Heat Recovery in Recent Refrigeration Systems in Supermarkets.

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Summary

Supermarkets are using large amounts of energy. The potential for increased energy efficiency is large and one option is to utilize heat pumping, i.e. heat recovery from condensers for heating of the premises. Obviously this option is only interesting in relatively cold area such as northern Europe, Canada etc.

A computer model that calculates the energy use in a supermarket with the possibility to simulate, and thus compare, different system solutions for the refrigeration system has been developed at the Department of Energy Technology, Division of Applied Thermodynamics and Refrigeration. The software is used in the present study to calculate the potential of heat recovery in Swedish supermarkets. Measurements of different parameters such as temperatures, relative humidity and compressor power have been carried out in a supermarket with heat recovery, and the results from the measurements supplement the theoretical calculations.

The present study shows that heating is readily supplied and additional energy for heating can be avoided completely, at least in theory. Practical experiences show however that installations are less efficient due to poor system solutions and/or control strategies.

Background

Supermarkets are using large amounts of energy; approximately 3% of the electric energy consumed in Sweden is used in supermarkets (1,8 TWh/year). A breakdown of the energy usage shows that, typically, 47% is used for medium and low temp refrigeration, 27% for illumination, 13% for fans and climate control, 3% for kitchen, 5% for outdoor usage + 5% for other uses.

Refrigeration systems, indoor climate control and illumination are the areas with the greatest potential for improvements. Since the energy systems of a supermarket are relatively complex, improvements in one subsystem affects other systems, thus making analysis of potential improvements non-additive. Typical efficiency improvements may involve refrigeration systems, heat recovery, more efficient illumination, night lids, more efficient control, floating condensation etc.

Several new system solutions have been developed and introduced in recent years to lower the refrigerant charge and, at the same time, minimize potential refrigerant leakage. Completely or partially indirect systems as well as cascade systems has been introduced. Modelling of supermarket energy systems and field measurements have been undertaken in a National research program for more than three years and the results have been part of the Swedish contribution to IEA Annex 26 (Advanced Supermarket Refrigeration/Heat Recovery Systems) under the *IEA Implementing Agreement on Heat Pumping Technologies.* The overall aim of the project is to develop a sound simulation model where different system solutions can be compared in detail with focus on energy usage, environmental impact (TEWI) and LCC (Life Cycle Cost). The program, “CyberMart” is built in modules dealing with subsystems such as in- and outdoor climate, display cases, cooling and freezing rooms, refrigeration machinery, the building envelope etc.

CyberMart is a day-to-day simulation program that allows the user to see the variation of different variables such as compressor power, refrigeration capacity and temperatures in the supermarket during one year. CyberMart is an easy to use Windows application and the users interface is shown in figure 1.

The model is currently under validation with four different supermarkets in Sweden in cooperation with KF and ICA, two major Swedish supermarket chains. The model development activities are now treating issues such as illumination, indoor climate and heat recovery, comfort cooling etc. Interesting issues to study is the potential in heat recovery in the winter and moisture control/dehumidification and floating condensation. Additional Field measurement to validate data is currently being set up.

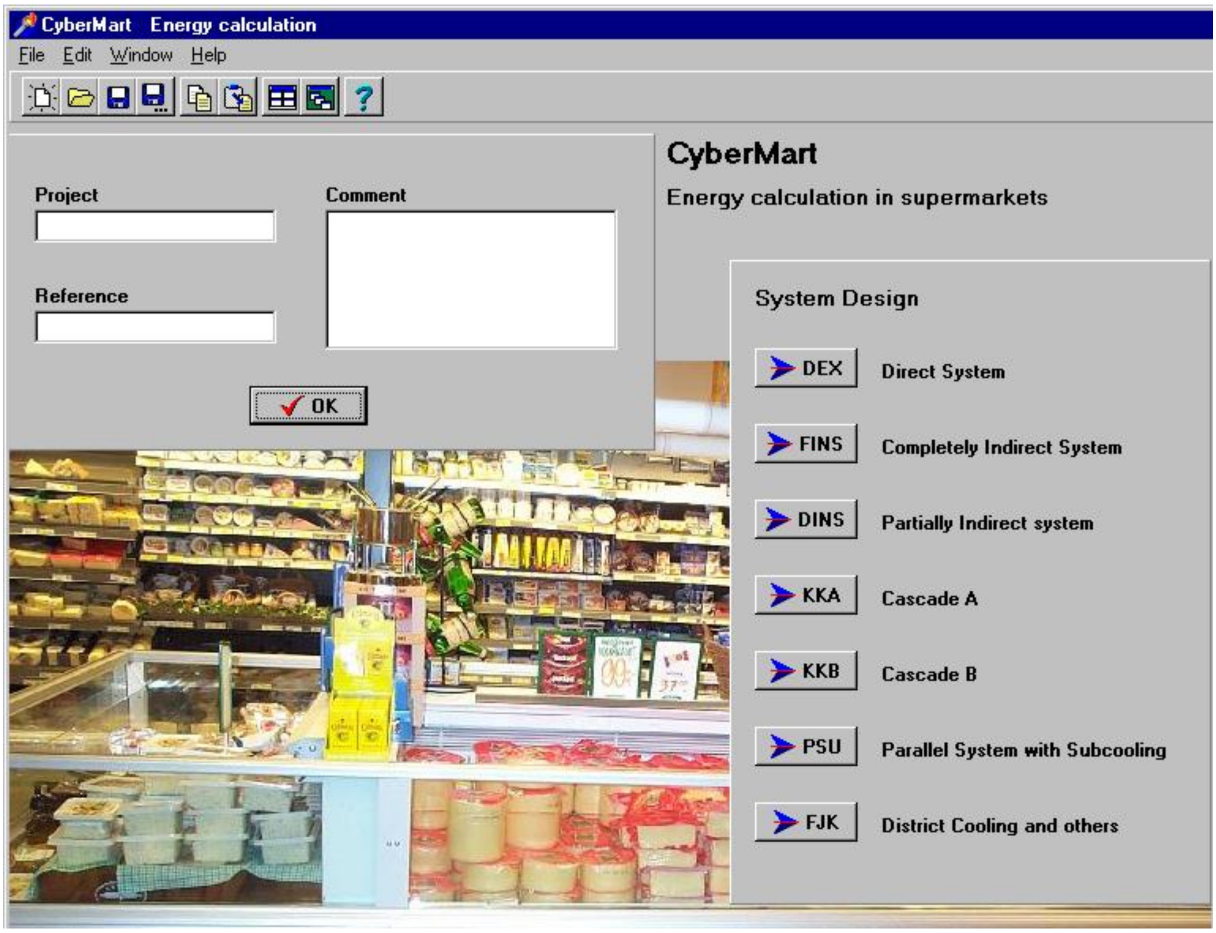

***Figure 1**, User interface for CyberMart with current system solutions*

Modelling, simulation and measurements

Figure 2 illustrates results obtained from simulation and field measurements from one of the supermarkets included in the Study. The total time in the example chosen is one year. The difference in calculated compressor power between simulation and model is depicted in the figure (the bottom curve, percent) and the yearly energy balance differs with 6.8%. It is clear that the general characteristics are relatively well recreated in the software.

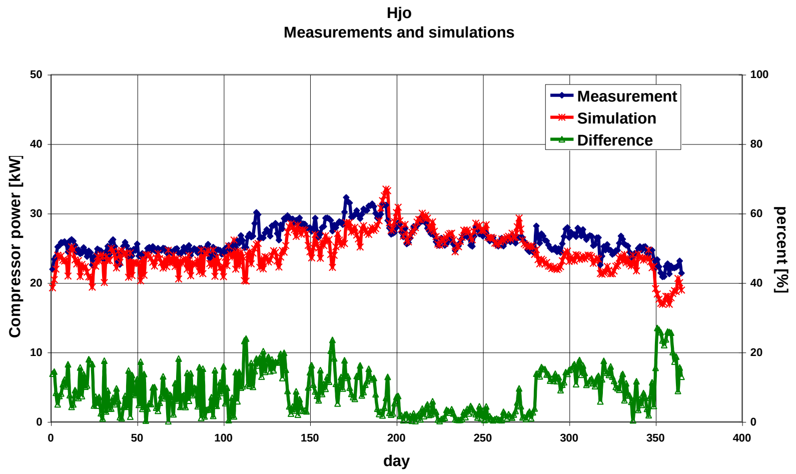

Figure 2, *Comparison of measurements and simulations for one supermarket included in our study.*

Comparing different solutions

One idea behind the development of the software Cybermart is to facilitate comparisons on different solutions for the same supermarket. Results from simulations are presented in figure 3, where two different systems are compared. The systems are a cascade system and a parallel system with mechanical sub-cooling. The results indicate that a parallel system with mechanical sub cooling is slightly more energy efficient than the cascade system. Mechanical sub-cooling means that the secondary refrigerant on the medium temperature side is used to sub cool the refrigeration system of low temperature circuit. The effect of this is dependant on the chosen refrigerant and in this case, R404A, almost 30% better capacity is achieved on the freezer side. The COP_2 of the high temperature system is also more energy efficient than the low temperature system

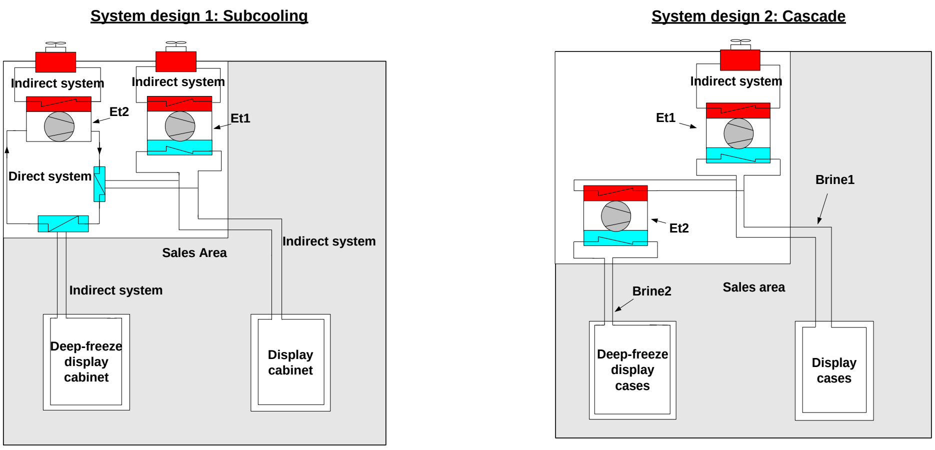

Figure 3. *A cascade system and a parallel system with sub-cooling considered in this paper*

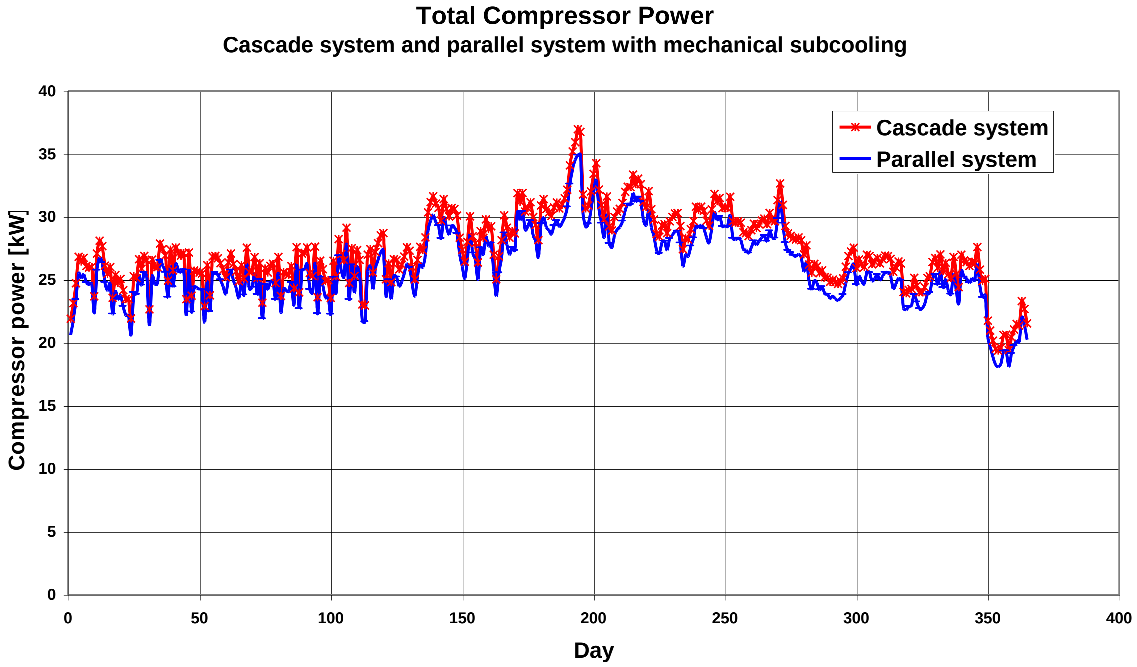

Figure 4: *A comparison of the two systems in figure 2.*

Heat recovery

Many supermarkets in Sweden utilize heat recovery from condensers as one way to increase the overall energy efficiency of the system. The obvious drawback is that the condensation temperature must be kept at a level where heat can be transferred to the heating system of the supermarket. This is normally an air coil in the supply air ventilation system. Another solution is floor-heating coils. A common experience among practitioners indicates that the typical required temperature level for the condenser coolant is 38°C after the condenser. This lead to increased energy consumption for the compressors. Several different control strategies may be applied and results from four different cases are reported here.

Table 1, *Estimated need for heating, district heating (by the meter), available and utilized condenser heat for he supermarket in Sala.*

	heat requirement	District heat	Condenser heat	utilized	percent
1999 - 2000	**kW**	**kW**	**kW**	**kW**	**%**
Oct	**16750**	**4691**	**95915**	**12059**	**13**
Nov	**28333**	**7402**	**85223**	**20931**	**25**
Dec	**36707**	**8516**	**88527**	**28191**	**32**
Jan	**44403**	**7572**	**88210**	**36831**	**42**
Feb	**40099**	**10176**	**80637**	**29923**	**37**
Mar	**35773**	**7807**	**88008**	**27966**	**32**
April	**20404**	**5529**	**89820**	**14875**	**17**

It is clear from table 1 that the available condenser heat is more than sufficient from an energy balance point of view. As the later discussion will show it is not always possible to utilize the full potential.

The four cases considered here are:

- Case 1, Floating condensation year round + aux. heating – no heat recovery.
- Case 2, Floating condensation and fixed “bottom” temperature level of condenser coolant set to 16°C + aux. heating – no heat recovery.
- Case 3, Condenser coolant set to 38°C all year round – heat recovery.
- Case 4, Condenser coolant set to 38°C during the heating season and floating condensation during the warm season - heat recovery.

The choice of case 2 is based on the fact that it is difficult to fully utilize floating condensation at low ambient temperatures due to hardware and control problems (the expansion devise for example). Case 1 and 2 does not utilize heat recovery at all.

The energy for the refrigeration systems is calculated using CyberMart software for all four cases. The results are given in figure 5 and table 2

.

***Table 1**, Energy and total cost for Case 2, 3 and 4.*

aug 1999 - jul 2000	No heat recovery	Heat recovery	Heat recovery floating during summer
District heating[kWh]	222468	51693	51693
District heating price[kr/kWh]	0,5	0,5	0,5
District heating cost [kr]	111234	25847	25847
Compressor power [kWh]	304162	425589	377753
Electricity price [kr/kWh]	0,5	0,5	0,5
Electricity cost [kr]	152081	212795	188877
Total cost [kr]	263315	238641	214723

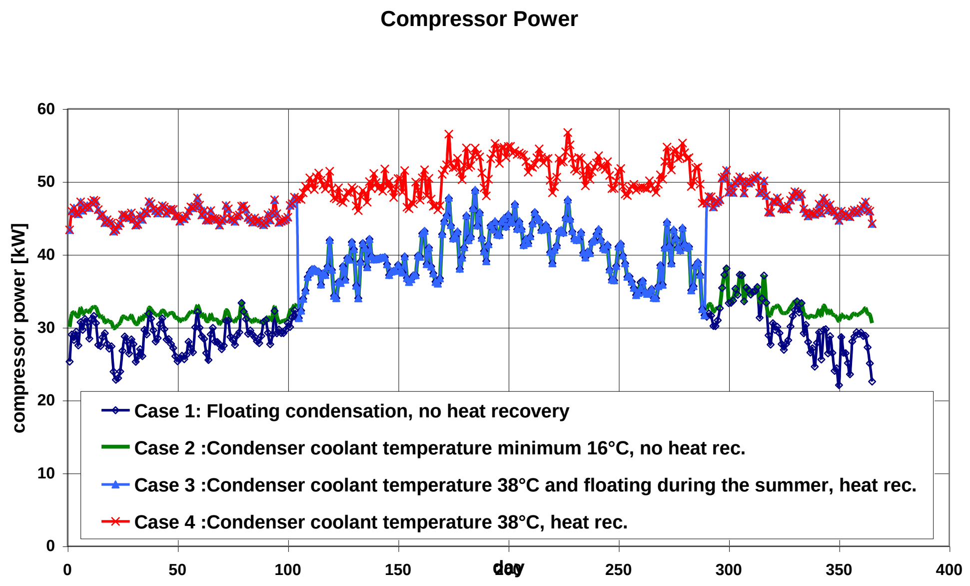

***Figure 5**. Results from comparison of cases 1-4.*

The results in table 2 show that Case 4 with condenser coolant outlet temperature set to 38°C during the heating season and floating condensation during the warm season by far the most economic of the four cases analysed.

Discussion

Heat recovery in practice

One interesting question is how much energy that can be utilized from the condensers in a real system. There are many points of view here and practical experiences indicate that 40 – 70% of the necessary heat can be recovered. One reason for this is that the refrigeration systems not operate continuous. Another issue here is that the design and operation of the refrigeration system and the HVAC systems not are done by the same people/organization and the communication between them is not always the best.

Field measurements, in a supermarket in the city of Sala in Sweden, have been carried out during the month of Mars 2001 to see the variation of the compressor power and the influence of this on the condenser coolant temperatures The refrigeration system design is of the Cascade type.

The area of the store is about 2700 m^2 and the supermarket has 10 display cases, 3 deep-freeze cases and 7 cold storages. The display cases are equipped with a night covering system. The refrigerant in the chillers is R404A and the secondary refrigerant at both temperature levels is Pekasol 50. The refrigeration capacities are 130kW for the intermediate temperature level and 30 kW for the low temperature level.

The temperatures and indoor and outdoor relative humidity have been measured with Tinytag-loggers from Intab, and the compressor power with Energy-logger Elit 4 from Pacific Science & Technology. The temperatures and relative humidity have been measured momentary and stored every fives minutes. The compressor power is also stored every five minutes but in this case the value represents the mean power during the last five minutes.

Figure 6 and figure 7 shows results from measurement of outdoors temperature, indoor temperature, relative humidity, compressor power, condenser coolant approach temperature and condenser coolant return temperature during the third and the eleventh of mars 2001.

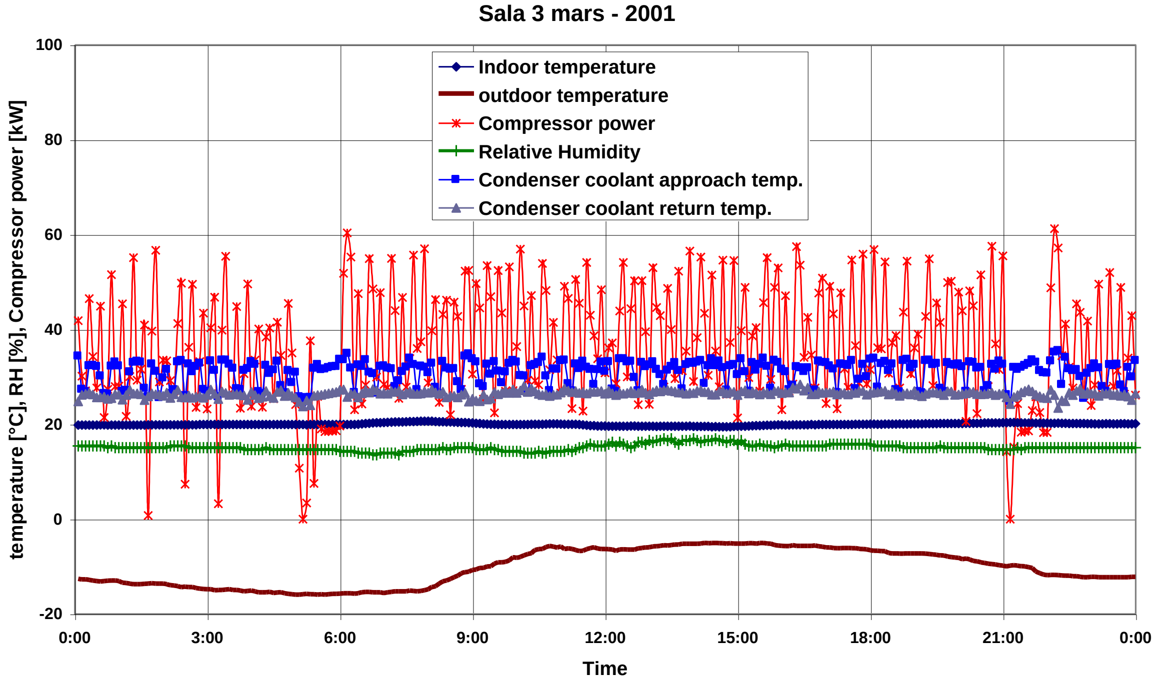

Figure 6, *detailed measurement from the supermarket in Sala the third of Mars 2001*

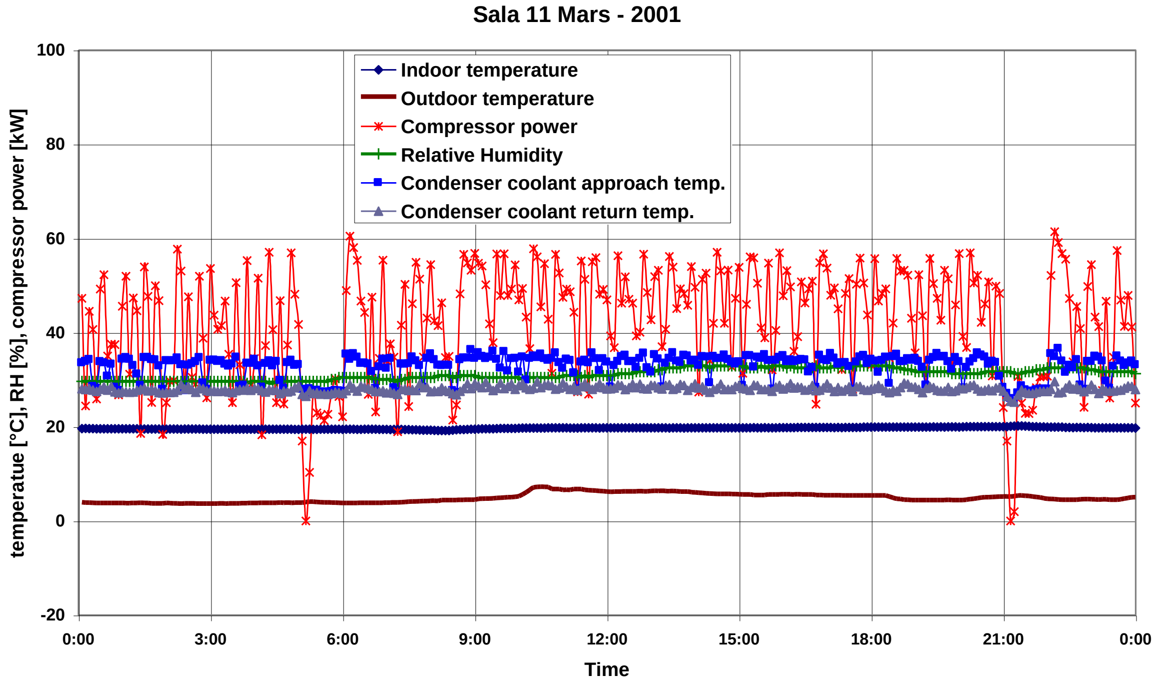

Figure 7*, detailed measurement from the supermarket in Sala the eleventh of Mars 2001.*

During the third of Mars 2001 the average of the compressor power was 36,4 kW and during the eleventh of Mars is 42,6 kW. Those values are equivalent to 64 % and 77 % of the nominal compressor power. The over dimension of the refrigeration system during cold days make the running time of the compressor very short which influences the condenser coolant approach temperature. In figure 6 and figure 7 it is possible to see the influences of the outdoor temperature and relative humidity on the compressor running time: The low average outdoor temperature, about –10°C, and relative humidity, about 18%, during the third of Mars caused lower compressor running time and bigger variation of condenser coolant approach temperature than the eleventh of Mars when the average outdoor temperature was about 5°C, and the relative humidity was about 33%.

Heat recovery system design

The refrigeration system in supermarkets always rejects a large amount of heat from the condenser to the environment and new efficient refrigeration system design takes advantage of the rejected heat by using it for air heating. The two biggest supermarkets chain in Sweden use two different types of heat recovery systems. The first heat recovery system design, presented in figure 7, has an approach temperature around 38°C to the dry cooler and a return temperature around 32°C.

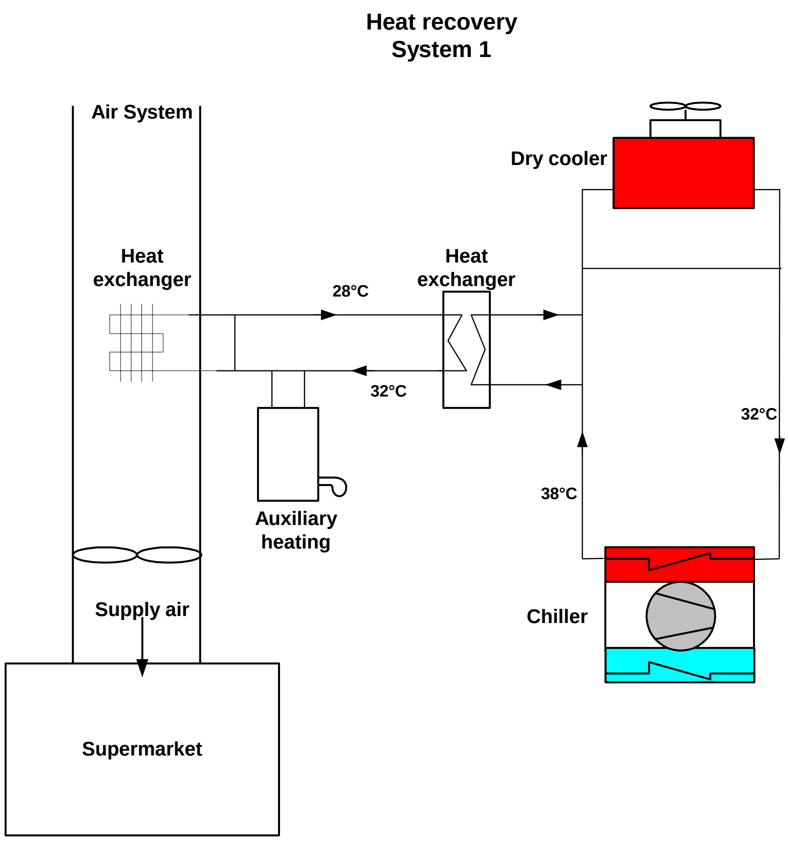

***Figure 8**, Heat recovery system design 1*

The heat rejected from the refrigeration system is recycled to the supermarket by the air system during the winter. The circuit between the condenser and the dry cooler is connected with the air system by an extra heat exchanger. An auxiliary heater has been connected after the heat exchanger to insure the desired hot water temperature before the finned heat exchanger. The reason for the extra heat exchanger is claimed to be the possibility to use another fluid, as water, with better thermodynamics properties than the secondary coolant (glycol/water mixture). The system design has two major disadvantages: the first is that the heat exchanger reduces the approach temperature to the coil in the air system and the second is when the air supply temperature is reached the control system by-passes the heat exchanger in the air system and, as often the case, the heat from the auxiliary heating is rejected to ambient in the dry cooler!

The second heat recovery system design presented in figure 8 avoids those problems. The heat from the condensers is rejected directly to the air system via a heat exchanger. The approach temperature to the heat exchanger is around 38°C, and the return temperature is around 32°C. The auxiliary heating is connected to the air system after the heat exchanger that recovers the heat from the refrigeration system as shown in the figure. The auxiliary heating is thus supplied in a separate system.

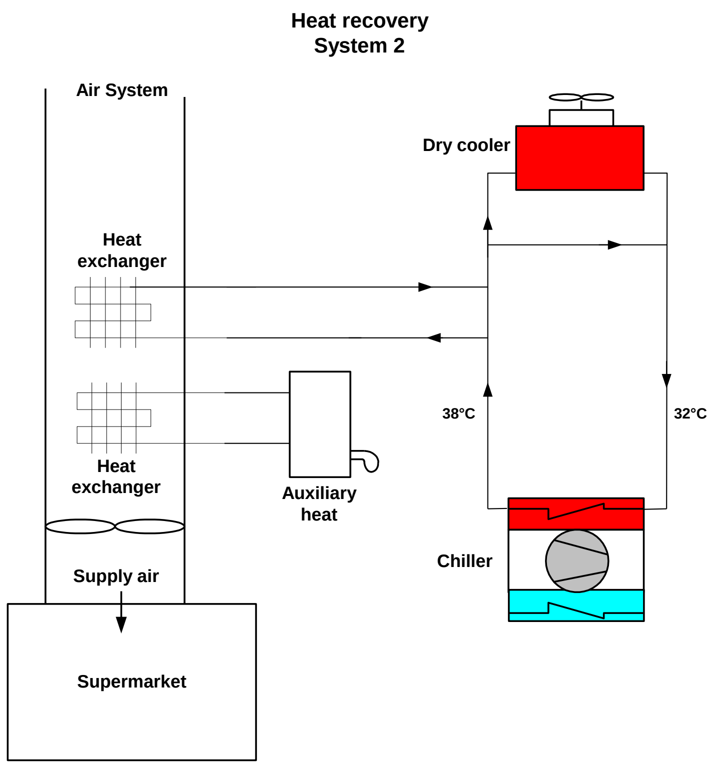

Figure 9 *Heat recovery system design 2*

Conclusion

The economy and overall energy efficiency of supermarkets, in cold climates, benefit from heat recovery. In theory the necessary heat can always be supplied from the condensers. Practical experiences show that in real systems only 40 – 70 of the necessary heat is recovered. There are many reasons for this but the most important are on/off regulation, low cooling load during cold days, poorly designed heat recovery systems and non-communication control systems for refrigeration and HVAC.

The influence of the outdoor temperature on the indoor relative humidity of air is an important factor to take in consideration when dimensioning refrigeration and heat recovery system in supermarkets. Lower, outdoor temperature and moisture affect the compressor power and the condenser coolant approach temperature.

Various system comparisons are readily performed in the software CyberMart. On example here shows that the completely indirect system with sub-cooling is more energy effective than cascade system for a typical Swedish supermarket. Other conditions may yield other results.

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