Utilization of industrial low-grade waste heat by means of new emerging high-temperature heat pumps

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ABSTRACT

A project supported by the Danish Energy Agency has the objective to accelerate the implementation of new large (> 500 kW) high-temperature heat pumps by means of full-scale demonstration.
High temperature is here defined as above 85ºC water temperature. In this project only natural refrigerants are investigated.
Although many other factors besides heat pump technology influence the feasibility of such technology, these new products will through the combination of high output temperature, refrigerant type and size of commercially available heat pumps, dismantle some of the existing heat pump barriers.
First phase is to examine 4 different suitable refrigerants (and unit types):

- R717 in a Vilter/Star unit.
- Hybrid (combination of R717 and R718)
- R744
- R718

The purpose of this examination is to make a map of which refrigerant is preferable for given conditions.

The project group consists of the Danish Technological Institute (DTI), Industrimontage, Arla Foods, Thise Dairy, Århus Abattoir, SPX AVP and Grontmij | Carl Bro.

1. INTRODUCTION

During the last years several official reports have pointed out the need for energy savings combined with a sustainable energy supply.
Energy recovery is import both in a society and an end-user company perspective. The society wants less impact on the climate along with less dependency on fossil fuels. And the end-user will reduce their production costs through energy saving and thus improve competitiveness.

One report [i] has calculated the direct reusable waste energy from the industry to be 5000TJ. This number can be increased dramatically by the use of heat pumps.
Other reports[ii], [iii] emphasise that district heating today represents 47% of the national heating – it is a national aim to raise this percentage to 70% in order to combine the production of space heating and electricity – and reduce both the CO2 footprint and the use of fossil energy.
Further industrial heat pumps using natural refrigerants are today available – even for high temperature solutions.
It is important to take advantage of industrial heat pumps because:

- There is a huge amount of waste energy available
- It is a national objective to increase the use of district heating
- Industrial high-temperature heat pumps with natural refrigerants are available.

2. OBJECTIVE

The purpose of the project is to demonstrate the feasibility of recovering industrial waste heat through emerging high-temperature heat pumps. That will be carried out by full-scale demonstrations.
Due to the Danish taxation system we have to distinguish between recovery of energy for process purposes and recovery for space heating (including district heating).
Thus the project is divided into two parts:

0. One for internal industrial recovery – this part is ongoing and started in August 2010.This part of the project is supported by EUDP[iv]
1. And onefor district heating –this part will start up in the summer of 2011.

Despite the taxation, we see that the interest for heat pumps is increasing in Denmark. Our aim is to push this interest and our obligation to add value to the decision process. Thus we are working with

- Screening tools
- Selection tools - mapping

3. PARTICIPANTS

Figure 1

At Arla Food´s milk powder factories it is estimated that at least 15 % of a total consumption of 16 MW can be recovered for process use with the new heat pumps.
The other project partners will develop new know-how, products and services which will lead to the consolidation of the Danish industrial refrigeration and heat pump industry creating new jobs and increasing turnover. IM, ANH, DTI and GCB have many international customers and therefore the project will lead to the export of efficient Danish energy technology.

4. SCREENING

The figure shows the result of the screening at Aarhus Abattoir.

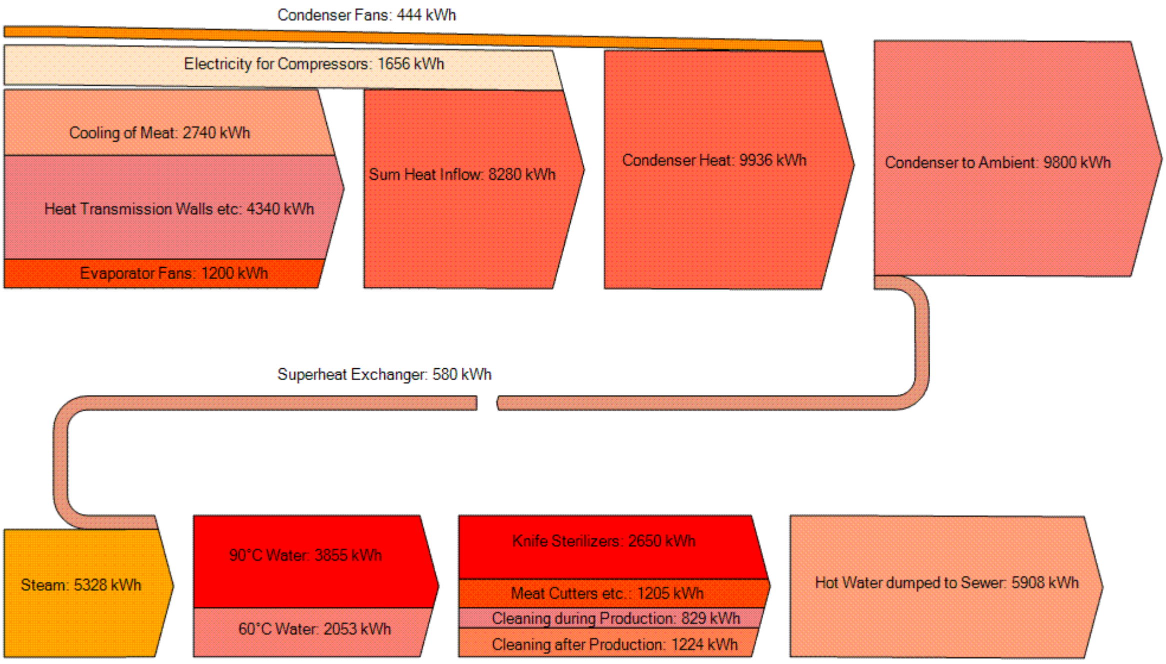

Figure 2

The figure shows that the waste energy from the condenser exceeds the energy required for heating. But the quality of the condenser energy is far lower that the energy needed for heating. To upgrade this heat a heat pump is therefore needed.

It is however important that before even thinking of a heat pump you have to consider:

- Can some unnecessary energy be eliminated?
  Here it was observed that most of the 90ºC water could be replaced by water of 60ºC.
- Is it possible to reuse some of the energy directly through heat exchanging?

Another aspect is the simultaneousness of the source and the receiver of the energy.

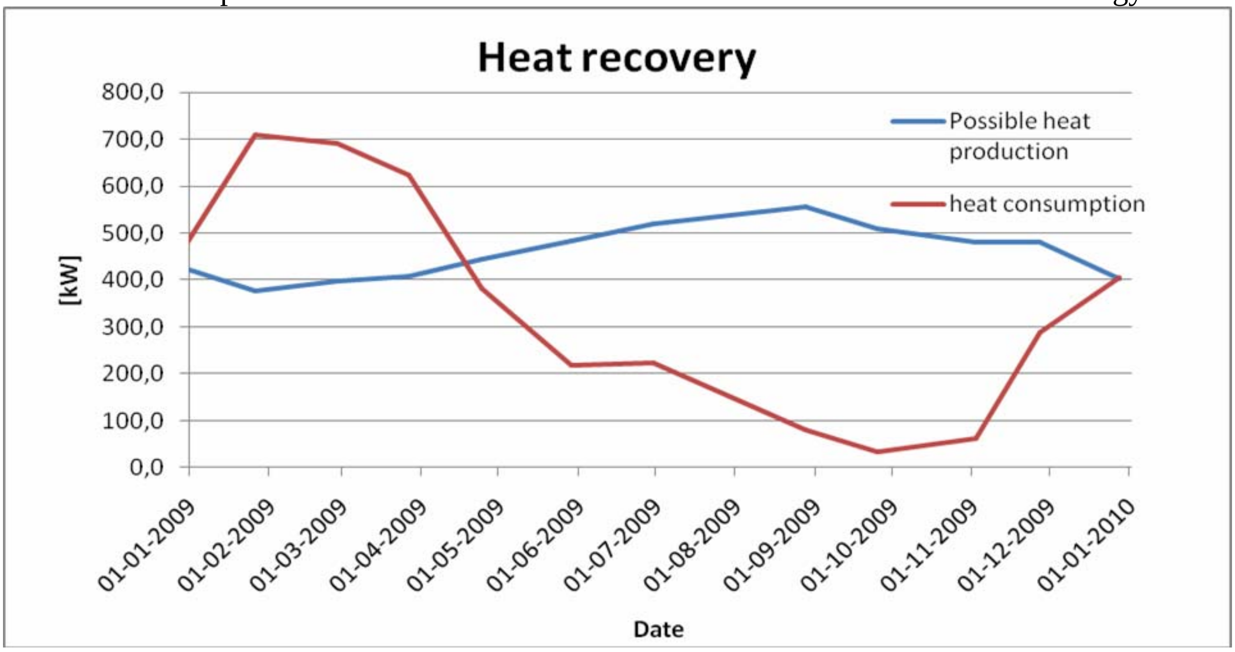

Figure 3

In this example the blue curve shows the potential heat pump production – the red curve the actual need. It shows that on a yearly basis there is sufficient energy available – but in real life about 25% of the time an alternative supply is needed.

5. MAPPING

The project focuses on

- heat pumps of a capacity of > 500kW
- a water outlet temperature of > 85ºC
- natural refrigerants

The refrigerants that have been examined are

- R717 (Vilter/Star solution)
- HC´s (R290 and R600a)
- R744
- R718
- Hybrid (mixture of R717 and R718)

The two first represent the common refrigeration circle – but with higher pressure than for ordinary refrigeration plants.

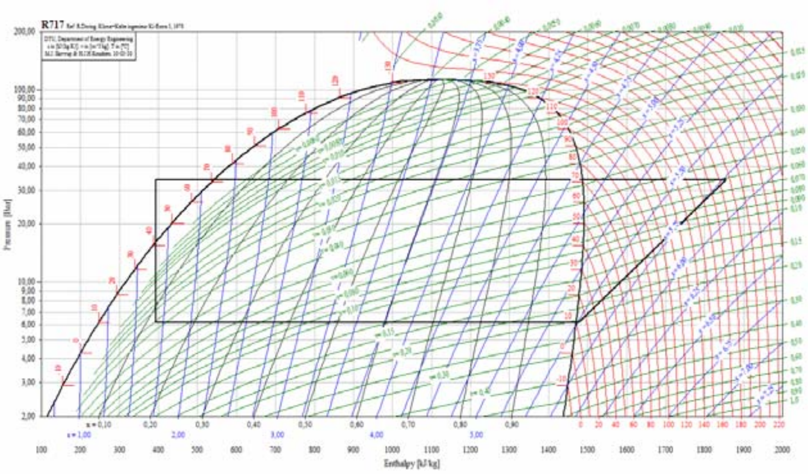

Figure 4

The third represent a transcritical process.

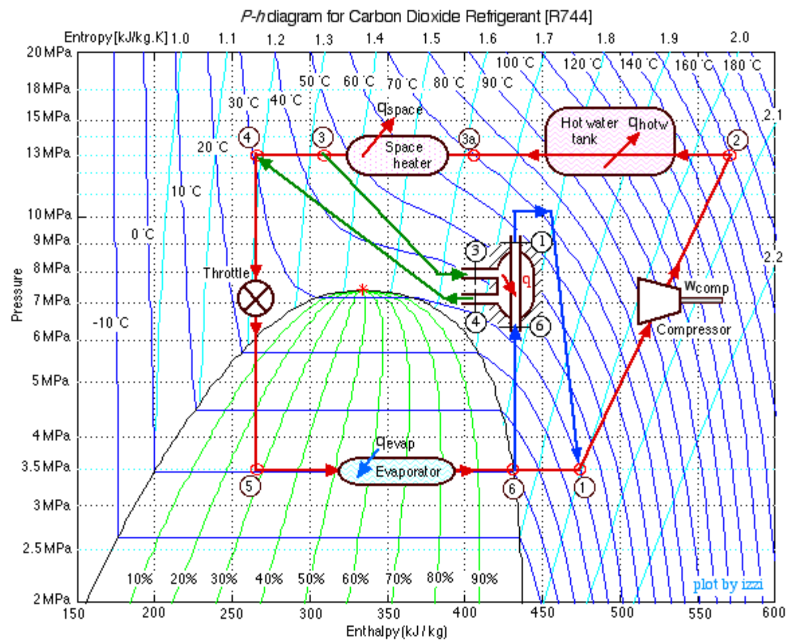

Figure 5

The last two represent alternative technology – e.g. the R718 solution can be made as a system where the primary and secondary refrigerants are one and the same – eliminating heat exchangers and the connected losses.

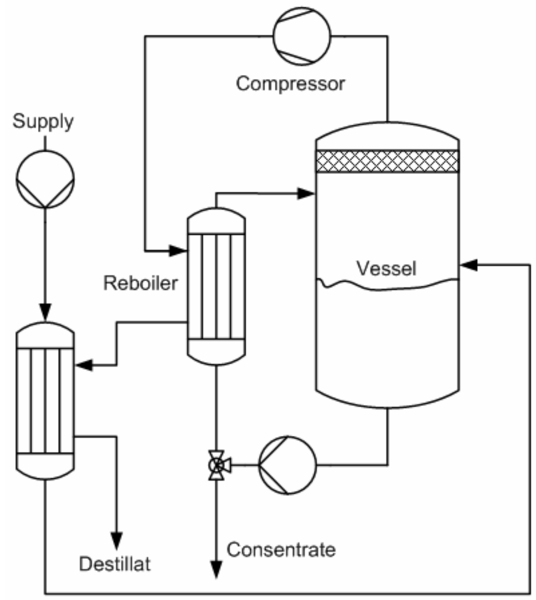

Figure 6

Hybrid (Osenbrück process) represents a process where the ammonia is mixed with water which increases the boiling (or condensing) point – resulting in the possibility of getting outlet water at a higher temperature than the pure ammonia solution would allow.

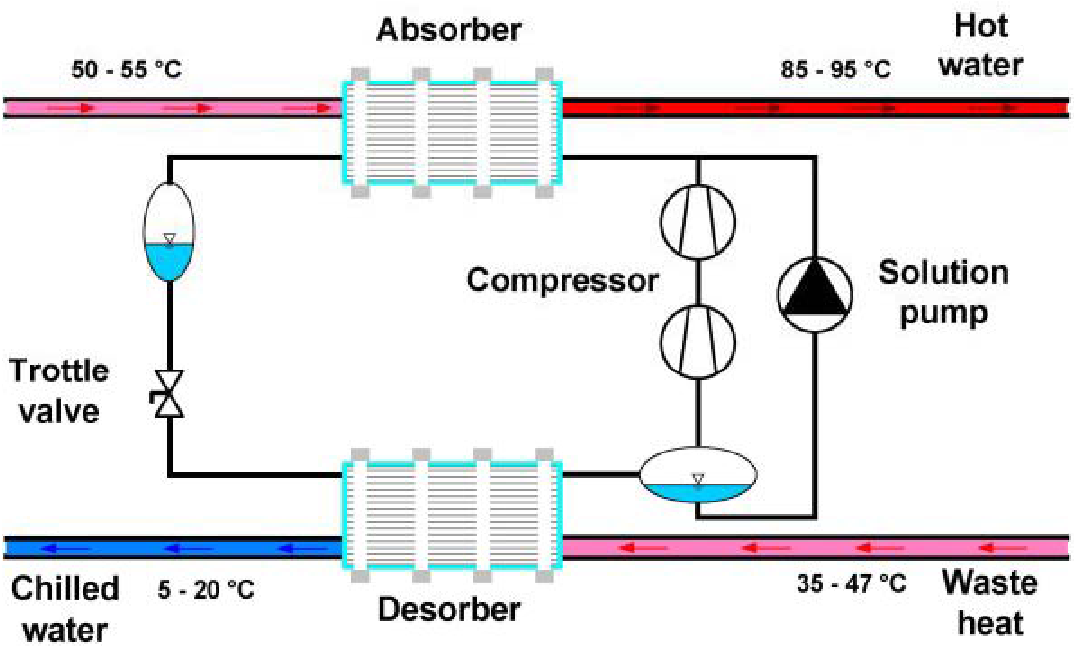

Figure 7

The Norwegian company Hybrid Energy has made several such plants – the oldest has been in operation for more than 20000 hours.

R718 in industrial size is not commercially available today – the others are.

A study[v] made at the Danish University of Technology shows how COP is influenced by the individual change of parameters:

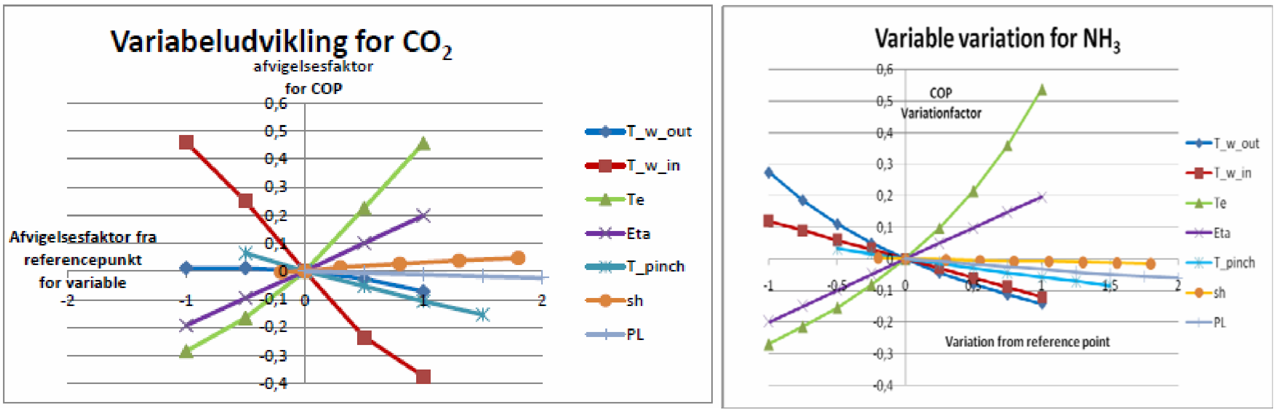

Figure 8

It can be seen that both for R717 and for R744 Water out/in and evaporating temperature are the parameters that have the largest influence on the COP.
Thus you can estimate a rather precise COP from these 3 numbers.

Heat Pumps systems
One step R717 Vilter compressor
One step R717 recip compressor (Sabroe)
Two step R717 Vilter/recip compressor
Two step R717 recip/screw (Sabroe)
One step R744

T_e = 10

T_w_in\T_w_out	60		70		80		90		100	
		5,44		4,86		4,28		---		---
10	5,76	4,79	5,13	4,12	4,64	3,63	4,25	3,26	3,46	---
	5,83	4,85	5,16	4,29	---	3,82	---	3,41	---	3,09
		5,27		4,71		4,07		---		---
20	5,01	4,53	4,54	3,92	4,15	3,48	3,84	3,13	3,08	---
	5,52	4,69	4,9	4,14	---	3,71	---	3,32	---	3,01
		5,1		4,55		---		---		---
30	4,18	4,28	3,88	3,73	3,62	3,32	3,39	3,01	2,7	---
	5,23	4,53	4,64	4	---	3,59	---	3,23	---	2,94
		4,92		4,38		---		---		---
40	3,13	4,03	3,12	3,54	3,03	3,17	2,89	2,88	2,31	---
	4,91	4,38	---	3,86	---	3,48	---	3,14	---	2,87
		4,72		4,2		---		---		---
50	2,39	3,79	2,39	3,35	2,39	3,02	2,32	---	1,93	---
	4,6	4,25	---	3,73	---	3,37	---	3,06	---	2,79
		---		4,02		---		---		---
60	---	---	1,75	3,16	1,75	2,87	1,74	---	1,54	---
	---	---	---	3,62	---	3,26	---	2,97	---	2,72
		---		---		---		---		---
70	---	---	---	---	1,19	2,71	1,19	---	1,16	---
	---	---	---	---	---	3,16	---	2,88	---	2,64
		---		---		---		---		---
80	---	---	---	---	---	---	---	---	---	---
	---	---	---	---	---	---	---	2,78	---	2,56

Figure 9

The table shows the estimated value at an evaporating temperature of 10ºC. Tables for other evaporating temperatures have also been made.
This is a tool for quick estimation of

- What kind of technology is reasonable to use
- Which COP value can be expected.

This part of the project is universal.

Further, we have looked into the energy prices and into the local Danish taxation system – including a prediction of future energy prices/taxation.
This leads to a diagram :

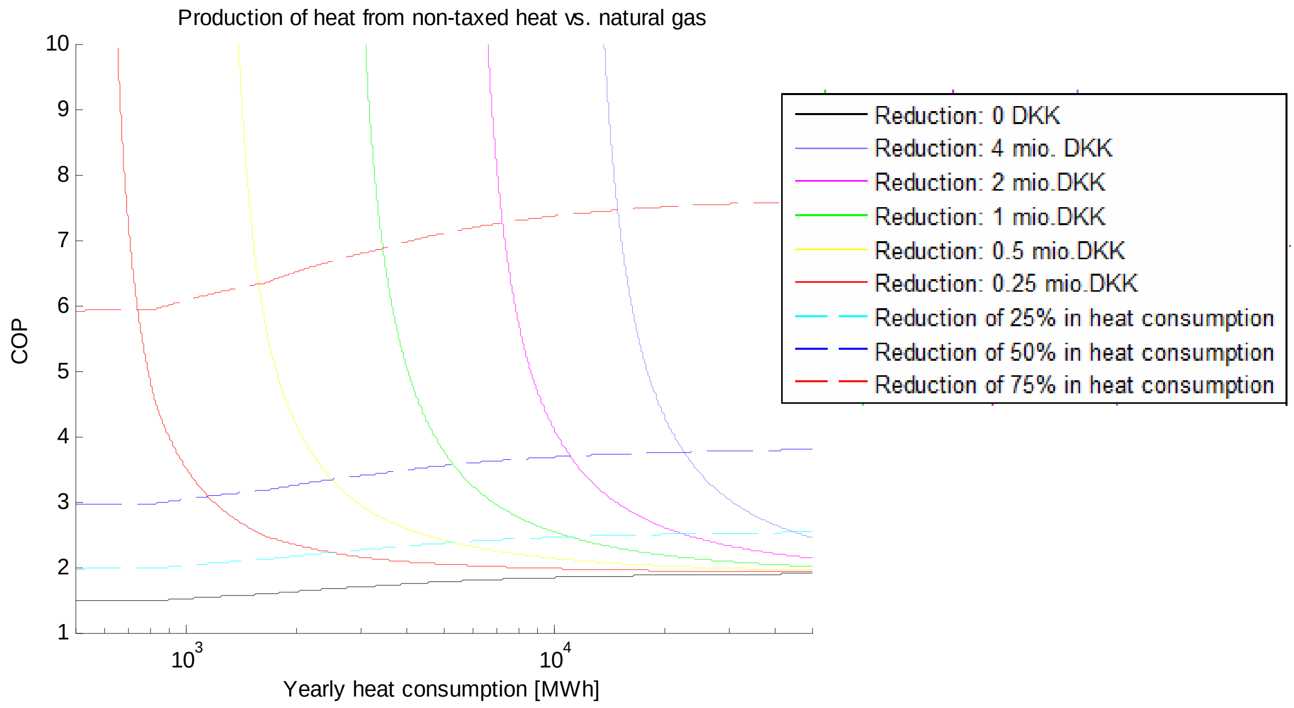

Figure 10

The COP is estimated from the study mentioned above.
The yearly heat demand should be known by the client, but it is important to take the simultaneousness between heat demand and heat production into consideration.

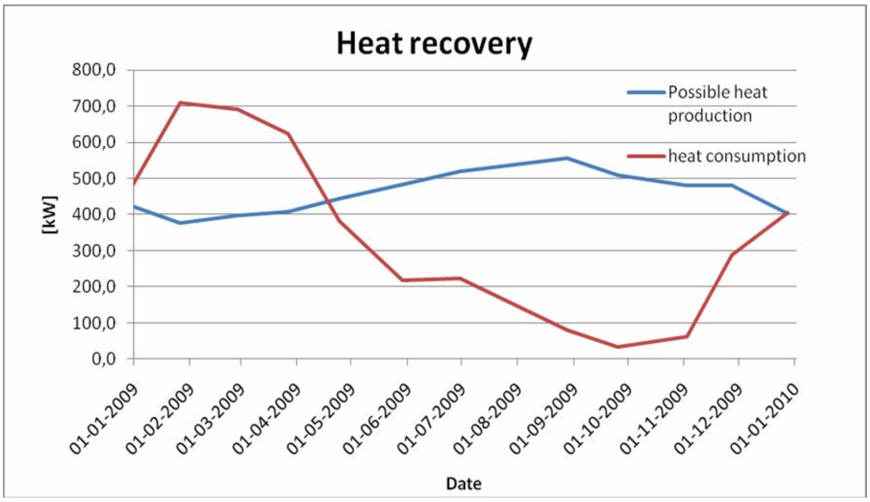

Figure 11

This example shows that on an annual basis the energy production is sufficient but during winter you would have to supply with an alternative source.

This is concentrated into 6 questions:

1. What kind of energy is the heat pump replacing?
2. What is the size of the requested heat load?
3. Which in and out temperatures are required?
4. What is the source of the energy?
5. What is the expected evaporation temperature?
6. How much surplus energy is available?

By answering these 6 questions it is possible to get a fast and reliable idea of

- Which type of heat pump is suitable
- What is the expected COP
- What is your saving potential

These tools are made for Danish conditions, Danish energy prices and Danish taxation rules but can easily be transferred to other countries.

6. FINAL COMMENTS

More or less new heat pump technology is unique as it paves the way for new possibilities for waste energy recovery in MW scale, which is a perfect match to the EUDP strategy on energy efficiency improvement.

The main selling point of the technology is that the waste energy now can reach very high temperature levels and can be used directly for process heating or it can be integrated into the transmission, and/or distribution system of district heating systems and boost the temperature level from e.g. 70 to 80° C. Therefore, the food industry can for instance recover condensation heat from refrigeration, dewatering or drying processes, and reuse the energy without paying taxes for sterilization of equipment, cleaning water or as heat supply for the dewatering or drying facility and thereby save e.g. 75 % primary energy.

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[i] Virksomhedsrentabel udnyttelse af overskudsvarme, Energistyrelsen, Copenhagen February 2009
[ii] Effektiv fjernvarme i fremtidens energisystem, Ea energianalyse, Ålborg 2010
[iii] Varmeplan Danmark 2010
[iv] EUDP - Energiteknologisk Udviklings- og Demonstrationsprogram (Energy Technology Development and Demonstration Programme)
[v] Industriel varmegenvinding med CO2- og NH3 baserede varmepumper – report: MEK-TES-EP2010-13, Michael Markussen and Stefan Wuust, Copenhagen 2010.