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# Cooperation for heat recovery from a supermarket's $CO_2$ refrigeration system

**Daniel STEUER*, Edwin ANDERSSON, Filip JOSEFSSON, Samer SAWALHA, Jaime ARIAS**
KTH Royal Institute of Technology
Stockholm, 100 44, Sweden
dsteuer@kth.se, edwin.andersson1@gmail.com, filjos@kth.se, samer.sawalha@energy.kth.se, jaime.arias@energy.kth.se

## ABSTRACT

This study evaluates heat recovery from a refrigeration system in a supermarket where the heat is supplied both to the supermarket and to apartments in the same building. As the incentives of the supermarket and the property owner are not necessarily aligned, collaborative heat recovery requires an agreement beneficial for both parties. The objective of this work is to demonstrate, using techno-economic analysis, that cooperation between property owners and supermarkets for efficient heat recovery from refrigeration systems can be achievable and beneficial for both parties. Results from field measurements of the refrigeration system with heat recovery are compared with those of modelled floating condensing operation. Despite higher electricity costs from increased compressor energy use, the supermarket decreases its refrigeration system's yearly operation costs by 36 %, with an investment payback time of 3.2 years, and the building gains 20 % savings in district heating costs.

Keywords: Heat Recovery, Cooperation, Supermarket, Refrigeration system, $CO_2$

## 1. INTRODUCTION

Supermarkets are major energy consumers in the commercial sector and they are responsible for the emission of considerable amounts of greenhouse gases. Swedish supermarkets are responsible for roughly 3 % of Swedish electricity use, and refrigeration systems account for about half of supermarket energy demand (Karampour, 2021). Increased energy efficiency is an important tool in the efforts to mitigate climate change and environmental impact. One possible measure for increased overall energy efficiency is heat recovery of condenser heat from the refrigeration systems. However, supermarkets' refrigeration and HVAC systems are typically installed and maintained by separate companies. The systems are controlled independently, which may lead to a reduction in the overall energy system efficiency (Arias, 2005). The integration of these systems is found to significantly increase energy efficiency (Karampour, 2021).

Following the EU F-gas regulations, many supermarkets are switching to natural refrigerants, where $CO_2$ has become a popular solution in many countries already, especially in colder climates (Zolcer Skacanova and Battesti, 2019). Using $CO_2$ as a refrigerant allows for trans-critical operation, resulting in high discharge temperatures, which can be favourable for heat recovery applications (Polzot et al., 2017). The performance of heat recovery performance in trans-critical $CO_2$ booster systems in supermarkets can be found to be comparable to currently available commercial heat pumps, with COP of around 4-6 (Karampour and Sawalha (2017). This makes it feasible to use the recovered heat to cover space and domestic hot water (DHW) heating demands in the supermarket building. When the available heat is higher than the supermarket's heating demand it can be exported to nearby heat consumers, such as residential buildings.

When heat from refrigeration systems is not recovered, it is usually dissipated to the ambient air through air-cooled heat exchangers. In city centres, however, cooling with ambient air may not be a feasible solution, due to the noise and negative aesthetics of the heat exchangers. (Lindberg et al., 2018). One possible alternative is district cooling, but it might not be available, or it might be expensive to connect to. The condensers are sometimes cooled with municipal water instead, which is a costly and wasteful solution. With recovering heat, supermarkets have an interesting possibility to minimize, or eliminate, municipal water use during winter by recovering its own heating demand and exporting the remaining heat to nearby buildings. This work investigates a supermarket in which the refrigeration system's condensers were previously only cooled with municipal water, but where a heat recovery system has since been installed.

## 2. CASE STUDY

This work is based on a case study of a small supermarket in the inner parts of Stockholm, with about 390 $m^2$ of sales area and 500 $m^2$ in total. It is located on the ground floor of a 3759 $m^2$ residential building with 25 apartments and 3 other stores. The building uses district heating and the costs of heating is included in the supermarket's lease. The supermarket has previously used municipal water only for cooling of the condensers in the refrigeration system. A new $CO_2$ refrigeration system was installed in the summer of 2019, followed by a heat recovery system installation that was finished in January 2021.

The $CO_2$ refrigeration system includes three units, one low temperature (LT) and two medium temperature (MT) units. These are interchangeably referred to as KA1 (LT), KA2 (MT1), and KA3 (MT2). All three units use direct expansion with liquid-suction heat exchangers and single stage compression. The heat recovery system includes three hot water tanks (HWT), heat exchangers, and pumps. The heat recovery system delivers heating to the supermarket's ventilation system and to the building's radiator and DHW systems, see figure 1. The system may operate in trans-critical conditions under high pressure, enabling higher water temperatures delivery and higher heat recovery capacity. The refrigerant is cooled first in the heat recovery de-superheater which is connected to the HWTs. Then, if necessary, it is further cooled by municipal water (auxiliary cooling), which was the only cooling method used previously. Heat is removed from the HWTs via coil heat exchangers for domestic hot water and space heating in the residential building. The relatively cold return line from the HWTs is led to a heat exchanger in the ventilation system heating the supply air to the supermarket. The radiator and DHW supply lines are further heated by district heating if necessary, and the incoming air to the ventilation system is heated also by ventilation exhaust air and an auxiliary electric heater if necessary. The reason for first delivering heat to the residential part of the building is technical; the DHW and radiator systems require higher forward temperatures than the ventilation system.

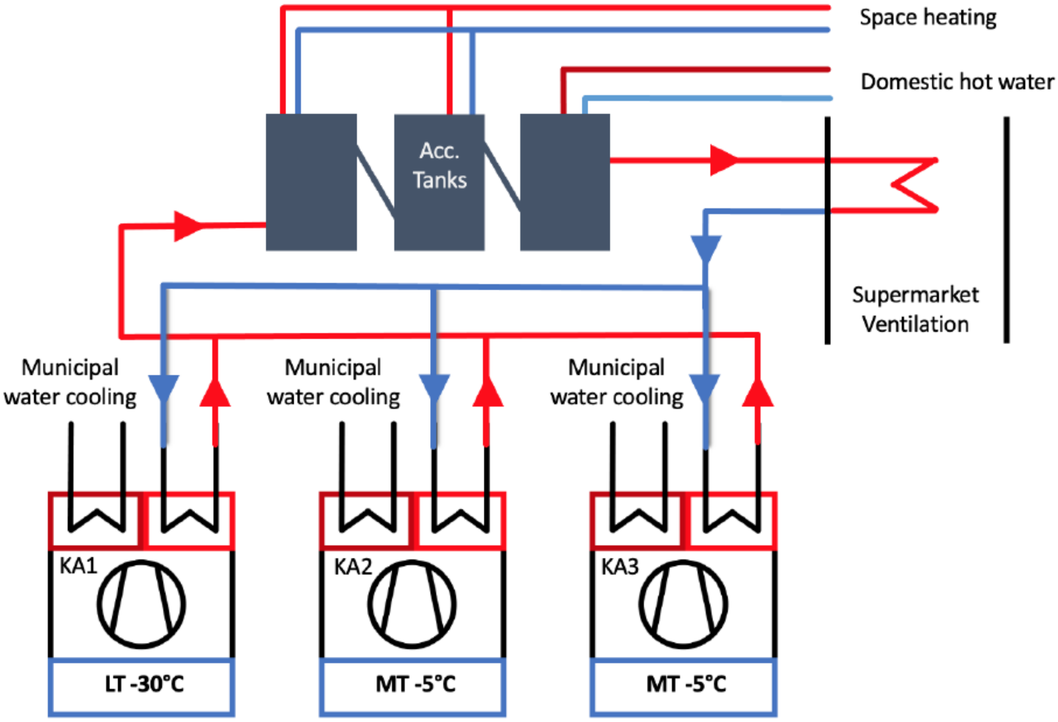

**Figure 1: Layout of the $CO_2$ refrigeration system with heat recovery**

## 3. METHOD AND DATA COLLECTION

The analysis of the present work is based on field measurements data from the case study and a comparison with floating condensing operation without heat recovery. Access to data from the refrigeration system was provided by the company Huurre through their monitoring system iTOP (Huurre, 2022). This includes real-time measurements, as well as historical data, on e.g. pressure and temperature at specific points in the refrigeration system. Data was collected for the time period from 1st of February 2021 to 31st of January 2022. The heating demand of the building was calculated as an adaptation to historical data provided by the district heating company, from the time when the building was only heated by district heating. The demand was represented as a function of outdoor temperatures, which were gathered from the Swedish Meteorological and Hydrological Institute (SMHI, 2022).

The building's DHW use was only available as a yearly value. While it is possible to estimate an average hourly value, it would be of little use, as DWH use is heavily dependent on occupancy schedules. Thus, this study focuses on space heating instead, which constitutes the major heating demand in the building anyway. The ventilation heat demand of the supermarket is calculated based on outdoor temperature, a set point inlet temperature of 20 °C, and an assumed fresh air volume flow rate of 830 l/s during the day, and half of that when the supermarket is closed, all of which is information that was provided by the supermarket manager. According to the supermarket manager, there is no need for air conditioning during the summer in the store, as part of the store envelope is underground. Thus, if the outdoor temperature is above 20 °C, it is assumed that there is neither any heating nor cooling demand. District heating prices were gathered from the district heating network operator, electricity spot prices as daily averages from Nord Pool (Nord Pool, 2022), and water usage prices were also provided by the supermarket manager. The electricity spot prices were assumed to constitute roughly 25 % of the total electricity costs, the rest coming from taxes and fees (Lindholm, 2021).

The heat available from the refrigeration system was calculated as the mass flow of the refrigerant multiplied by the enthalpy difference over both the heat recovery de-superheater and the water cooled condenser, as described by Eq. (1) below.

$$\dot{Q}_1 = \dot{m} * (h_a - h_c) = \dot{m} * (h_a - h_b) + \dot{m} * (h_b - h_c) \qquad \text{Eq. (1)}$$

$\dot{Q}_1$ is the available heat in kW, $\dot{m}$ the refrigerant mass flow in kg/s, $h_a$ the refrigerant enthalpy at the de-superheater inlet, $h_b$ the refrigerant enthalpy at the de-superheater outlet, which is the same enthalpy as that of the refrigerant at the condenser inlet, and $h_c$ the refrigerant enthalpy at the condenser outlet. Figure 2 below illustrates the position of these points in the system.

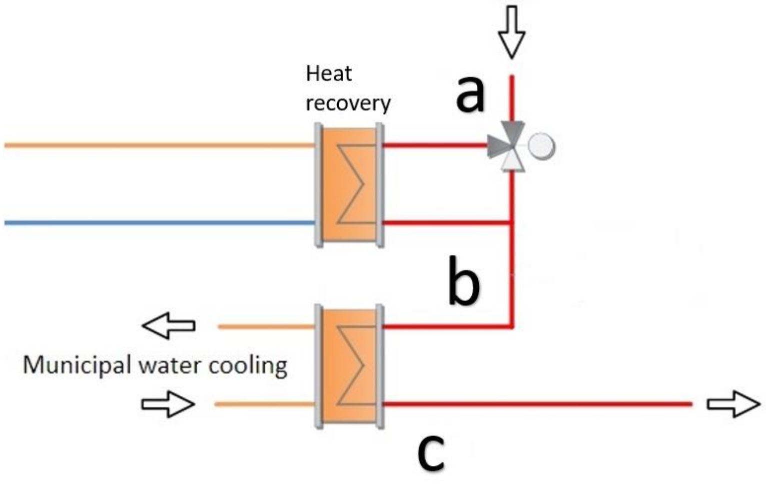

**Figure 2: Schematic of heat recovery de-superheater and water-cooled condenser**

The refrigerant mass flow was estimated at the compressor inlet as the product of the density and volume flow rate. The volumetric and total isentropic efficiency were estimated from manufacturer data as functions of the pressure ratio. The compressor capacity was an available data point as a percentage of the maximum, which in combination with the volumetric efficiency was used to determine the real volume flow. The total isentropic efficiency was used to determine the used compressor power according to Eq. (2):

$$\dot{E}_k = \frac{\dot{m}*(h_{1,is}-h_{2k})}{\eta_k} \qquad \text{Eq. (2)}$$

$\dot{E}_k$ is the compressor power, $\dot{m}$ the refrigerant mass flow, $h_{1,is}$ the refrigerant enthalpy at the compressor outlet for isentropic compression, $h_{2k}$ the refrigerant enthalpy at the compressor inlet, and $\eta_k$ the total isentropic efficiency.

The use of municipal water was available through checking a manual water gauge, which has been done on a monthly basis, providing monthly average values. For hourly average values, auxiliary cooling was estimated according to Eq. (3):

$$\dot{Q}_{water,aux} = \dot{m}_{water,aux} * c_{p,water} * (t_{out} - t_{in}) \qquad \text{Eq. (3)}$$

$\dot{Q}_{water,aux}$ is the cooling effect of municipal water, $\dot{m}_{water,aux}$ is the cooling water mass flow, $c_{p,water}$ is the specific heat capacity of water (assumed constant), and $t_{out}$ and $t_{in}$ the outlet and inlet temperatures of the water in the condenser. The cooling effect was calculated on the refrigerant side and the inlet temperature was available as a data point in the monitoring system. The outlet temperature was assumed a few degrees lower than the inlet temperature of the refrigerant in the condenser, and parametrically determined to match the actual measured water use.

If no heat recovery system was available, the system should have been operated at lower head pressures; i.e. in floating condensing mode. The discharge pressure of the system in floating condensing mode is set as low as possible, still allowing the refrigerant to condense at a temperature higher than that of the available heat sink (Arias and Lundqvist, 2006). The condensing temperature was set to 5 K above the available municipal water temperature. Figure 3 illustrates floating condensing operation for the MT2 unit. The figure shows how the higher the temperature of the available heat sink is, the higher must the head pressure be. The figure also shows the actual head pressures measured, which are higher than those of floating condensing, but not higher than 73.8 bar, which is the limit for trans-critical operation.

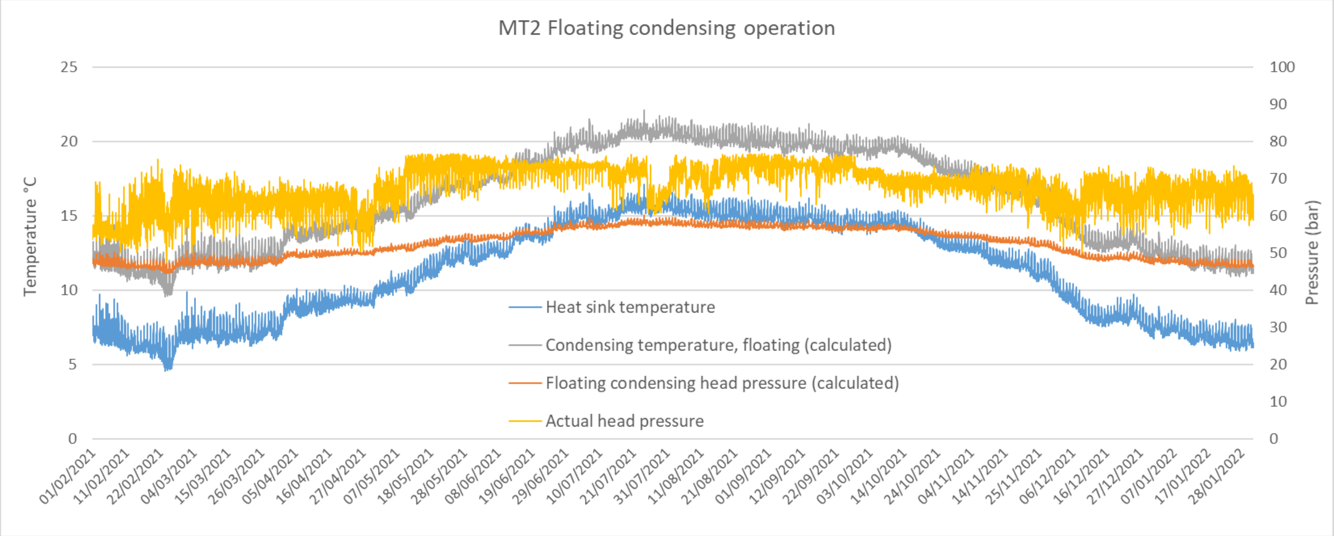

**Figure 3: Floating condensing operation in MT2**

## 4. TECHNO-ECONOMIC ANALYSIS OF HEAT RECOVERY

This techno-economic analysis is based on evaluation of field measurement data with heat recovery and a theoretical operation in floating condensing mode. Figure 4 is a plot of the total available heat delivered from the refrigeration system, the heat demand of the supermarket (i.e. ventilation heating), and the heat demand of the property's radiator system. The diagram shows that during most periods of the year, the available heat is more than enough to cover the heating demand of the supermarket. The available heat is also typically enough to cover a significant share of the heating demand in the property's radiator system.

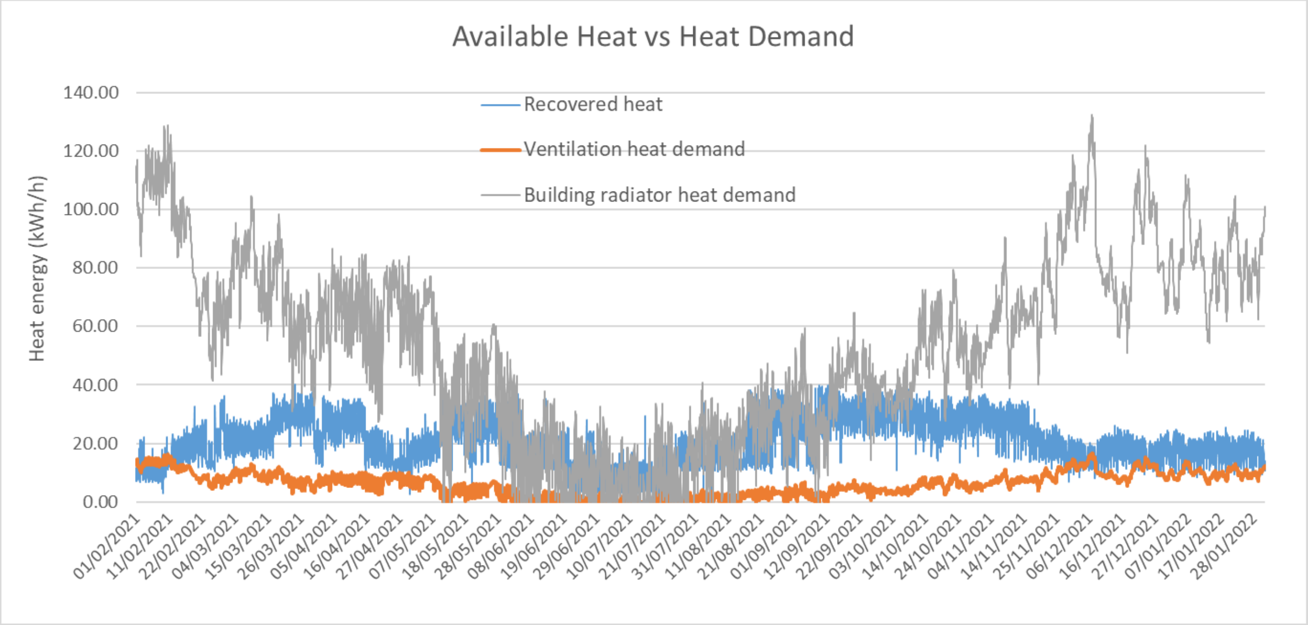

**Figure 4: Recovered heat available from the refrigeration system, building radiator heat demand, and supermarket ventilation heat demand**

The value of recovering the available heat has two components, namely the reduced use of municipal cooling water and the reduced use of district heating. However, these savings occur at the expense of increased electricity costs from compressor operation. With a water cost of 5.75 SEK/m$^3$, figure 5 below illustrates the cost savings in water usage for the supermarket on an hourly basis. In total, the use of heat recovery decreases the water costs of auxiliary cooling from 145 390 SEK to 62 450 SEK during the investigated period of, a reduction of 82 941 SEK, corresponding to about 57 %.

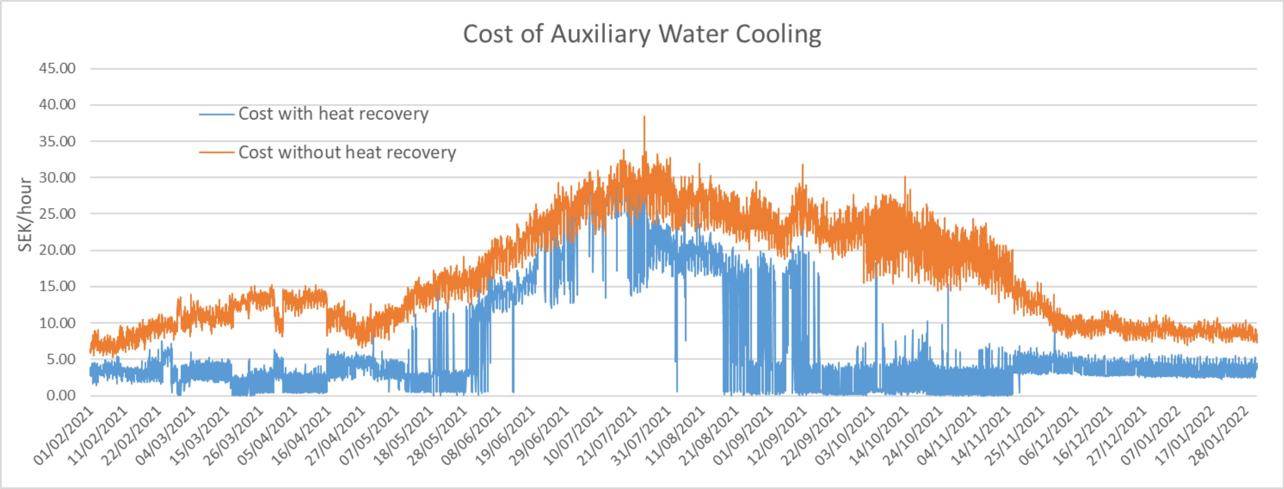

**Figure 5: Hourly cost of municipal water cooling with and without the heat recovery system**

Figure 3 previously illustrated that the system is not operated trans-critically and figure 5 shows that municipal water is still used for cooling in the winter. This shows that there is a potential for increasing the recovered heat from the system by operating it trans-critically without municipal water cooling.

Figure 6 below shows the power consumption of the compressors in floating condensing operation compared with that of heat recovery operation. The system uses about 55 MWh in floating condensing mode, and about 79 MWh in heat recovery mode, over the investigated period. This electricity use leads to costs of 37 652 SEK and 53 883 for the respective scenarios. Thus, the heat recovery operation leads to a 16 231 SEK increase in electricity costs, corresponding to about 43 %. The net effect is that the supermarket still saves 66 710 SEK, corresponding to about 36 %, of the electricity and water costs combined. Given the investment cost of 212 000 SEK, the savings yield a payback time of roughly 3.2 years. These savings occur without any compensation for the exported heat.

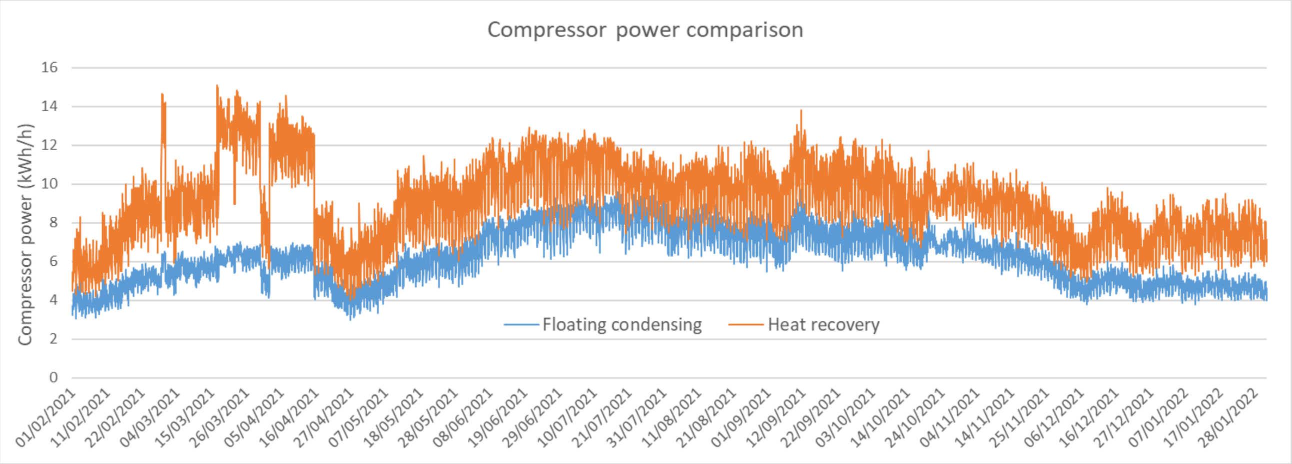

**Figure 6: Compressor energy use in floating condensing and heat recovery mode**

Moreover, figure 7 below shows the district heating cost savings for the property. District heating costs are made up of three components: a peak load fee measured in kW, an energy use fee measured in kWh, and a possible penalty fee for high return temperatures (Stockholm Exergi, 2021). The cost of energy usage from district heating were 250 SEK/kWh from April to October and 656 SEK/kWh in 2021. The two scenarios have the same peak load of 132 kWh/h, and no measurements on the return temperatures to the district heating network are available. Thus, only the cost of energy use is included in this analysis. In total, the running district heating costs are reduced from 229 896 SEK to 184 988 SEK during the investigated period, yielding a cost reduction of 20 % for the property owner.

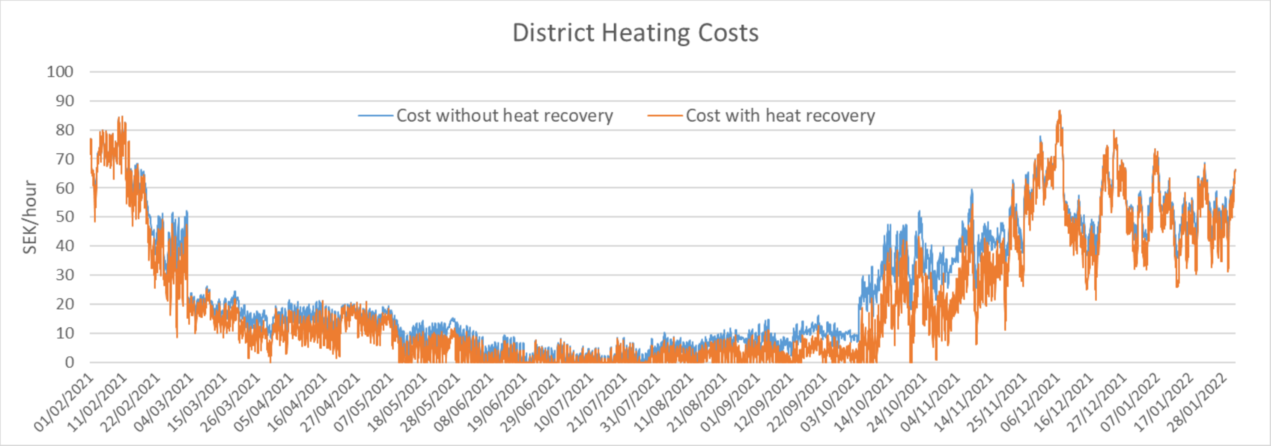

**Figure 7: Hourly district heating costs for the property, with and without heat recovery**

# 5. DISCUSSION

The results demonstrate that the installation of a heat recovery system benefits both the supermarket and the property owner in the studied case. Over the studied period, the supermarket saves 57 % in water use costs and the property owner saves 20 % in district heating costs. However, the supermarket increases its electricity costs with 43 %, but still decreases its combined costs with 36 %. The payback time for the supermarket's investment is about 3.2 years. However, the figure 5 showed that municipal water is still used for cooling the condensers in the winter, even though the heating demand of the building significantly exceeds the recovered heat. Thus, there is still room for improvement in operation of the refrigeration and heat recovery systems, through increasing the head pressure of the system in the winter months to trans-critical levels. Unfortunately, as this requires more electricity use for the compressors, which increases the costs for the supermarket, while no compensation is given for the exported heat, there is not a clear incentive for this.

Several barriers to successful collaboration between supermarkets and property owners have been identified by Termens (2020). Some of these are technical ignorance and unwillingness, especially pertaining to unwillingness from property owners to recognize the fact that heat recovery leads to higher operational costs of the refrigeration systems for the supermarket. From the supermarket perspective, if it is unlikely that they are financially compensated for delivering heat to the building, there is no financial incentive to install a heat recovery system or increase energy use in the refrigeration systems for more heat recovery in an existing system. In the present studied supermarket, the cost savings in water usage alone were enough to justify the heat recovery investments, as they offset by far the increased electricity costs.

Three types of agreements are identified by Termens (2020). The first type is financial compensation for delivered heat. The price can be determined in several ways, e.g. as a fixed rate, a function of outdoor temperature, or a share of the property owner's district heating fee. Certain demands on the supermarket's delivered heat regarding its power or temperature may also be present. This kind of agreement has been difficult to achieve due to reluctance from property owners to pay for the heat.

The second type of agreement, referred to as "zero sum", involves the property owner giving the supermarket free heating of the store in exchange for the heat recovery. This may sound simple enough but can cause disagreements, due to for example the fact that the recovered heat from the refrigeration systems can at times cover all demand in the store. In the present study, the supermarket is self-sufficient in terms of space heating in the store, despite exporting heat to the rest of the building, so they should not have to pay for any heating anyway.

The last type of agreement is referred to as "win-win without requirements" and neither involves any financial compensation, nor any demands on the supermarket, but cost savings occur anyway. An example of such an agreement is when the property has a geothermal heat pump with boreholes, to which heat from the supermarket's refrigeration system can be supplied. The property owner's boreholes are charged while the efficiency of the supermarket's refrigeration system is increased due to improved operating conditions with lower condensing pressure. Another example is that of the present study, where avoided use of municipal water cooling alone was enough to justify a heat recovery installation.

# 6. CONCLUSIONS

The supermarket in this case study previously had an old refrigeration system using municipal water for cooling. The recently installed system with heat recovery to the supermarket and the residential building yields a notable decrease of water usage costs of 57 %. Simultaneously, the property owner gained a 20 % district heating fee reduction over the investigated time period. However, the supermarket increases its refrigeration system electricity costs with 43 % due to higher head pressures in the system, but still decreases its combined electricity and water costs of the refrigeration system with 36 %. The calculated payback time for the supermarket's investment is about 3.2 years. This is achieved despite the fact that the refrigeration system is not controlled for optimal heat recovery and that there is no compensation for the delivered heat.

Further studies will explore the forming of agreements which would, through financial compensation or other mutually benefitting terms, encourage supermarkets and property owners to optimize the overall energy efficiency in buildings.

## 7. ACKNOWLEDGEMENTS

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