
Climate change: melting glaciers, diminishing water resources, trapped sunrays increase global warming

REFRIGERATION PLANTS AS BENEFICIAL ENERGY CONVERSION FACILITATORS

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Abstract

Compared to previous studies the opportunities for using the refrigeration system as a total energy facilitator have increased with emerging thermal and electrical storage opportunities. In this paper, several opportunities for integration of refrigeration systems with internal as well as external energy grids are investigated. A hierarchy of technologies, which surrounds the refrigeration plants, is described with the aim of reducing the cost for the owner and at the same time reducing CO2 emissions from the conventional thermal and electrical energy production. It is outlined how a cost reduction of more than 40% can be achieved. More specifically it is outlined how PV electricity production and storage can add extra value in combination with the refrigeration system and how the opportunities for utilizing the temporary unused cooling and capacity of the systems can yield a good payback.

Keywords

Smart systems, Energy storage, Refrigeration, District heating, Supermarket, Food Retail

Introduction

Cooling applications covering refrigeration, air conditioning, and heat pumps are responsible for 15-20 % of the electricity consumption globally and likely going to increase in the future with the increasing electrification. The fundamental energy management of these systems are mostly based on the old energy paradigms and not exploiting the opportunities for improving the overall performance. The primary improvement potentials are found in the composition and performance of system components and are typically regulated by Minimum Efficiency Performance Standards (MEPS) like in the Eco-design directive. The validity of MEPS methodology has been proven over the decades; however, it also implies its limitations based on strict testing measures and system (commodity) definitions. When systems are in operation, they correspond to variable conditions where sizing, modus of operation dramatically can change the actual versus expected efficiency. Furthermore, the dawn of variable energy cost - and remuneration - has pushed the perception of traditional efficiency. Is the COP of a system more important than the availability of cheap wind or PV energy? Or does it make a good business case to store energy? The consumer would argue that the best measure is the accumulated cost of energy seen over a period. The cost of energy at the end summarizes the needs of the players in the energy system – and the means for obtaining the lowest energy cost be planned to accomplish the best business case or pay back.

Buildings / Vapor Compression Systems and the External Energy System

The vapour compression system is located inside the building envelope and regarded as the central part of an energy system, see figure 1. The system uses electricity to operate, and the electricity can be sourced through the external grid, or it can be supplied by the building through installed PV panels. Electricity can be stored in a battery. The vapour compression system produces a thermal product (cold and hot media) through its compressor work, which can be used directly for comfort, refrigeration of products, or it can be stored in ice banks or hot water containers. Heating and cooling can also be exported through thermal networks [1].

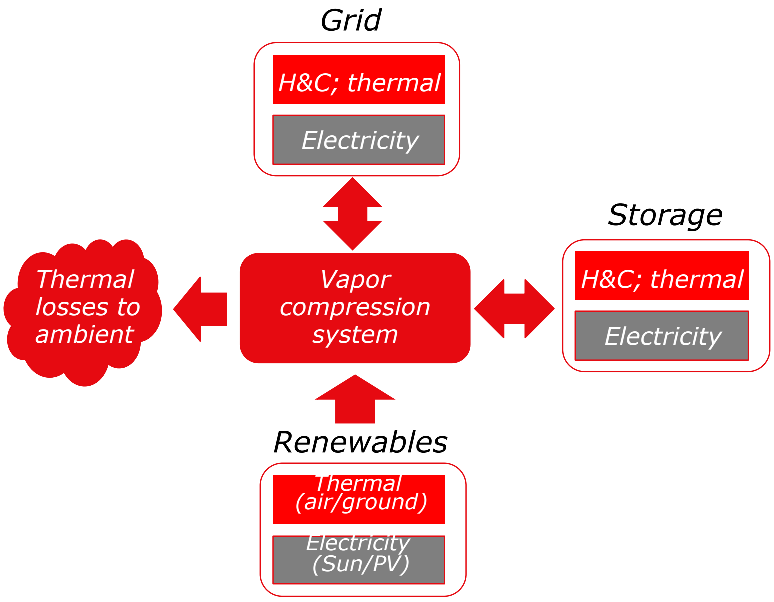


Figure 1, The energy flows, Vapour Compression

The external energy suppliers charge a rate for providing energy, and they may also buy energy or flexibility within the energy consumption. The rates can likely dependent on time. In this dynamic scenario, there is a possibility to lower the energy cost considerably and at the same provide decentral capacity and flexibility for the grid operators.

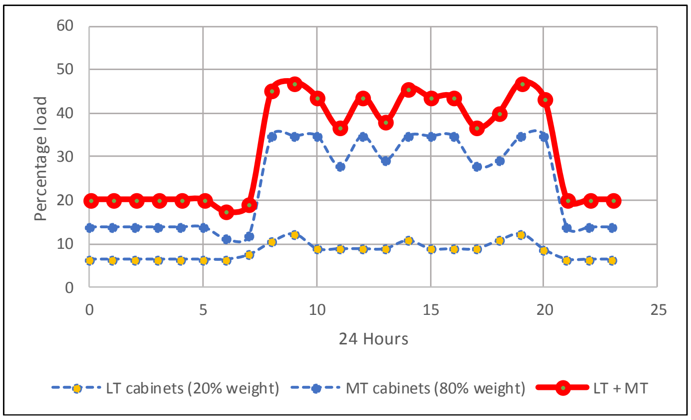


Figure 2, The average load of a supermarket

The vapor compression system has a certain capacity, and it runs with a particular COP dependent on the operating conditions. Normally the capacity of the system is much higher than the actual primary needs. As an example, supermarkets on average only use around 30 % of their installed capacity over a year, see figure 2. The seemingly over dimensioned capacity is justified by ensuring food safety [2] in peak seasonal conditions like high outdoor summer temperature and humidity. Equation 1 shows the relation between the capacity of the compressor rack and a number of display units

$$Qc = K * \sum_{k=1}^{n} Qc,k \qquad (1)$$

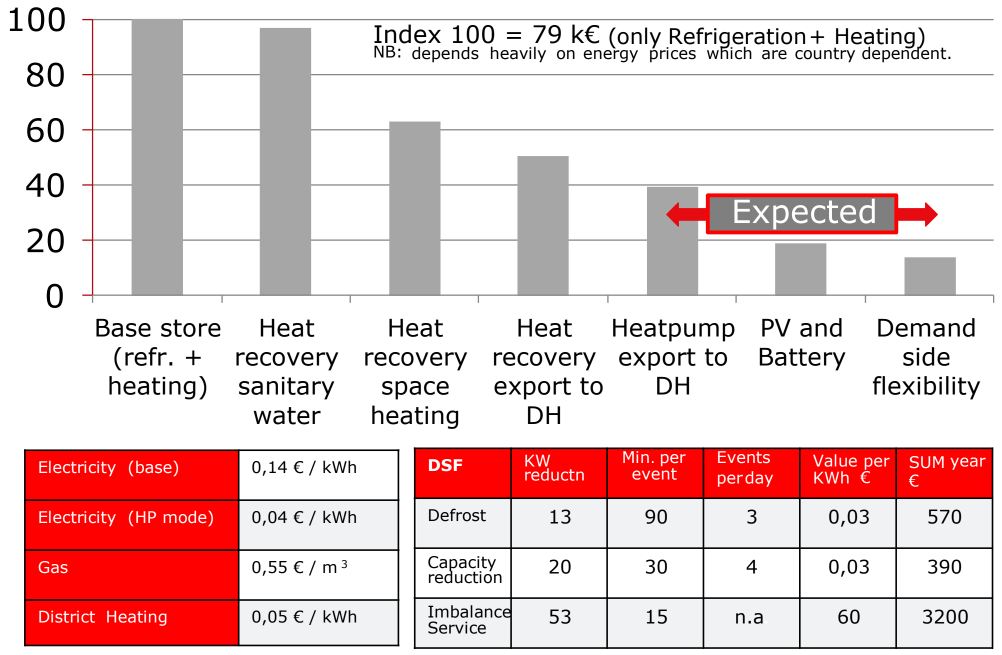
Where Qc is the cooling capacity of the compressor rack and Qc,k the capacity of the single display cases in the store. K is a safety factor which usually can be taken as 1,10 – 1,15. The cooling capacity of the display cases relates to certain test conditions, which can be found in e.g. ISO 23953. The rating condition relies on a temperature of 25°C and a humidity of 60% (EU).

Traditional heat recovery is per definition based on the energy obtained in the cooling units in the store and can be regarded as 'free' bonus energy. However, the utilization of the extra compressor capacity is a trade opportunity, which is dynamic throughout 24h. Consequently, an automated evaluation on when and how to operate needs to be in place. An attractive cost balance for a certain minimum time is needed before activating the extra capacity. The cost balance is positive if the relative heat remuneration (C_h) exceeds the relative electricity cost (C_e) divide by the $COP_{h,u}$ which is the energy of usable heat divided by the energy for running the system, see equation 2.

$$C_h > \frac{C_e}{COP_{h,u}} \qquad (2)$$

This implies that the operator knows these parameters and has an online measurable COP factor [3] giving an estimation of the COP development for the next hours.

A Case Considering the Cost Optimization and Emission Reduction



Electricity (base)	0,14 € / kWh
Electricity (HP mode)	0,04 € / kWh
Gas	0,55 € / m^3
District Heating	0,05 € / kWh

DSF	KW reductn	Min. per event	Events perday	Value per KWh €	SUM year €
Defrost	13	90	3	0,03	570
Capacity reduction	20	30	4	0,03	390
Imbalance Service	53	15	n.a	60	3200

Figure 3: The operating cost depending on energy saving and utilization of capacity and demand side flexibility

Based on the supermarket case previously described in [3] further cost validations have been made. The baseline is a conventional CO_2 refrigeration system without heat recovery, demand response and without any solar panels and storage. The improved store has heat recovery internal in the store and exports heat to the local DH network. Based on the running conditions (COP and energy prices) and energy cost comparisons can be made (see Figure3. The first and second cost savings come from the heat recovery which is used for sanitary hot water and space heating in the store and fully substitute gas heating. The third saving consists of income from selling heat to the district heating system based on the export of the surplus of energy under normal load conditions i.e. around 30% capacity utilization.

The fourth saving is designated the further utilization of the available compressor capacity not used for refrigeration. It is assumed that in 25% of the time the electricity price is attractive (30% of average) due to the amount of renewable energy production and that the $COP_{h,u}$ is 1,5. The selling price of heat is not affected. This saving can likely be higher but depends on local conditions and should only be taken as an example.

The fifth cost reduction is obtained using solar PV panels and a battery storage. The installment of PV panels will add value to the supermarket in two ways. First, there is a correspondence between highest compressor power need and solar irradiation (summer conditions) which means the highest potential electricity savings during high-priced hours. Secondly, it allows in combination with batteries to add committed flexibility to the supermarket. In this case, 500 m^2 PV panels are mounted on the roof and producing 75 MWH from April to October and 40 kW in the peak hours of the season. A battery of 80 kWh (2 hours average consumption) is installed to capture cheap grid electricity during the night. The savings consisting of peak shaving during peak hours and committed flexibility are substantial around 20% of the baseline.

Finally, the sixth cost reduction is an income based on selling demand side flexibility (DSF) to the electrical grid operator. DSF is about optimizing the timing of electricity usage to have the lowest electricity bill by managing the consumption. One example is the shedding of defrost and refrigeration loads during peak hours. Another example is the imbalance services implying very fast load reductions to help keep the grid frequency.

The associated CO_2 emission reductions can be estimated calculating the CO_2 content of the saved gas consumption and for the DH export part (fifth column) the CO_2 difference between electricity consumption and heat production. The solar power is a direct CO_2 saving while the battery contribution is counted as zero. The DSF part is regarded as having zero CO_2 emission influence because it is only moving energy consumption. However, indirectly from the electricity supply side emissions are likely saved to due to a lower CO_2 emission based energy mix.

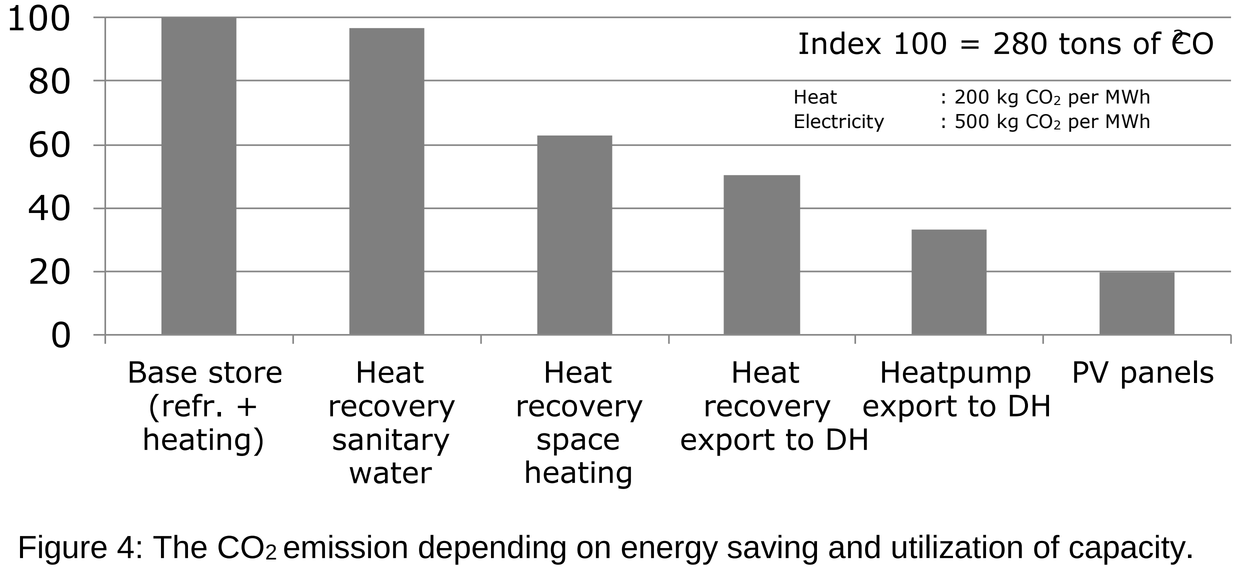


Figure 4: The CO_2 emission depending on energy saving and utilization of capacity. Demand side flexibility is not accounting for indirect emission saving.

Conclusions

- The integration of heating and cooling in vapor compression systems has proven to be an effective cost reduction method. The majority of energy savings is based on the heat recovery.
- Besides conventional heat recovery the utilization of unused compressor capacity for heat export can be an opportunity to increase the store income.
- Electricity obtained by solar panels can in general reduce the cost of electricity but additionally correspond very good with the electricity consumption of vapor compression systems.
- Batteries are seen as a resiliency tool in the local energy management system – it supports the solar energy generation but also acts as source for DSF services
- Selling DSF services from supermarkets is an obvious opportunity to reduce energy cost but still needs to mature in the market
- CO_2 savings using heat recovery, Heat pump capcity and PV panels are very high

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