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# POTENTIAL APPLICATION OF SOLAR PROCESS HEAT IN THE MEAT SECTOR CONSIDERING HEAT RECOVERY AND INDUSTRIAL HEAT PUMPS AS COMPETING TECHNOLOGIES

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## Abstract

Food industry, specifically the slaughter and meat processing industry, is a promising field for solar process heat. Several processes, such as scalding or hot water generation for washing and cleaning, offer feasible integration points due to the low temperature level and conventional heating equipment. For the German meat sector, a technical potential of one million square meters of collector area was estimated. However, heat recovery systems can reduce this potential significantly, especially if they are installed in combination with industrial heat pumps. Thus, the questions arise how heat recovery systems can be operated most economically with respect to the condensation temperature of compression chillers and which influences have to be expected for the integration of solar heat and industrial heat pumps.

Keywords: Solar process heat, Slaughter and meat processing industry, Heat recovery, Industrial heat pumps

## 1. Introduction

Based on the temperature level and constant high heat loads, the food and beverage industry hast the highest potential for solar heat in industrial processes (Schmitt et al., 2015). However, the market penetration of solar process heat failed to meet the expectations in this field of application based on several reasons. One crucial point is the identification of a feasible integration point which can be very complex. Due to a high hot water demand for washing and cleaning purposes, the German slaughter and meat processing industry has been analyzed regarding that fact. Based on the high cooling demand for preserving the meat products, low temperature waste heat from compression chillers plays a particularly important role for the evaluation of solar heat integration. Additionally, the waste heat offers the opportunity to install industrial heat pumps using it as heat source ending up in an improved efficiency.

## 2. Suitable applications and technical potential of solar process heat in the German slaughter and meat processing industry

In contrast to other branches of the food industry the diversity of heat consuming processes in the slaughter and meat processing industry is rather limited as a literature research has proven. Additionally, the heat demand is mostly limited to process temperatures below 100 °C. This demand is dominated by the preparation for hot water which is especially used for washing and cleaning processes. To reduce the bacteria load, the carcasses as well as any utility that have been in contact with the carcasses has to be cleaned regularly. Especially the cleaning of animal transporters, which is done after unloading on site, guarantees a constant warm water demand. At least once a day, all production rooms have to be lathered and cleaned.

The slaughter processes of pigs and poultry are very comparable. After several prewashing steps with warm and cold water, the carcasses have to be scalded at temperatures between 50..65 °C, making the subsequent step of bristle removing and de-feathering much easier. Therefore, the carcasses are moved through one or

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several warm water baths. These baths have to be kept at temperature during all time which is ensured by external heat exchangers or steam injections. However, due to the high bacteria load and the carryover by the carcasses, fresh water has to be fed constantly. But, the bacteria load can only be reduced to a certain extent by feeding fresh water. Consequently, the whole bath capacity has to be changed at least once a day. In alternative to these baths, the carcasses can also be sprayed with warm water which ensures a reduced water and energy demand in addition to a reduced bacteria load on the carcasses. The bristles and feathers are removed by scrapers and rollers, partially supported by valves which spray warm water on the carcasses. Pigs have to be processed in a gas oven additionally, where any remaining bristle is burned at temperatures above 200 °C. The carcasses of cattle don't have to be scalded, because the skin is peeled off. In summary, there are several integration points for the use of solar process heat in the slaughter industry: The integration on the supply level using the hot water network is just as feasible as the integration on the process level, for example maintaining the bath temperature in scalding processes in the set temperature range.

Beside the supply of hot water for cleaning, it is more complicated to integrate solar heat in processes in the meat processing industry. The filling of kettles and other machineries in cooking and pasteurizing processes at the beginning of every day or batch can be done with solar heated water. In contrast, the use of solar heat for the continuous heat demand to maintain or increase the process temperature is very often restricted by technical reasons and the conventional heating equipment.

Other processes such as smoking and maturing are conventionally heated by steam, gas burners, or electrical heaters. Although the products are processed at relatively low temperatures, the integration of solar heat is difficult due to the conventional heating equipment. Depending on the product, the temperature range of smoking can vary between 10 to 100 °C while the process time is inversely proportional to the temperature. Often steam is used directly to generate smoke, which makes it almost impossible to replace it by solar heat. In these cases, the limited space does not allow the retrofit for a water based heating system which is necessary for the utilization of solar heat. However, in case of a significant amount of direct steam consumption, the required make-up water can be supplied with solar heat easily.

Whereas in smoking chambers it is not possible to integrate solar heat, maturing halls, for example for sausages, is more promising instead. The maturing process can take up to several days or even weeks. During this time, the products are placed in big halls which are temperature- and humidity-controlled. Steam injections for heating and humidification on the one hand and cooling machines for cooling and dehumidification on the other hand try to control temperature and humidity in a very small range, which is necessary for an optimal maturing result. If the control is not balanced here, there is a relevant potential for energy savings. Since maturing halls typically have a lot of available space and a relative continuous load profile, it can be possible to replace the conventional heating by steam injections to water heating surfaces here. Such modification would allow the efficient use of solar heat at a low temperature level here.

There are several processes, especially for a dry heat treatment as baking or roasting, where the use of solar heat is impeded– on the hand due to the temperature level and on the other hand due to the fact that the conventional heating is based on direct electrical heating.

To sum up, there are several promising integration points in heat consuming processes within the slaughter and meat processing industries as shown in Tab. 1. In both industries the majority of the heat demand is used for hot water preparation, which makes it generally easy to identify a suitable integration point for solar heat on supply level. The use of solar process heat in maturing halls is a very promising application on process level due to the very low temperature level and the constant heat demand due to dehumidification.

**Tab. 1: Heat consuming processes in the slaughter and meat processing industries regarding the potential for the use of solar process heat; The solar potential is evaluated with respect to the climate in Central Europe**

| Process | Temperature level | Annotations | ST Feasibility |
|---|---|---|---|
| **Both sectors** | | | |
| Cleaning and Washing Processes | 50..60 °C | High and constant hot water demand, simple integration at supply level | + |
| Make-up water | 15..95 °C | Material use of steam requires constant replacement of feed-water | + |
| **Slaughter Industries** | | | |
| Scalding | 50..65 °C | Bath filling and refilling with solar heated water and continuous bath heating | + |
| Singeing | > 200 °C | No potential due to conventional heating equipment | - |
| **Meat Processing Industries** | | | |
| Scalding and Cooking | 60..100 °C | Bath filling with solar heated water. Continuous heating not feasible | 0 |
| Pasteurizing | 80..100 °C | Possible use of solar heat depends on heating equipment | 0 |
| Sterilizing | > 100 °C | Temperature level and heating equipment impede the use of solar heat | - |
| Smoking | 10..100 °C | No potential due to conventional heating equipment | - |
| Maturing | 15..25 °C | Promising application, needs modification of heating equipment | 0 |
| Baking, Frying, Roasting | > 200 °C | No potential due to conventional heat supply and heat transfer | - |

Based on the process analysis, a technical potential for use of solar process heat in the German meat sector has been calculated. The overall energy demand in the German slaughter and meat processing industry was 7.3 GWh in 2011 (BMEL, 2013), whereby 58 % of the energy was consumed for heat generation by fossil fuels[1] (excluding heat generated by electricity). Almost 60 % of the heat demand is eased by the meat processing industry, whereas 40 % are consumed in slaughter houses. The heat supply is dominated by the central combustion of natural gas feeding steam or hot water networks distributing the process heat.

In slaughter houses for cattle and poultry, all heat demand, as shown before, is needed at a temperature level below 100 °C which makes it very feasible for solar heat. During the slaughter process of pigs, there is also a heat demand at a higher temperature level for the bristle burning which accounts for 30 % of the heat demand in the pig slaughter process (Rosenwinkel, 2014). Taking into account the average heat demand per carcasse (weight) (VDI, 2009) and the absolute slaughter figures (Maennel, 2014), the heat demand can be distributed to heat which is needed below 100 °C (78.4 %) and above (21.6 %). Using the methodology of Lauterbach et al. (2012), taking into account a potential for efficiency measures, competing technologies and a limited solar fraction as well as suitable roof areas, there is a technical potential for solar heat of 172.4 $\text{GWh}_{\text{th}}$ (383,000 $\text{m}^2$[2]) in slaughterhouses.

For the meat processing industry, it has to be relied on cross-sectoral data for the food industry presented by Nast et al. (2010), whereas 43 % of the heat demand is needed below 100 °C, 41 % between 100..150 °C and 16 % above. This results in a technical potential of 239.5 $\text{GWh}_{\text{th}}$ (532,000 $\text{m}^2$) with respect to a feasible

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[1] Electricity which is used for heat generation, for example in baking processes, is not included here.

[2] Assuming a solar yield of 450 $\text{kWh/m}^2\text{a}$.

temperature level up to 150 °C.

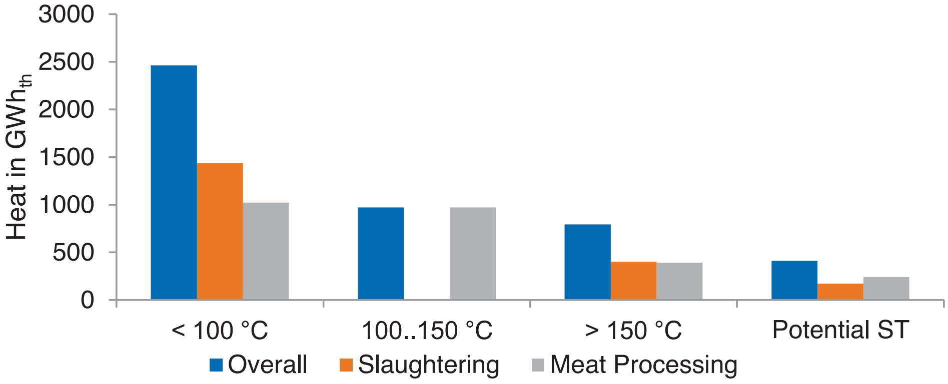

**Fig. 1: Distribution of the heat demand and technical potential for solar process heat in the German slaughter and meat processing industry**

In total, referring to Fig.1, there is a technical potential for solar process heat of almost 412 $GWh_{th}$ (< 150 °C) in the German slaughter and meat processing industry which is corresponding to a collector potential of almost 1,000,000 $m^2$.

However, this potential has to be seen in relation to the massive potential for low temperature waste heat due to the widespread application of compression chillers. Here, it is estimated that more than 114,000 cooling systems are operated up to a cooling capacity in the megawatt range (Steimle et al., 2002). Following Preuss (2011) this potential can be calculated assuming an average COP (Coefficient of Performance) depending on the cooling temperature[3], operational time and installed cooling capacity with respect to the size of the company. Using eq. 1, a theoretical potential for heat recovery (hr) from compression chillers can be calculated.

$$\dot{Q}_{hr} = P_{el} \cdot (COP + 1) \qquad \text{(eq. 1)}$$

Theoretically, there is a potential for low temperature waste heat from compression chillers of 5.2 $TWh_{th}$ in the German meat sector, whereby this potential exceeds twice heat demand below 100 °C in this sector and the technical potential for solar process heat by the factor 10. Still, only a share of this heat recovery potential can be exploited due to the low temperature level (20..40 °C), the lack of storage possibilities and other technical limitations. Still, this comparison shows that waste heat can massively reduce that potential of solar heat using it for example for water preheating.

## 3. Heat generation costs of industrial heat pumps

Industrial heat pumps have a great potential to cover the low temperature process heat demand in industrial applications, especially if waste heat with a temperature about 30 to 40 °C can be used as heat source in the evaporator. Still, there are only a few industrial heat pumps (approx..80 in 2011) installed in Germany so far (Preuss, 2011) but the market development is positive. In the meantime heat pumps with a thermal capacity up to a double-digit $MW_{th}$ range are available. Supply temperatures with single-stage heat pumps can reach up to 75 °C. Beyond that, the heat pump has to be operated two-staged. There, even supply temperatures above 100 °C can be provided. In general, heat pumps and solar thermal systems have in common that they can work most efficiently if they produce heat at a low temperature level. Thus, even if they can be installed in combination with solar thermal systems they are a concurrent technology to solar process heat.

To evaluate the competitive situation, the heat generation costs of single-stage industrial heat pump systems are calculated with fixed parameters in a reference scenario for the design data. Part-load performance or a

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[3] For this calculation, it is assumed that normal refrigeration accounts for 40 % and deep freezing accounts for 60 %.

certain load profile have not been respected. The parameters of this scenario are given in Tab. 2.

The heat generation costs are calculated over a period of 20 years with the annuity method. The investment and installations cost are taken from Lambauer et al. (2008). As it can be seen in fig. 2, the specific costs per installed capacity are heavily decreasing with the thermal capacity of the heat pump system until a capacity of 500 kW$_{th}$. Beyond that, the specific investment costs are more or less the same. Regarding the investment costs, the conditions of German subsidies are taken in to account[4] for the calculation of the heat generation costs. The supply temperature, the heat pump has to provide, is 65 °C (hot water generation) whereas the source temperature is 30 °C. This source temperature can easily be provided by the compression chillers' waste heat referring to a condensation temperature of 35 °C considering a temperature difference of 5 K for the heat exchanger.

**Tab 2: Parameters of the reference case for the calculation of the heat generation costs of an industrial heat pump**

| **Parameter** | **Value** |
|---|---|
| $\kappa_{el}$ | 0.15 ct/kWh$_{el}$ |
| $T_{E,HP}$ | 30 °C |
| $T_{C,HP}$ | 65 °C |
| $\dot{Q}_{HP}$ | 300 kW$_{th}$ |
| Full Load Hours | 1530 h/a |
| $j_{el}$[5] | 1 %/a |
| Refrigerant | R134a |

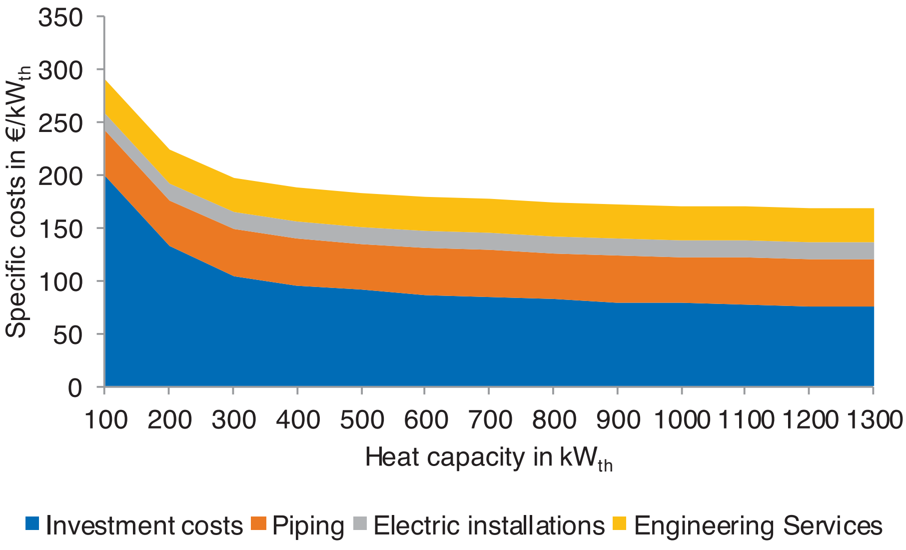

**Fig. 2: Investment and additional cost for the installation of an industrial heat pump from Lambauer et al. (2008)**

With the given parameters, the heat generation costs are 3.9 €-ct/kWh$_{th}$.

Subsequently, the sensitivity of these parameters is analyzed to quantify their effects on the heat generation costs. The results of the sensitivity analysis with a variation of the parameters by 50 % are given in Fig. 3

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[4] Heat pumps with a heating capacity of > 100 kW$_{th}$, 30 % of the total investment cost can be funded.

[5] Increase of electric costs in %/a

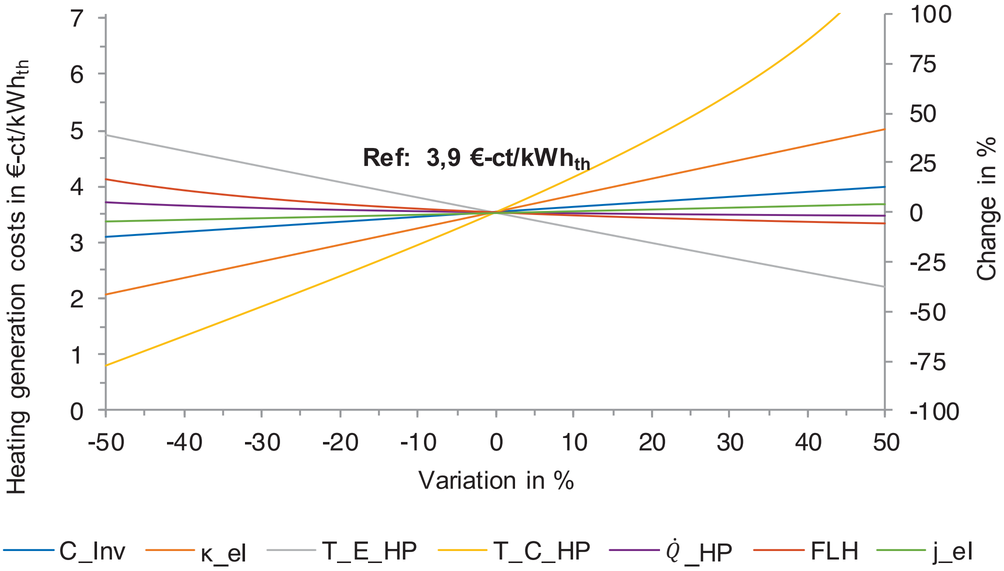

**Fig. 3: Results of the sensitivity analysis with the absolute heat generation costs (left axis) and the change in percentages (right axis)**

The sensitivity analysis underlines that the main determining parameters for the heat generation costs are on the one hand the temperatures of the low temperature heat source (TE,HP) and the heat sink (TC,HP) and on the other hand the price for electric energy (κel). The influence of the total investment costs (CInv), in contrast, are less relevant. Here, an increase of the investment costs by 50 % only results in an increase of the heat generation costs of 12 %. Such an increase of the price for electric energy would lead to heat generation costs of about 5 €-ct/kWh$_{th}$ (+ 41,7 %). The operational time and the amount of delivered heat does also only play a minor role due to the fact that the investment costs are less relevant. Decreasing the operation time does only result in higher investment costs per delivered heat. But this change in the heat generation costs secondarily in relation to the operation costs for electricity.

As the price of electricity and the operation temperatures of the heat pump has been determined as the key factors for the heat generation costs of an industrial heat pump, several simulations has been carried out with varying parameters. The results are given in fig. 4. There, the heat generation costs are given in dependence of the temperature lift of the heat pump (x-axis) and the price of electricity (y-axis) for a process temperature of 60 °C (e.g. hot water preparation). The temperature loss which has to be taken into account due to the use of heat exchangers is already respected. Thus, if the waste heat temperature, which is used as heat source for the heat pump, is about 30 °C and the process temperature 60 °C, a temperature lift of 30 K has to be used in the diagram. The efficiency of the heat pump is calculated with additional 10 K, resulting in a temperature lift of 40 K. As it can be seen, quite low heat generation costs can be achieved by a heat pump if waste heat at a suitable temperature is constantly available. With the given example ($\Delta T_{HP}$=30 K), the heat generation costs would be in the range of less than 3 ct/kWh$_{th}$ up to 5 ct/kWh$_{th}$ depending in the price of electricity. These costs can be very different, even in industries, especially if there is a high electricity demand. Obviously other waste heat sources apart from compression chillers might be used as well.

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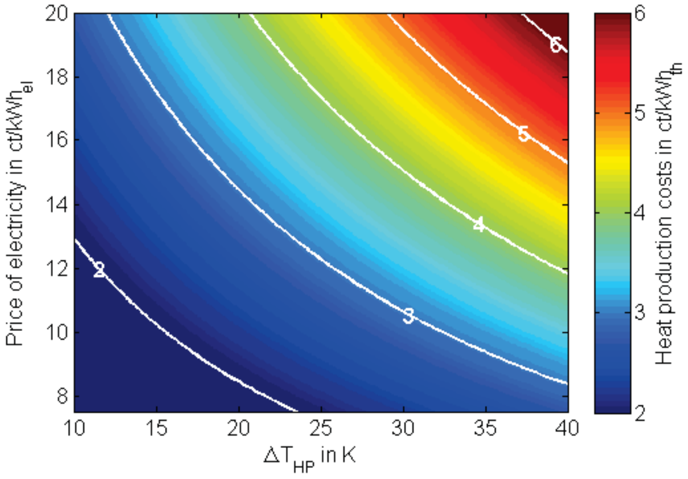

**Fig. 4: Heat generation costs in €-ct/kWh$_{th}$ of industrial heat pumps in dependence of the temperature lift the heat pump has to provide (x-axis) and the price of electricity (y-axis) for a process temperature of $T_{Process}$=60 °C**

## 4. Optimized operational mode of compression chillers with respect to the condensation temperature

As shown in Section 2, there is a huge theoretical potential for the use of waste heat from compression chillers. The subsequent technical potential is mainly dependent on the temperature level in the condenser ($T_C$) which can be varied according to the system and the temperature in the evaporator ($T_E$). Generally, this condensing temperature has to be chosen as low as possible, operating the compression chiller as efficient as possible (high COP) according to Eq. 2, whereas the evaporating temperature ($T_E$) is typically limited by the transfer and distribution of the cooling energy in the cooling room. Calculating the COP via the temperatures $T_C$ and $T_E$, only gives the theoretical optimum. In practice, the COP is much lower due to technical reasons.

$$COP = \frac{\dot{Q}_C}{P_{el}} = \frac{T_C}{T_C - T_E} \qquad \text{(eq. 2)}$$

However, there is also a minimum for the condensation temperature, which is given by the installations for recooling and the ambient conditions. It has to be guaranteed, that the waste heat from the compressor can always be dissipated by air or water cooling. For air cooling, the condensation pressure has to be chosen to result in a condensation temperature which is about 10 K above the ambient air. So, the chiller works with a floating condensation temperature over the year in dependence of the air temperature resulting in a changing efficiency (COP), too. In case of water cooling, the wet-bulb temperature, which is always below the ambient air temperature, determines the condensation temperature. Very often, especially with outdated chillers constant condensation levels over the year can be found in industry, resulting in inefficient operation during the majority of the year.

As shown before, a low condensation level results in an efficient cooling system. In contrast, a higher condensation temperature might result in a higher amount of heat that can be used. Thus, the operator ends up in a target conflict between an efficient cooling system and an increased waste heat potential. To find the optimal solution, simple considerations were made with respect to the design values. As before, regarding the consideration of the heat pump, neither a part-load behavior of the compressor or the whole chiller nor any specific cooling load were considered. On the one hand, the additional amount of waste heat energy ($\Delta Q_{hr}$), that can be used for water preheating by increase of the condensation temperature by 1 K can be determined with Eq. 3 if the daily hot water demand ($V_{HW,d}$) is known.

$$\Delta Q_{HR} = V_{HW,d} \cdot c_{p,HW} \cdot 1K \qquad \text{(eq. 3)}$$

On the other hand, you have to take into account the additional amount of electric energy per day, you have to use for the less efficient cooling system (Eq.4). Here, the factor f is used to approximate the decline of efficiency.

$$W_{el,d,new} = f \cdot W_{el,d,old} \qquad \text{(eq. 4)}$$

Afterwards, the relation of saved costs by the surplus of recovered heat to the extra costs for electricity has to be considered with the specific costs for heat ($\kappa_{th}$) and electricity ($\kappa_{el}$). $K_{hr}$ represents the saved costs by increasing the condensation temperature. Subsequently conventional energy needed for heating the water can be saved. $K_{el}$, however, represents the additional cost for electricity which have to be paid due to the less efficient cooling system.

$$\frac{K_{hr}}{K_{el}} = \frac{V_{WW,d}}{W_{el,d,old}} \cdot \frac{\kappa_{th}}{\kappa_{el}} \cdot \frac{c_{p,W} \cdot 1K}{f} \qquad \text{(eq. 5)}$$

As shown in Eq. 5, there are two ratios which determine the most cost efficient mode of operation. At first, this is the ratio between the amount of water that can be preheated by the heat recovery system. The more water can be heated, the more interesting it can be to use the chiller as a heat pump, whereas this is less attractive if there is a lot of electric energy demand for cooling. The second ratio is the relation between the costs for heat and electricity which play an important role. In case of a company that has to pay high prices for electricity in relation to the costs for heat generation, it is energetic and economical more efficient to operate the chiller with the lowest condensation possible. This should be the case in most companies. But in turn an institution has to pay relatively low prices for electricity and a relevant amount of the waste could be used, for example for water preheating, it might be profitable to increase the set temperature of the condensation.

Finally, the factor f has to be determined. Therefore, a model has been built in Matlab (MATLAB, 2010) using the database CoolProp (Bell et al., 2014), which offers the possibility to calculate compressor load and the amount of waste heat from the condenser in dependence of the cooling load and the ambient temperature. The parameters of the model are given in Tab. 3.

**Tab. 3: Models Parameter**

| Parameter | Value |
|---|---|
| Refrigerant | R134a, R404A, R407C, $NH_3$ |
| Cooling load | 200 $kW_{th}$, constant |
| $T_E$ | -20..0 °C |
| $T_C$ | 35..45 °C |
| $\Delta T_{overheating}$ | 5 |
| $\Delta T_{subcooling}$ | 3 |
| $\eta_{isentropic,comp}$ | 0.7 |
| $\eta_{el,comp}$ | 0.9 |

As shown in Fig. 5, the factor f is dependent from the temperature level in the evaporator as well as from the refrigerant. In deep freezing applications the effect in the decrease of the COP is less relevant (approx. 2.2 %/K) than for normal refrigeration (approx. 3 %/K). Additionally, there are differences in the performance dependent on which refrigerant is used. Cooling systems which are filled with Ammonia ($NH_3$) are more attractive to use as heat pump, generally. In contrast, if R404A is used, the decrease of the efficiency of the cooling system is stronger.

Having determined the factor f, the target conflict can be solved with respect to the ratio of energy costs and the demand supply ratio which can be calculated easily. The range of the realistic ratio of energy costs is from 0.2 to 0.55 ($ct/kWh_{th}$)/($ct/kWk_{el}$). Fig. 6 shows the ratio of cost savings for a factor f of 2.2 % (left) and 3 % (right). The white line is marking the inflection line, where a change of the condensation temperature would have no cost saving effect. Below this line, the company should decrease the condensation temperature as far as possible to benefit from savings. Since, the saved conventional heat generation costs cannot be amortized by the heat recovery system. Here, the costs for electricity outweigh the savings. Otherwise, if the demand-supply-ratio and the ratio of energy cost result in an intersection point above the white line, the operator of the cooling system can save costs by increasing the condensation temperature and use the chiller as a heat pump.

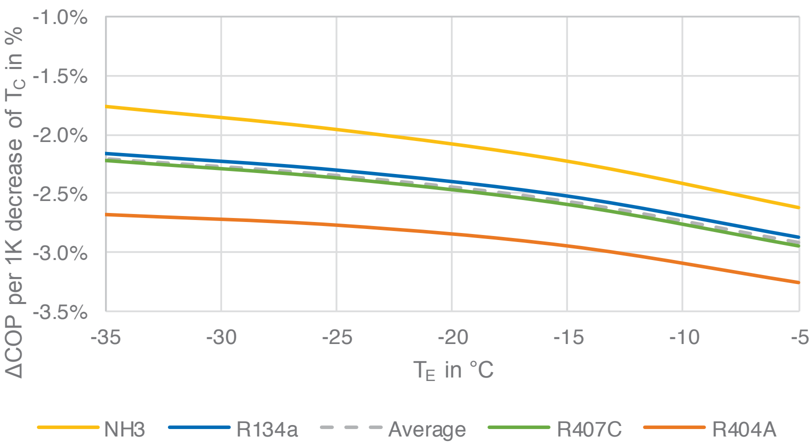

**Fig. 5: Change of COP (factor f) per 1 K decrease of $T_C$ in dependence of the evaporation temperature and common refrigerants**

As an example, a company of the meat processing industry is considered. The daily hot water demand is approx. 45 m³/d, whereas 375 $kWh_{el}$/d are consumed for normal refrigeration and the same amount for deep freezing. Assuming that for each cooling application, there is an own heat recovery system, 22.5 m³/d can be preheated by each system. This results in a demand-supply-ration of 0.06 (m³/d)/($kWh_{el}$/d).

Here it is assumed, that ratio of the meat processing factory has a value of 0.4. As it can be seen in Fig. 3 in case of normal refrigeration and a factor f of 2.2 %, the cooling system can be used as a form of heat pump since an increase of the condensation temperature is interesting from an economical point of view. Here, the savings in heat generation account for up to 30 % in relation to the additional costs for the electric energy demand for cooling. In contrast, with a view to the deep freezing system on the right, the cooling system should be operated as efficient as possible with the deepest condensation temperature possible.

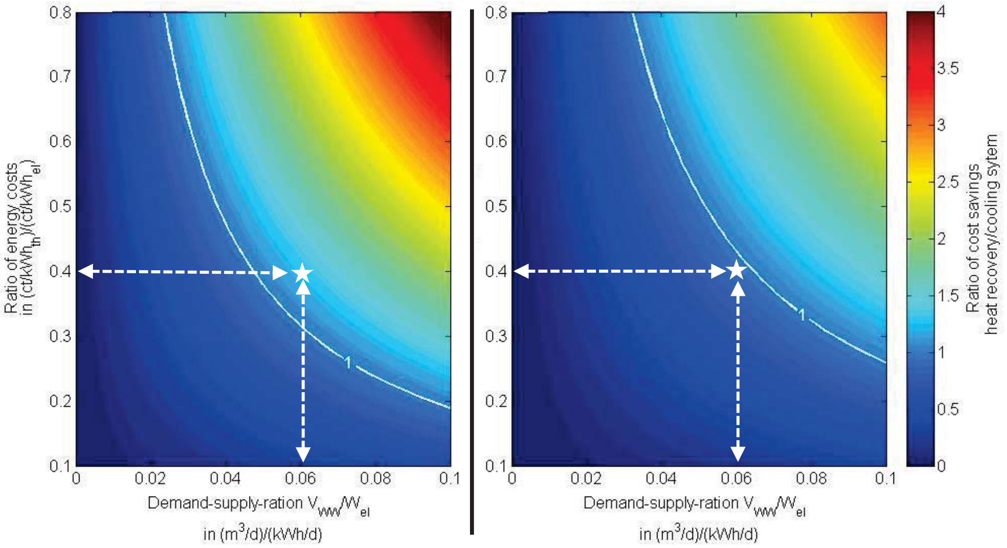

**Fig. 6: Ratio of cost savings operating the cooling system most efficiently in dependence of the defined ratios, left: factor f=2.2 %, right: factor f=2.9 %**

This calculation does only take the preheating of hot water into account. If there is another heat consuming process on a low temperature level (25..35°C) which can be fed by the heat recovery system, the savings due to an increase of condensation temperature can be even more relevant. Additionally, the costs for recooling the waste if not needed are not considered. This could make a use of the chiller as heat pump even more attractive, because the heat can be used and does not have to be recooled for which additional electricity for fans and pumps, as well as water in case of evaporative recooling, is needed.

Finally, it has to be discussed how to operate a cooling system if a heat pump system is installed downstream, using the chiller's condenser waste as heat source for its evaporator. Therefore, several simulations have been carried out. These simulations aimed at the increase of required electric energy demand for cooling by increasing the condensation temperature of the cooling system in relation to the decrease of the electric energy demand of a heat pump system by increasing the evaporator's temperature level. The results are given in Fig. 7. The change of electric energy is given in dependence of the temperature level of the condenser of the chiller (first x-axis) and of the evaporator of the heat pump (second x-axis). As before, it is assumed, that if the heat pump uses the chiller as heat source, there is a temperature difference between the two temperature levels of 10 K due to the two required heat exchangers. With the given figure and in knowledge of the electric energy demand for the cooling system as well as for the heat pump, it is possible to decide if is more profitable to decrease the condensation temperature of the cooling system and let the heat pump take this additional temperature lift or vice versa. As it can be seen, especially for normal cooling, for a lower condensation temperature level of the cooling system, the percentage reduction of the energy demand for cooling is higher than the percentage increase of the energy demand for the heat pump. In deep-freezing applications with lower evaporation temperatures, the temperature difference between evaporator and condenser in the compression chiller is already that big, that an additional increase does not affect the total energy demand significantly. The same effect can be seen for the heat pumps with the higher set target temperature, even though for higher evaporation temperatures the efficiency is increasing faster. For a better understanding, in the following, an example is given

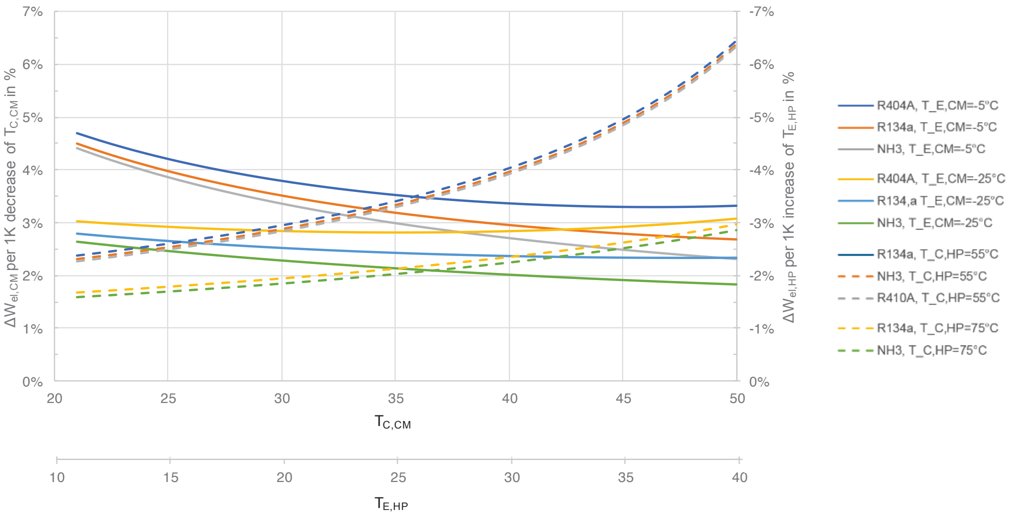

**Fig. 7: Comparison between the increase of the electric energy demand per 1 K increase of the condensation temperature of the chiller (left axis, continuous line) and the decrease of the electric energy demand per 1 K increase of the evaporation temperature of a heat pump (right axis, dashed line). Valid for customary refrigerants and evaporation temperatures (chiller) and condensation temperatures (heat pump)**

## 5. Conclusion

The process and energetic analysis has shown that there is a significant potential for solar process heat in the German meat sector. The technical potential is 1,000,000 m². The big amount of hot water simplifies the identification of a suitable integration points. Especially the maturing process is promising regarding the further use of solar heat. It has to be weighed if the retrofit to water heating is beneficial.

Due to the massive use of compression chillers for cooling the products, industrial heat pumps can reach low heat generation costs. The solar heat industry should focus on creating complementary systems of solar collectors and heat pump. If there is only a small temperature lift to provide. Heat pumps are going to be the favourable solution. As is could be shown, in general, cooling systems should be operation as efficient as possible, resulting in a very low condensation temperature. If there is a significant demand for hot water in relation to the used electric energy for cooling, it can be beneficial to use the compression chiller as heat pump, enabling an intensified use of heat out of the condenser. The combination of heat pumps and compression chillers is very promising. But, finding the optimal combination heavily depends on the system. If all of the waste can be used in a heat pump it can be profitable to increase the condensation temperature of the cooling system making the heat pump even more efficient.

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