The potential of thermal energy storage in food cooling processes in retail markets for grid balancing

Tommie Månsson, M.Sc. [1]
York Ostermeyer, Assistant Professor [2]

[1] Chalmers University of Technology, Sweden
[2] Chalmers University of Technology, Sweden

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SUMMARY:
An upcoming demand for higher energy efficiency in the society requires multiple actions to reduce the amount of unutilised energy. Supermarkets are part of the sixth largest energy consumers in Germany, the food industries, and hold a great potential for increase of its energy efficiency and at the same time contribute to buffering capacity needed in grids that have a large share of renewables.

A state of the art supermarket designed according to the demands of Passive House Institute has been built by REWE in Hannover Germany. Measurements are proving it to have energy consumption substantially lower than an average supermarket of the same size. Monitoring also proves a substantial amount of buffering capacity in the cooling processes.

Extrapolation shows a substantial potential for buffering grid fluctuations due to delaying cooling processes in Germany especially when complementing the system with ice storage.

1. Background – Storage demand in renewable grids

Any electrical grid with a large share of renewables faces problems with fluctuations in energy supply and therefore needs buffering or storage capacities (Farhangi 2010). In this context the NPO Agency for Renewable Energy (Agentur für Erneuerbare Energien e. V.) reviewed several governmental and non-governmental studies on future storage demands for the German grid (Renews, 2012). According to this the additional demand for electrical storage and buffering will likely reach 18 TWh by 2030 with renewables reaching 50% of power generation in Germany. By 2050 the demand of storage and buffering capacity will reach 30 TWh with renewables reaching 80% of power generation in Germany.

Besides direct storage the concept of delaying electricity consumption and therefore tailoring consumption to demand is another option to manage the grid. Large energy consumers should therefore be assessed on their potential to react flexible in their consumption. One such area of consumption is food cooling.

2. Energy consumption of food retail markets

Food production and distribution processes are two of the main consumers of energy in many societies. Together, they currently rank as the sixth largest within the processing industry in Germany, with an annual electricity consumption of 54 865 TJ and a heat consumption of 7 742 TJ in 2011(Destatis, 2013) . One dominating reason for this high level of energy consumption is the need for cooling food in warehouses, during transport, and finally in the supermarkets.

From monitoring of supermarkets in UK it's clear that the energy consumption for supermarkets is exceptionally high in comparison to residential buildings and even offices. FIG 1. shows the annual energy consumption of Saintsbury markets in the UK sorted by net sales area ranging from 500 to almost 3000 kWh/m^{2}a, offering similarly a high potential for shifting loads.

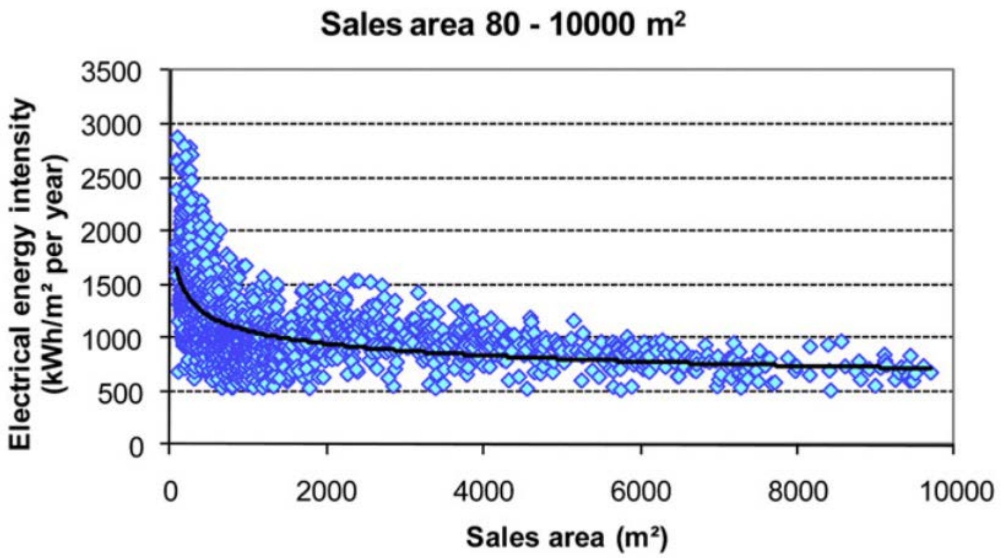

FIG 1. Variation of electrical energy intensity of 2,570 UK retail food stores with sales area from 80 m^2 to 10,000 m^2 (Tassou et al, 2011)

The implemented refrigeration system is found to be responsible for 39-47% of the annual energy demand in food retail markets in Sweden and the US in recent surveys (Arias, 2005).

These cooling processes offer the potential to buffer electrical energy in a thermal process with a higher efficiency than any kind of conventional electrical storage and are therefore in focus of the current discussion.

In general, supermarkets are not particularly energy efficient, as energy costs pale when compared with turnaround and profit (Arias et al. 2006). Rising energy prices and the need for companies to present themselves as environmentally friendly have, however, caused a re-think among supermarkets in recent years, resulting in a number of promising projects and technological developments (Arteconi et al. 2009 and Ostermeyer et al 2008). The potential for improving energy efficiency, reducing energy consumption, and the resulting emissions is very high in this sector (Ardito et al. 2013).

Obviously efficiency measures should be applied first in supermarkets from an environmental and in the end also from an economic viewpoint instead of designing inefficient cooling processes to create artificial consumption just to create load shifting potential. After applying economically feasible efficiency measures it has to be assessed how much energy is still consumed by the cooling processes. As the different components of cooling cabinets, cabinet, doors and heat pump are provided by different companies and the cabinets often run in complex networks the only sure way to assess the energy consumption is to monitor it in existing markets. This paper therefore takes measured data from a state of the art market and extrapolates from there.

3. State of the art food retail markets

Throughout the year, supermarkets need energy for heating to create a comfortable indoor environment and for cooling food storage at different temperature levels. Innovative concepts therefore utilize cascade heat pump systems to achieve high efficiency for the different temperature levels, and recover the process heat to help cover the heat energy demand by two-pipe or three-pipe based Cooling-Heating-Networks. With the heat recovery system alone, the heat energy consumption can be reduced substantially, about 30 to 40%, however peak demand related problems remain (Ostermeyer et al. 2008). The Passivhouse Institute Darmstadt in cooperation with Chalmers TU and REWE built on such concepts and designed the passive house standard for supermarkets to push even further.

3.1 The first Passive House Supermarket in Hannover/ Germany

In Hannover, the first Passive House Supermarket in Germany(Zero:e Park,2012), run by the REWE Group, was built in November 2012, based on a heating and cooling system as the one described above, and on specific tailoring of the envelope in order to reduce the additional heating demand after recovery to 15kWh/m^2, year.

All equipment within the supermarket was selected using a top-runner approach, which meant that only the most energy efficient products were installed. This includes high performance glazing in front of all cooling cabinets which, besides changing the energetic behaviour of the cabinet also resulted in complex hygro-thermal issues as humidity is not anymore condensing in the cabinets but remains in the sales room potentially causing the growth of fungi and mould.

Installing doors in front of the cooling cabinets and running them in a cooling network via a centralized heat pump in a cascade with the freezing cycle results in a consumption pattern that is extremely complex. The main challenge is that the performance of a single cabinet influences the complete system. The market therefore serves to assess the overall concept in general but the performance of the cooling and freezing processes in particular. FIG 2. shows some pictures of the market.

FIG 2. The first supermarket in Passive house Standard in Hannover

The market is monitored by nearly 200 sensors allowing for solid assessment of its performance. In addition it is equipped with a weather forecasting system. This will allow predicting future energy consumption based on similar conditions in the past which will be critical when starting to shift loads in the market at a later stage.

3.2 Monitoring results

The project results so far show that the energy consumption has been significantly reduced beyond the expectations in the design phase. FIG. 3 shows the overall consumption of the market which has now nearly completed an annual cycle. The consumption relatively stable at 8000 to 12000 kWh/week with a predicted annual consumption of around 250 kWh/m2 net floor area.

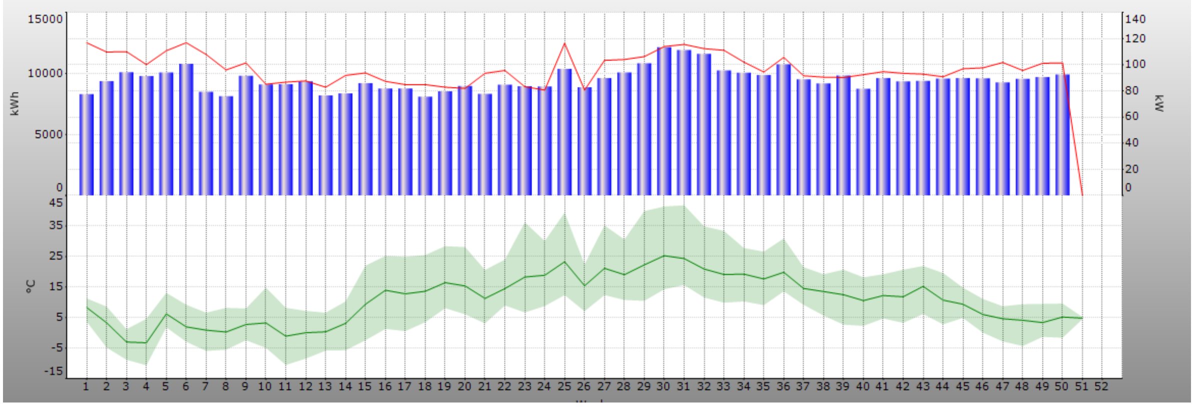

FIG 3: overall energy consumption (system border, market, all kWh in electricity), source FrigoData monitoring

FIG 4. Shows the cooling processes are in a range between 3000 kWh/week in winter and peaking at around 5000 kWh/week in summer.

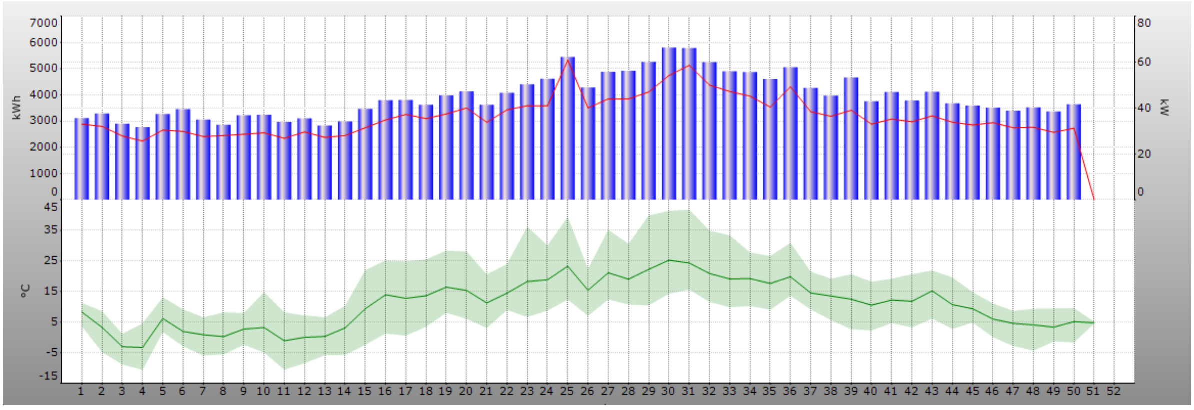

FIG 4: energy consumption for food cooling (system border, market, all kWh in electricity), source FrigoData monitoring

Peak loads in general are in line with the consumption with the exception of the starting phase of the market that included the heating of the formerly cold thermal building mass and some drying of still humid concrete parts.

Electricity consumption for food cooling (as opposed to freezing) is the most attractive consumption to be delayed in the market for two reasons:

1. The temperature level needed for the process allows for ice storage which would result in rather small modules making use of the phase change of water
2. The process heat from freezing processes is needed for regulating the sales room air temperature. Delaying both cooling and freezing would let the sales room cool down.

Delaying only freezing and not the cooling consumption is not possible because of the design of the cascade system.

Based on the current monitoring in the market in Hannover there is a potential to delay a consumption of 400 to 600 kWh/d. The necessary delay of 24 hours or more is currently not possible by thermal means alone which is limited to a delay of around 6 hours. 24 hours and more could be achieved though by ice storage modules which is the next step to be taken.
This also would create synergies with a remaining problem in the system which is the fluctuating energy demands of individual refrigerators and, to a lesser extent, the freezer units. As in order to be able to recover the process heat, all cooling devices have to be run in a combined cooling liquid grid (152a or 134a for cooling, CO_2 in the freezing area of the cascade system), erratic demand in a single device can affect all other devices and the overall system efficiency, as the refrigerators no longer have individual heat pumps. Ice storage could flatten the individual load of the cabinets and therefore improve the overall COP of the system.

4. Conclusions and outlook

Already with a single store buffering 100 kW over the time of six hours, impressive numbers would be achieved by the REWE Group alone. As their supermarkets are refurbished every 15-20 years, nearly all 3,000 stores could be fitted with these systems by 2030. Taking this idea even further, supermarkets in Germany could together contribute substantially to grid buffering. If they could be outfitted with ice storage the numbers would be even more impressive while at the same time further improving the performance of the cascade network.

In a long term scenario, about 5% of the needed storage and buffering capacity in Germany could be covered by food retail markets and cooling processes – without the need for new infrastructure and the resulting environmental effects.

The use of supermarkets as buffering and storage units for the electrical grid is a unique and world-first move. An increase in the proportion of renewable energy sources will result directly in the need for an improved storage and buffering capacity. The creation of such capacities therefore directly benefits society by allowing it to reduce its dependency on nuclear and non-renewable energy production and the problems associated with these.

What remains to be seen is whether the identified storage opportunity will result in supermarket consortia selling this capacity to power generators, like wind parks, or aiming to become self-sufficient via own energy generation for example by photovoltaic .

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