ENGINEERING TOMORROW

Danfoss

Supermarket Refrigeration as an Important Smart Grid Appliance

This paper was presented at the 16th European Conference, Technological Innovations In Refrigeration And In Air Conditioning Politecnico Of Milan 12th-13th June 2015

Abstract
This paper describes the smart grid opportunities for a combined heating and refrigeration cycle applied in food retail applications. The potential of adding the flexibility of supermarkets to a smart grid network is outlined as well as the potential of utilisation of unused compressor capacity. In connection with external thermal networks a functional storage opportunity for renewable energy sources like wind is shown viable and backed up by a new case study. The business implications of connecting the supermarket to the district heating are briefly outlined.

Introduction

The energy and climate challenges call for innovation in the most energy intensive consumer applications. Cooling applications covering refrigeration, air conditioning and heat pumps are responsible for 15 – 20 % of the electricity consumption and thereby also a targeted innovation area to contribute to an efficient and smart future energy market. For many years the efficiency focus has been on consumer appliances and their specific measurable efficiencies covered by e.g. the Ecodesign Directive. This focus has pushed the market to higher efficiencies and lower costs. However, increased efficiency is not the only answer to the energy challenge. Energy effectiveness i.e. when and how energy is used, may even become more important especially to serve the increasing amount of fluctuating electricity supply. Flexibility in electricity demand can be addressed by demand response technologies and the supermarket sector is an obvious candidate which is outlined together with the smart grid deliverables in fig.1. Important is that supermarkets provide flexibility within short term by accessing the relatively easy handles for load shedding. Additionally interesting perspectives arise when connecting supermarkets to the heating and cooling grids.

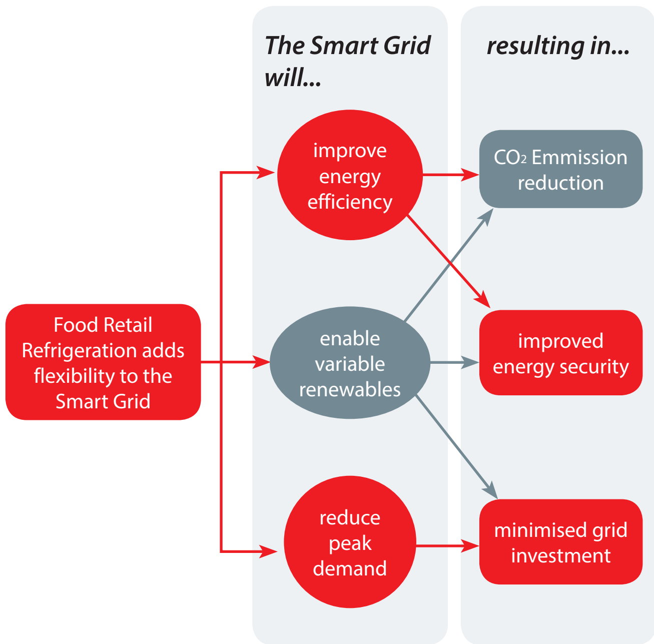

Figure 1. Food retail and smart grid

Smart Grid and supermarkets

Electricity grids carrying a high percentage of renewable electricity like wind and sun are increasingly challenged in balancing the demand and the supply of electricity. A supermarket has a high thermal capacity due to the cooling of considerable thermal masses of food. This means the sector can play a stabilizing role as 'virtual power plant' by adjusting electricity consumption for refrigeration and for other electricity consuming activities like defrosting and rail heating of the cases. In this context it is important to notice that supermarkets account for 1 – 2 % of all electricity consumption in Germany[1][4]

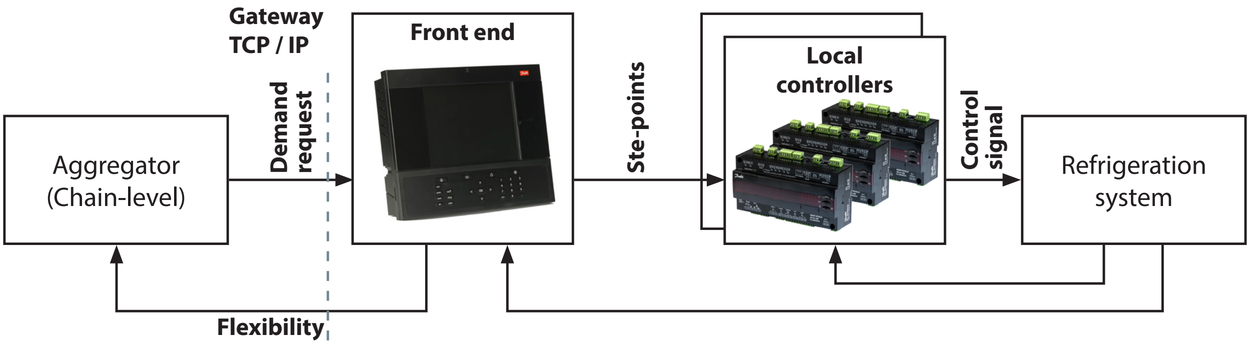

Figure 2. The controller hierarchy in a supermarket and the connection to the grid

Parameter	Value	Comment
Thermal storage of a typical supermarket	25 KWh	5 °C temp. change in 20 cabinets of 500 kg food, C_p= 1.7 KJ/(KG 5 °C)
Compressor cooling capacity to maintain normal operation	100 KW	Full capacity is 250 KW
compressor power with a COP of 2.5	40 KW	COP will vary during the year
Time with 100 – 60 % reduced power	15 – 25 min	–
Time without Defrost	90 min	Defrost event is not dependent on the cooling capacity event
Defrost power flexibility	13 KW	–
Total power flexibility	15 KW	For 500 stores adds up to 26.5 MW

Table 1. Results and estimations on the flexibility in supermarkets

Most supermarkets are energy managed by a central controller connected to multiple cooling cases to control temperature levels. The hierarchy of the controls in a supermarket and the communication to the grid operator can be seen in fig. 2. It is worth noticing that even in older systems changes in the control set-up can be done without big investments i.e. main assets as compressors refrigeration cases will not need to be replaced.

Flexibility can be practiced in various variants, see fig.3, and depends on the need of the electricity provider. Short term response called FFR (Firm Frequency Response) is applied when the frequency in the grid drops under a certain critical value and needs compressor shut downs within 5-10 seconds. Longer and scheduled consumption adjustments e.g. during peak hours, can be obtained by intelligent energy storage utilization or specific tailored defrost schedules.

Some test trials on demand response have been executed in selected supermarkets in the UK and France, see table 1. If properly managed supermarkets can be flexible with around 60 – 80% of their normal cooling capacity for around 20 minutes and most importantly react very fast on specific grid request. Figure 3 shows that actual executed reaction times can be within a few seconds to minutes. Longer event durations offer smaller capacities because the cold storage energy is a constant. To obtain sufficient flexibility (aggregators often require 3 MW) stores must be aggregated and supermarket chains are well suited for aggregation as a few hundred stores would be an attractive package to operate.

Flexibility is not always a question of reducing load. Often the balancing problems in the grid are based on excess electricity production e.g. wind farms may produce a lot of electricity during the night where demand is low. Unexploited is the unused capacity of the compressor racks. Approximately 60 – 70 % of the installed compressor capacity is in average unused. If these capacities can be exploited by providing heat and cooling to thermal networks or other thermal storage facilities, the flexibility potential can even be increased.

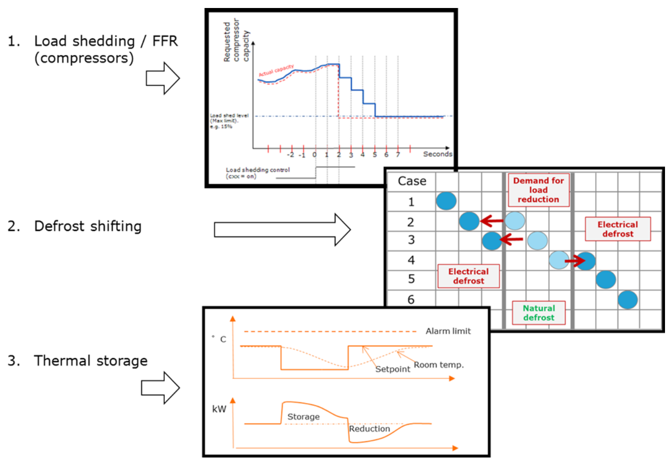

Figure 3. Supermarket flexibility opportunities

Supermarkets and District Heating (DH)

The cooling process produces heat like a heat pump and traditionally the heat is not used but instead released to the surroundings. Heat recovery of the process is often a very attractive source for the heat required by the store[3]. This combined cooling and heating process is increasingly getting installed in the market as very attractive business cases. From January 2015 the new EU F-gas Regulation has been in force. Especially for supermarkets this implies a dramatic change from refrigerants with high global warming potential (GWP) to low GWP substances like CO_2. One of the emerging technologies with CO_2 shows unique properties for the combined cooling and heating cycle. The reason for this success is that CO_2 can provide a relatively large amount of heat at high temperatures compared to the traditional refrigerants.

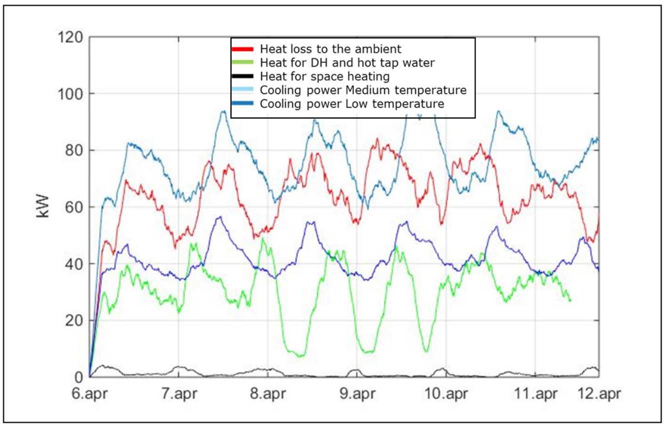

Figure 4. Measured powers one week April.

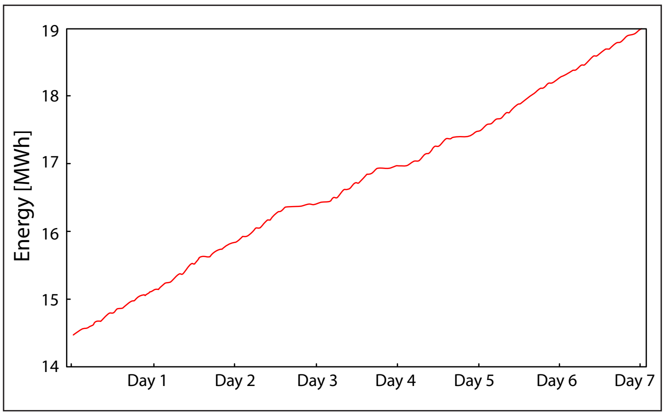

Figure 5. Accumulated heat produced for the DH grid during 1 week in April

In communities where there is a DH grid or plans for establishing such a grid a supermarket can even become a decentral heat supplier. The upsides for having decentral heat suppliers are numerous. The supermarket will get a revenue from selling heat to the grid and the grid owner will normally see a decentral production of heat as attractive due to excess free asset capacity and the opportunity of fewer on-off cycles in the summer months of smaller central heating plants. Especially future low-temperature DH grids will invite for attractive efficiencies when exporting heat to the grid[2].

Once connected to the DH grid the supermarket will face potential new opportunities beyond the traditional heat recovery. Traditionally supermarkets are designed for a very high cooling load respecting extreme summer conditions with high temperatures and high humidity. As a result the average running capacity of the compressors is only 30 % of maximum capacity. Connected to the 'infinite' heating reservoir this unutilised capacity can be used as a heat pump capacity. This will add a tremendous extra opportunity to the local energy supply.

To quantify the gains from combining heating and cooling in a district heating context a pilot store was selected and monitored. The store is located in the south of Denmark and was previously used as a case for internal heat recovery[2]. The principal outline of the set-up is shown in Figure 6. The DH system amendment is done without interrupting the refrigerant high-pressure part. Only the water circuit to the high-temperature tap water reservoir is rebuild connecting the flow and return lines of the DH system. To overcome the 6 bar pressure difference between the flow and return line a pressure pump has been added.

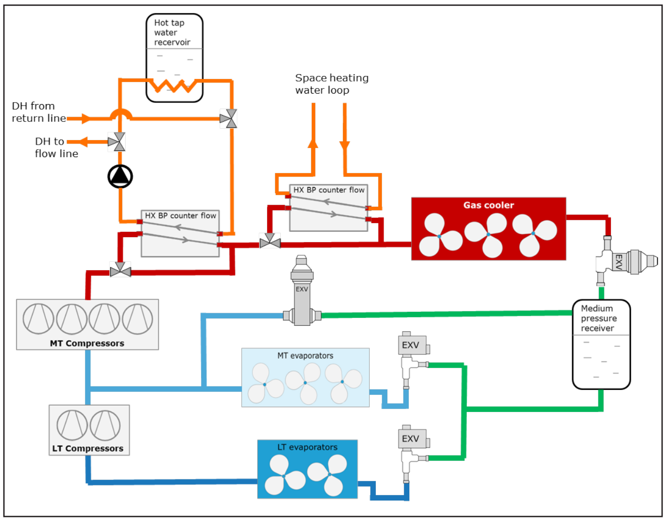

Figure 6. The concept of the CO_2 refr.system with heat recovery and DH connection

The DH return line water is circulated into the counter flow heat exchanger at a temperature of 35 °C and is heated to 65 °C by the hot CO_2 refrigerant. It is then pumped back into the flow line of the grid. The control system of the compressor rack is in control of the heating priorities of the store. 1st priority is to serve the basic heating needs in the store i.e. keeping comfort temperatures within the building. During the data collection time in April the need for space heating was very low due to relatively high ambient temperatures (10 °C) meaning that other heat sources in the store were sufficient to keep the desired comfort level. The 2nd priority is to keep up the temperature level in the hot tap water heat reservoir. As 3rd priority the district heating supply is served. During the testing period, the majority of the heat has been delivered to the district heating system. As previously explained this is due to the temperature conditions of the specific week of the year – however – no big differences are expected even for colder periods. The reason for this is that space heating water only needs temperature around 35 °C to heat the store even at 0 °C ambient, and this corresponds well with the temperature leaving the DH heat exchanger

Environmental and Economy gains

The recently installed DH connection has shown to be a good solution for the energy efficiency of the DH grid and also for the supermarket system.

- DH grid losses are minimized as the on - off cycles are reduced especially during summertime
- The heat loss from the refrigeration system to the ambient has been reduced considerably (40 %) and turned into a revenue stream
- The heat produced by the supermarket in the case is equivalent to 16 standard homes and is saving the environment for the equivalent amount of CO_2

Even though the present case has a very modest heat value rate of 25 € per MWh, due to the use of biomass fuel, it has resulted in a 1½ year payback investment case. In the case of a gas-fired plant the pay back would be less than 1 year.

In a larger scale perspective, connecting supermarkets to external thermal networks and utilizing the fluctuating renewable electricity can provide a large heat contribution. Germany has a food retail outlet area of 30 mill m^2. Assuming this area to represent an equivalent opportunity to export heat to the DH grid would mean that around 6 TWh of heat could be delivered – just based on the waste heat itself. If 50 % of the excess and today unused compressor capacity could be used an additional 8 TWh heat would be the result or more than 7 % of today's heat provided by the German CHP plants[4]

Conclusion

- Supermarkets can play an important role in the coming smart grid market. The offered flexibility is attractive and can relatively easy become operational without major investments. The flexibility has shown to be operational from the very fast response times to longer scheduled events.
- The main barrier for a wider introduction is the missing business models and market regulations on the electricity grid side.
- Supermarkets can become important heat contributors for the district heating grid. The obvious advantages as fast payback and reduced emissions make the heat export case very attractive for all stakeholders.
- If the full potential of installed compressor capacity could be utilised for creating heat during low electricity price time slots, a considerable contribution to the overall heating can be obtained.

References

[1] Arnemann M. Real Energy Efficiency in Supermarket Refrigeration systems, Institute of Refrigeration and … Karlsruhe University of applied Science, 2014.

[2] Lund,H et al ; 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems; Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.02.089

[3] Funder-Kristensen T. Fösel G. Bjerg P. ; Supermarket refrigeration and heat recovery using CO_2 as refrigerant, Cryogenics and Refrigeration Proceedings of ICCR2013 Paper ID: B129

[4] EU energy in figures , Statistical pocket book 2014, ISBN 978-92-79-29317-7

Authors

Funder-Kristensen T Ph.D. Head of Public & Industry Affairs, Danfoss
Green T. Ph.D. R&D Engineer, Controls, Danfoss
Bjerg P. M.Sc. Lead Application Specialist, Danfoss