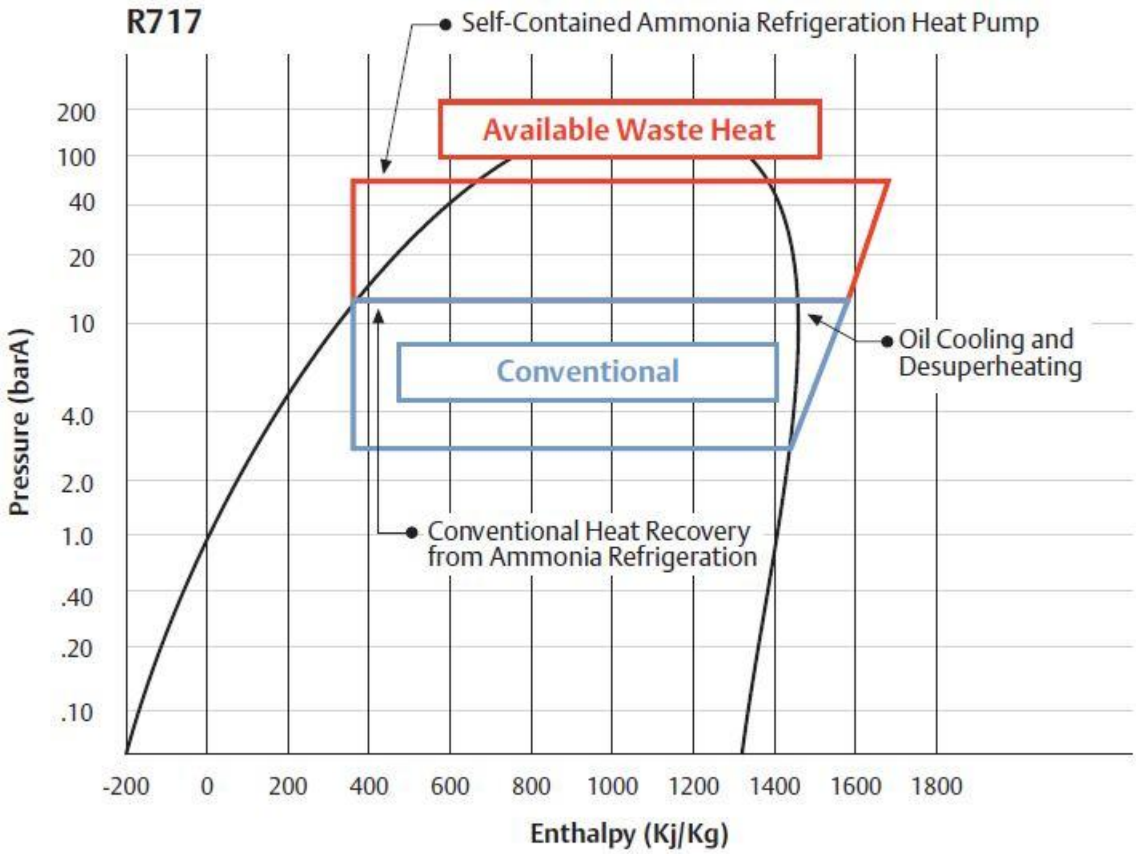


Figure 15. Conventional heat recovery in industrial refrigeration systems utilise only 10-15% of the total heat of rejection including superheat and oil cooling. The majority of the heat is rejected through the condenser. However, the temperature of this heat source is typically too low for beneficial use.

From year 2018 it will be possible to connect Star Food to the district heating system as there will be an expansion of this system in the region - in connection with this expansion it is expected to implement the second stage of the project. Depending on the agreement, which may be negotiated with the district heating supplier regarding backup of heat, the steam boiler will be decommissioned and replaced by either district heating or by a significantly smaller hot water boiler. The generation of the modest steam consumption for preparation of raw materials will be replaced by an electrical steam generator.

The saving will be the total gas consumption by heating about 60 m^3 of water (62° C) for cleaning purposes minus the saving, which has been implemented already.

OPTION 3 (second stage)

As option 2 did not show a particularly attractive payback time (see table below, “Project Economy"), a third option was investigated - the steam boiler will be decommissioned and replaced by a smaller steam boiler with a much better efficiency, which will only supply the raw material department with steam. The need for heat and hot water beyond what can be recovered from the existing heat recovery system is purchased from the district heating company from the year 2018. As shown in the table below ("Project Economy"), this will significantly reduce the payback time compared to the option that involves the heat pump technology.

Project Economy

Project	Saving Category	Energy Saving [kWh/year]	Cost Savings [USD/year]	Investment [USD] and Simple Payback [year]
Water and Energy Conservation in Cleaning	Natural Gas and Water	438.000	36.000 (N Gas and Water)	15.000 0,42
Heat recovery OPTION 1 (stage 1)	Natural Gas	846.000	47.300	180.000 3,8
Heat recovery OPTION 2 (stage 2)	Natural Gas and Maintenance	1.124.000 N Gas reduction 484.000 Electricity consumption increase (Electric Steam Generator and Heat Pump)	62.800 (N Gas) 10.000 (Maintenance) 55.800 Increased electricity cost	186.000 10,9
Heat recovery OPTION 3 (stage 2)	Natural Gas and Maintenance	251.000 N Gas reduction	14.000 (N Gas) 5.000 (Maintenance)	46.100 2,4