SEWAGE AS AN ENERGY SOURCE

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Abstract: The city of Zurich is known for its leading role in the energy friendly use of energy. Further has the city of Zurich a politically binding mandate. The buildings in the city councils portfolio shall be technically and economically exemplary in the use of natural ressources.

The city of Zurich can support technologies with the use of pilot-projects that are state of the art in the forseeable future. These projects must use energy ecologically and stand a chance of becoming economically feasilbe.

The heat pump in the Limmat-school uses sewage as its energy source. The sewage has a yearly average temperature of 12 °C. This is a higher average temperature than that of the lake of Zurich. A further advantage of sewage is that the temperature in winter almost never sinks below 10 °C, even after a fortnight of really cold temperatures. In sommer times on the other hand the temperature will not rise above 18 °C. This makes sewage a perfect energy source for a heat pump.

The heat pump installed produces 85 % of the yearly heat, the remaining 15 % heat is produced conventionally with a gaz boiler.

The heat-pump is also producing the hot water for the three sporting halls which mean that for the hot water production the condensation temperature is close to 65 °C in a single stage process.
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Key Words: ***heat pumps, sewage water, energy source***

1 THE OBJECT, THE PROCESS AND THE HEATING CONCEPT

The Limmat-school is a large primary school with over 40 class rooms. It has been built in 1909. The historic building with a radiator heat system explain the relatively high temperatures the heat pump must produce for the existing heating system.
Until 2003 the Limmat school has had two conventional oil/gaz boilers with a total of 970 kW capacity.

class rooms	34
teacher rooms	4
working class rooms	6
kitchen class rooms	6
library	1
aula	1
sporting halls	2
janitorflats	2

Figure 1. Number of class rooms

In the first phase in 2004 these two oil/gaz boilers were replaced by a new modern modulating gaz boiler with 485 kW only and at the same time all regulation valves and the electronic has been changed to a modern system.

In the second phase a heat pump was installed and came into operation in January 2006 with a capacity of 240 kW. Sizing the heat pump for full heating capacity had been econimcally inefficient. With the installed heating capacity of 240 kW the heat pump produces enough heat until -2 °C. Below that temperature the gaz boiler supports the heat pump.



Figure 2: The Limmat school, building from 1909

The technical clarification

The size of the heating room is comfortable due to the fact that in 1909 the underfloor heating room was also the charcol celler. Also a positive point was the fact that one of the main sewage pipe of the city of Zurich is flowing in the street bordering the Limmat school. Detailled clarifications further showed, that the sewage flow volume is high enough throughout the year.

An ecopoints study before the project (according to accredited ecoindicator points) showed a clear ecological gain.

The project was started in 2004 and economically is based on an oil price of 35 $ / barrel. On that basis the payback rate is 20 years. But since 2004 the oil price has doubled and the paypack rate is half of the originally projected 20 years.



Figure 3: dry sewage channel with the heat exchange elements

2 THE HEAT PUMP AS A PILOT PROJECT

2.1 The heat pump

Due to the fact that the Limmat school is an old building it was clear that we needed high condensation temperatures. Projeted condensation temperature was +65 °C.

In consultation with the compressor manufacturer the condensation temperature has been lifted recently to +70 °C. The process is closely monitored and an oil probe will be taken after two months experience. Such high temperatures are a challenge itself but became possible due to the fact that with sewage water with 10-14 °C throughout the year the suction temperature is around +5 °C and therefore relatively high.

With a range of **technical features and gimmicks** the temperature differences are realised with the highest possible effiziency.

The discussion of refrigerants was central. It became quickly clear that **only propane (C3H8) as a natural refrigerant can fullfill all requirements**.
Ammonia (NH3) had been to expensive for this size of heat pump besides the fact that such pressure ratios are not possible single stage with NH3 and carbon dioxide (CO2) does not have the thermodynamical properties for the temperatures we needed.

The involvement of people with a good knowledge of EN378 (1-4) and the local authorities showed that propane is possible even though the heat pump is in an underfloor cellar.

Eventually a 240 kW heat pump was built with 21 kg of propane.

2.2 Propane as refrigerant and working fluid

The advantages of propane are that it is an ecologically neutral refrigerat with favourable thermodynmical properties and the use of a 28 bar technology makes it economically interesting. Further can be said that the knowledge gained from smaller refrigeration cycles are positive an there are no technical unsolved questions.

The disadvantage of propane is its explosivity between 2.1 - 9.5 Vol-% in the air and that it has an ignition temperature of 470 °C.

2.3 Proof of conformity and explosion safety

The size of the heat pump and the volume of propane made an accreditation by a notified body (TÜV) necessary and measure needed to be taken to pass examination.
These measures have been discussed at an early stage and it became clear that these measures impact costs. External costs could be contained to + 5 % of total costs - not included the internal hours spent to specify the many different details with all relevant official bodies included of which the TÜV where only one.

2.4 Economic aspects

Compared with a standard heat pump with a halogenated refrigerant we calculated a 20 % higher Coefficient of Performance (COP). That such a substantial improvement is possible can be seen www.schulhauslimmat.ch.

Looking at the COP the reader must also take into consideration the relatively high temperatures produced. The quality grade (compared to the theoretical Carnot cycle) of the heat pump is with 55 -60 % high (the quality grade describes the value between the theoretical Carnot cycle and the achiveable value in the field. A value above 45-50 % is considered acceptable.

The heat-pump produces roughly 85 % of total heat including the hot water production for the three large gymnastic halls. In case the heat pump can not produce the necessary temperatures ,i. e. heat production, a conventionl gas boiler will support the heat-pump.

For the heat pump the following set of data has been agreed with the manufacturer. Remark: The design of components were made für the heating mode with a condensation temperature of +60 °C.

design data		**heating mode**	**hot water mode**
suction temperature	[°C]	**4**	**4**
condensation temperature	[°C]	**60**	**65**
heat source	[C]	**untreated sewage water +14 °C**	
inlet temperature (evaporator)	[°C]	**9**	**9**
outlet temperature (condenser)	[°C]	**5**	**5**
difference	[K]	**4**	**4**
Agreed Coefficient of Performance (COP)	**[-]**	**4.1**	**3.7**

Figure 4: Sizing data of the heat pump

2.5 Differences to a standard heat pump

Propane (C3H8) with a molecular weight of 44.1 has ideal thermodynamic properties and a favorable isentropic exponent of just 1.14. Compared with a molecular weight of 102.1 and an isentropic exponent of 1.24 for R134a.

I.
A molecular weight of 44.1 is ideal. If the compressor plate valves have been optimised for propane there are less internal friction losses and thus a better compressor performance.

II.
The compressor motor must have an efficiency class eff1 (according to www.seeem.org/news.php). The question was forwarded to the compressor manufacturer at an early stage and afterwards the cosρ was measured.

While from a eff1 motor you would expect a cosρ in the region of 0.920-0.935 our suction gaz cooled compressor motor has a cosρ of 0.85-0.87 which is clearly not what we expected. Personally I would expect a cosρ of 0.91-0.92 from a 22 kW motor.
Obviously is a cosρ of 0.86 acceptable for a suction cooled compressor motor. The reason is that tolerances between rotor and stator are bigger as suction gaz flow must be secured in a half hermectic compressor. Personally I believe that there is room for improvements for compressor manufacturers. The question remains unanswered.



Figure 5: compressor cosρ values between 0.85 and 0.87 at 100 [%] load

III.
Trough the installaton of a subcooling cycle (Figure 6) the quality grade compared to Carnot is improved by 10%. A subcooling of 2 to 3 K is achieved by the embedding the plate heat exchanger after the liquid collector into the heating system [1].
Also embedded into the heating system are the cylinder heads [2]. Normally 5-8 % of electrical compressor input irradiates on the compressor surface. With the cooling of the cylinder heads some irradiation losses are regained and thus increase the COP. As a further advantage the temperature of the gaz at the end of the discharge compression cycle can be lowered which in turn allows the increase of the condensation temperature.

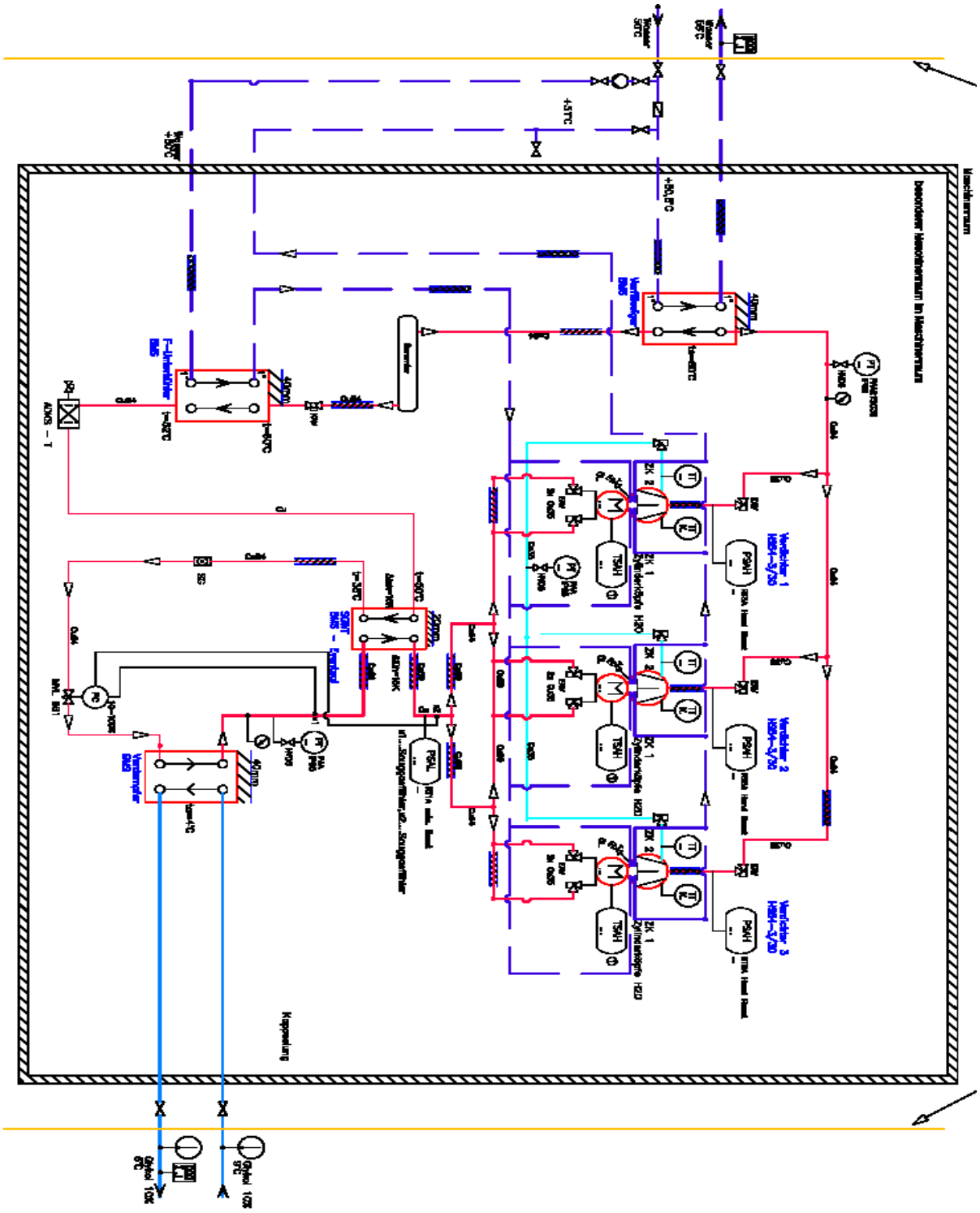


Figure 6: P&I diagram for the propane heat pump

The total mass flow of this cycle [1], [2] is 10 % to 15 % of condenser mass flow and the cycle contributes 10% to condensation and heats up the inlet of the main condensation by 0.5 K.

IV.

In a second internal subcooler [3] the liquid propane is further subcooled. This internal plate heat exchanger subcools the liquid propane and heats up the vapourous propane on the

suction side of the compressors. The theoretical analysis with coolpack (www.et.web.mek.dtu.dk/Coolpack/UK/download.html *[1]* shows a gain of 2 to 3 %. Confirming this knowledge is the work of TU Dresden *[2]* (Figur 8).

In our case the internal subcooler had to be sized carefully in order not to heat up the suction gaz too much and thus increasing the discharge temperature (discharge temperature after the discharge valve plate - which is measured - should not exceed 135 °C). Further should X6 > 0.25 (Figur 7) to ensure the best possible heat transfer in the evaporator (VDI heat atlas www.vdi.de *[3]*).

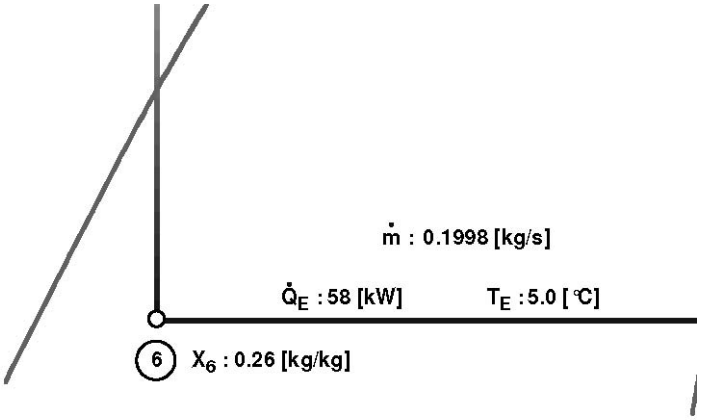
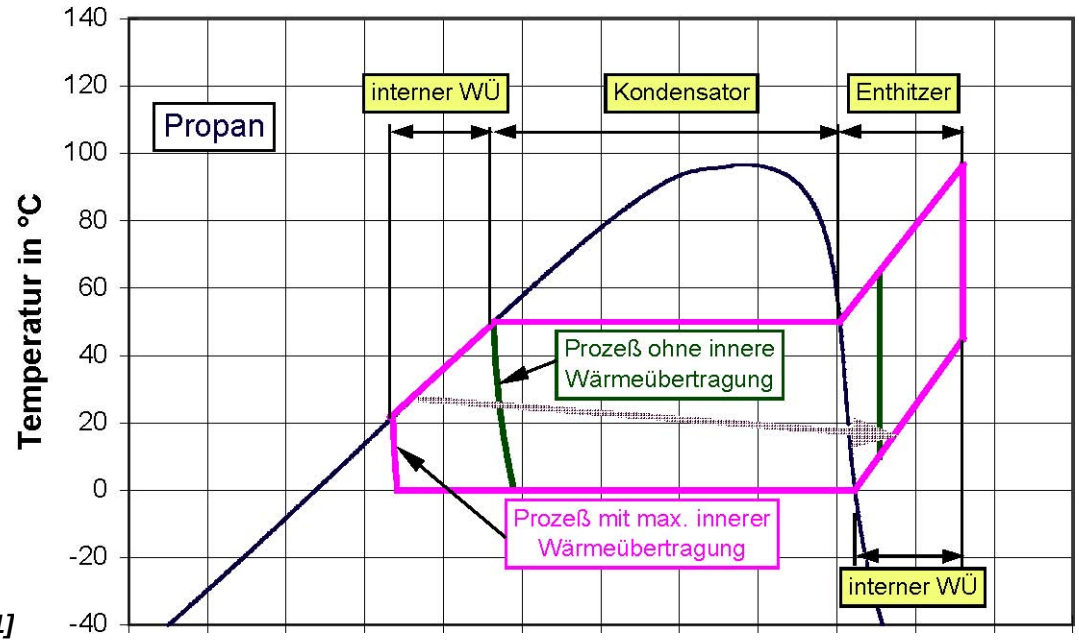


Figure 7: Process after expansion. Procentage of liquid in vapour



[1]

Figure 8: Process with internal heat exchanger for propane *[2]*

3 ENVIRONMENTAL BENEFITS

Trough the heat pump which covers up to 85 % of total heat production a CO2 reduction of 230'000 kg/year is acieved.

Reduction in thermal heat productione	800 MWh/a
Reduction in CO_2	**230'000 kg/a**
equivalent in oil per year	80'000 kg
equivalent in gaz per year	71'200 m3

Figure 9: CO_2 Reduction

3.1 Performance tests

The first performance tests confirm 85 % of total annual heat production is produced by the heat pump.

At the moment performance tests (yearly working number) are still in progress. What can be said is that the coefficient of performance (COP) is better that expected.

In January 2008, after two years of experience we decided in accordance with the compressor manufacturer to lift the condensation from +65 °C to +70 °C. An oel probe will be taken in March 2008 to learn more about this step.

3.2 Next Steps

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In a next step an exergie analysis will be made by an independent Engineering office. The exergy analysis shall focus on the heat pump.

4 REMARKS

The efforts to build a heat pump with an environmentally neutral refrigerant have been worthwile. It has been proven, that a heat pump with a natural refrigerant is only marginally more expensive than with a hydroflourocarbon refrigerant.

With a production ban for synthetic refrigerants by 2012 a similar development as with R22 is forseeable. Only use of a natural refrigerant is an investment warranty!

5 SUMMARY

Building a propane heat pump according to EN378 and accredited by a notified body requires a similar work approach as an ammonia heat pump what PED directives *[4]* is concerned. Additional to PED a propane heat pump must conform to ATEX *[5]* which is mandatory since 1st July 2003.

A difficulty we experienced in 2004 was that most parts suppliers were not aware of ATEX.

Since 2004 the number of large propane heat pumps has increased. For example are a number of Swiss companies only sourcing refrigeration systems with natural refrigerants. Propane is an ideal refrigerant as it possesses similar pressure values as R22.

REFERENCES

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[2] Diploma work, Dipl. - Ing. S. Preusser TU Dresden
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[3] VDI Wärmeatlas

[4] The **P**ressure **E**quipment **D**irective (PED) 97/23/EC affects equipment operating at a pressure greater than 0.5 bar. It entered into force on 29th November 1999 and is mandatory from 29th May 2002.