

IEA ANNEX 26: ADVANCED SUPERMARKET REFRIGERATION SYSTEMS

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SUMMARY

Present supermarket refrigeration systems require very large refrigerant charges and are heavy electricity consumers. IEA Annex 26 was formed to investigate and help promote use of energy efficient, low-charge refrigeration system designs. Analyses show that advanced systems can reduce energy consumption by over 10% and total equivalent warming impact (TEWI) by as much as 60%. Further, they show that integrating refrigeration and HVAC functions can potentially reduce combined operating costs by over 10%.

BACKGROUND

Supermarkets are one of the most energy-intensive types of commercial buildings with consumption ranging from about 400 to 1000 kWh/m²/yr worldwide. Energy consumption to refrigerate products in display cases and storage refrigerators and freezers accounts for about half of total supermarket energy – from 1 to 1.5 million kWh annually in North American stores.

Figure 1 shows a layout for a typical large modern supermarket. Today's most commonly supermarket used refrigeration system is the multiplex direct expansion (DX) system. In large (3700 - 5600 m²) stores several compressors are arranged in parallel on two or more racks. Individual compressors cycle on and off automatically so that compressor capacity closely matches the refrigeration load. Compressors are connected to DX evaporators in each display case and cold store room via long pipe runs requiring thousands of meters of pipe with individual case connections. Heat rejection is usually done with air-cooled condensers due to low cost and easy maintenance. Evaporative condensers will reduce condensing temperature and system energy consumption, but also increase maintenance costs. System controls are usually set to allow the condensing temperature to float with the outdoor ambient to a minimum level of around 21°C.

The refrigerant charge for this type of system is very large - 1300 - 2500 kg. The large amount of piping and connections required can result in large refrigerant losses – 30% or more of the total charge in older stores. New systems designed for reduced leakage can achieve leak rates of 15% or lower [1]. This large charge and high loss rate results in high values of TEWI (total equivalent warming impact) with direct refrigerant loss impact accounting for about half, Figure 2.

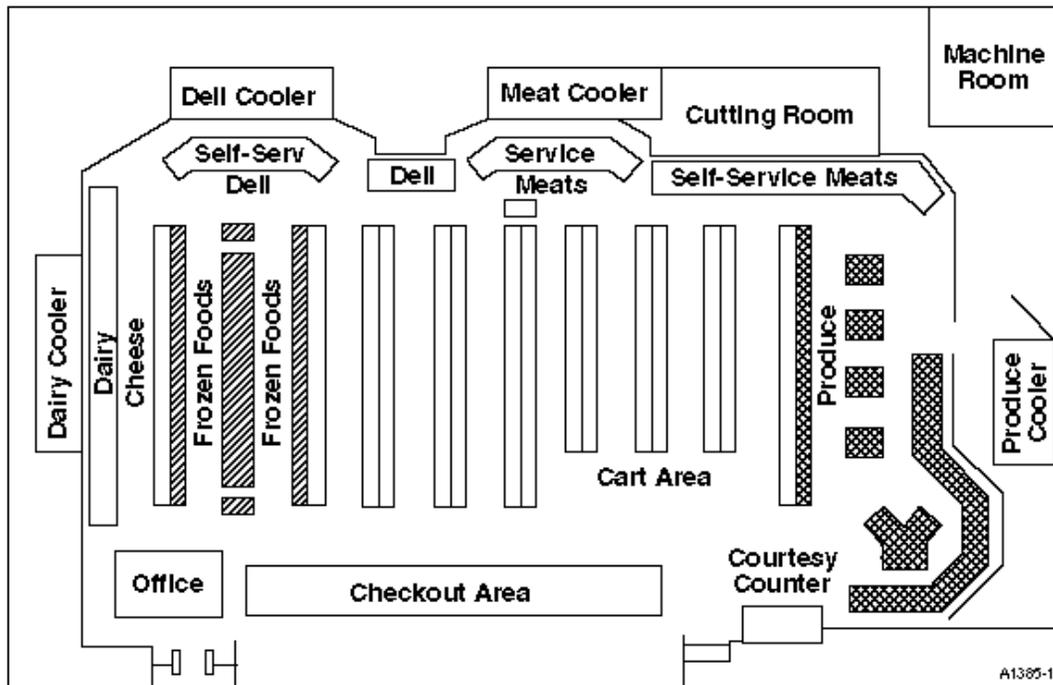
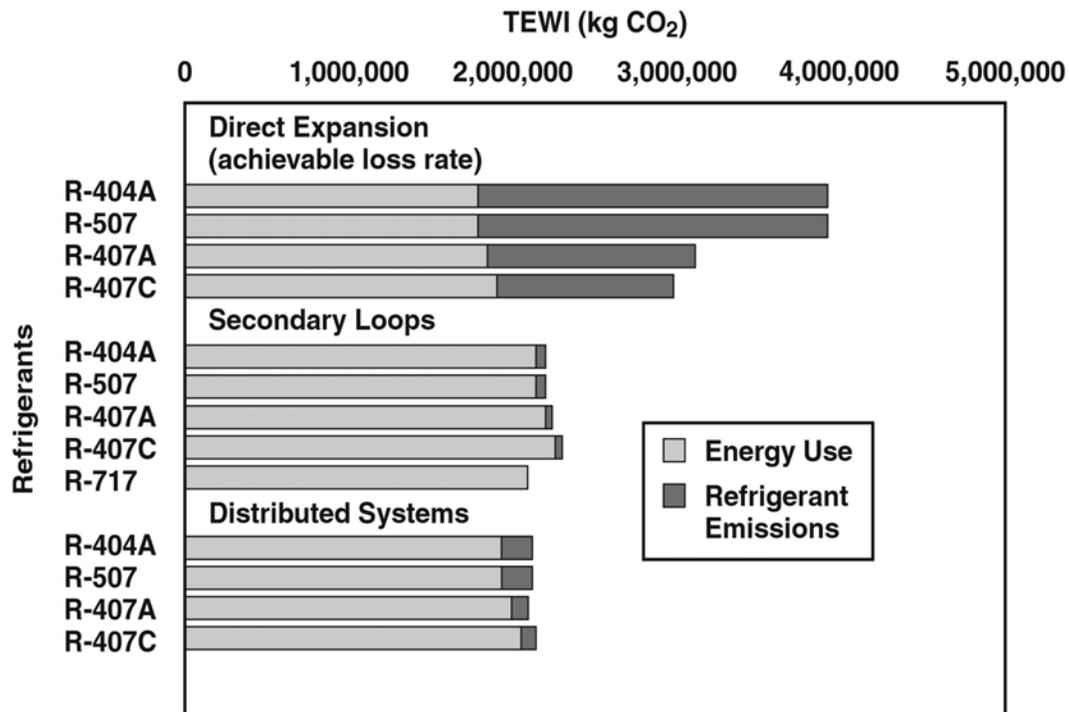


Figure 1 – Layout of a typical modern supermarket

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To help promote the development and use of advanced, low-TEWI systems, the International Energy Agency (IEA) established IEA Annex 26 (Advanced Supermarket Refrigeration/Heat Recovery Systems). Annex 26 focuses on demonstrating and documenting the energy saving and environmental benefits of advanced systems for food refrigeration and space heating and cooling for supermarkets. Advanced in this context means systems that are more efficient and produce lower refrigerant emissions. The Annex has five participants: Canada, Denmark, Sweden, the United Kingdom, and the United States.



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Figure 2 – Total equivalent warming impact (TEWI) for low temperature supermarket refrigeration in North America.

Advanced systems under investigation include the following:

Distributed compressor systems – Small multiplex compressor racks located in close proximity to the food display cases they serve, significantly shorten connecting refrigerant line lengths. Rooftop air-cooled condensers may be used for each rack or all may use fluid-cooled condensers connected to a common secondary loop with remote cooling tower.

Secondary loop systems – A central chiller is used to refrigerate a secondary coolant that is pumped to the food display cases. In large stores, two or more secondary loops (each with its own chiller and controls) may be used to meet refrigeration loads at different temperature levels.

Self-contained display cases – Each food display case has an integral refrigeration unit. Fluid-cooled condensers would typically be used with secondary loop and remote cooling tower to reject heat away from sales area.

Low-charge DX – Similar to conventional supermarket systems but with improved controls to limit charge.

Heat recovery approaches to integrate store HVAC and refrigeration systems investigated include use of heat pumps.

A workshop on advanced supermarket refrigeration was held October 2-4, 2000 in Stockholm. The workshop proceedings are available from the IEA Heat Pump Centre [2].

ANNEX PARTICIPANT ACTIVITIES

Canada. Two advanced systems and a baseline multiplex DX system are under test. One advanced approach uses a multiplex DX system with heat reclaim for space and water heating and ground water to supplement heat rejection. The other has heat pumps integrated to provide space heating for the store and subcooling for the refrigeration system. Figures 3 and 4 illustrate the heat pump integration approach. In winter, the discharge gas from the refrigeration compressors goes first through three plate heat exchangers that serve to desuperheat and precondense the gas. The three heat exchangers also serve as evaporators for rooftop heat pumps that supply space heating to the store. Using heat pumps for heat recovery places no minimum limit on refrigeration system condensing pressure, as is the case for traditional heat recovery approaches. A fourth rooftop heat pump is integrated with the liquid line exiting the air-cooled condenser via a fourth plate heat exchanger. This heat pump subcools the refrigerant leaving the condenser and uses the recovered heat for store space heating. Initial baseline tests in 1999-2000 showed that both advanced approaches achieved about 6% lower specific energy consumption (kWh/m²/yr) compared to the baseline store. A technology showcase is planned to be installed in a Montreal area supermarket in 2002.

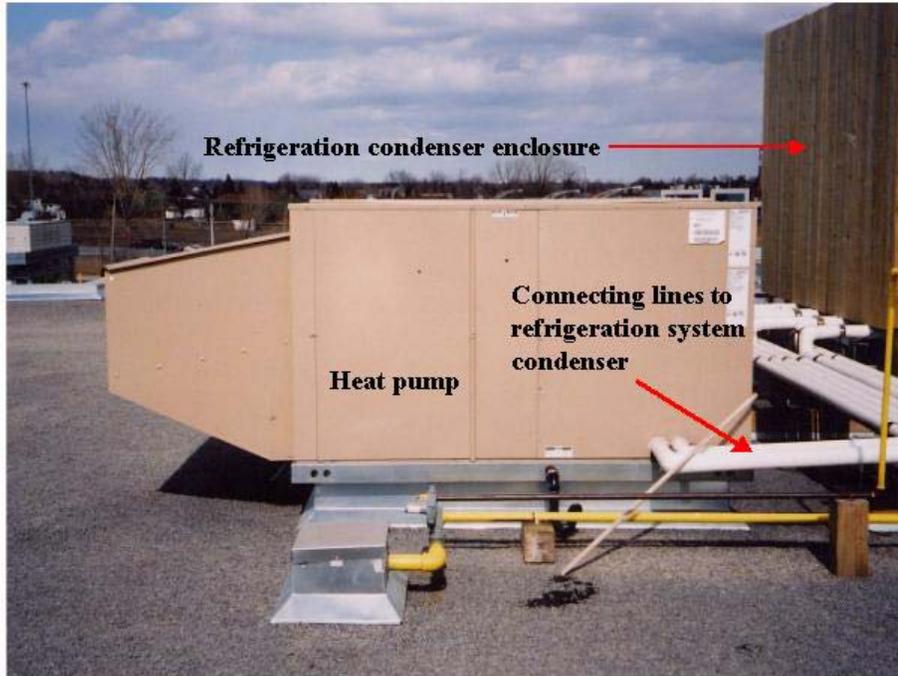


Figure 3 – Roof top heat pump unit, Canadian test store.

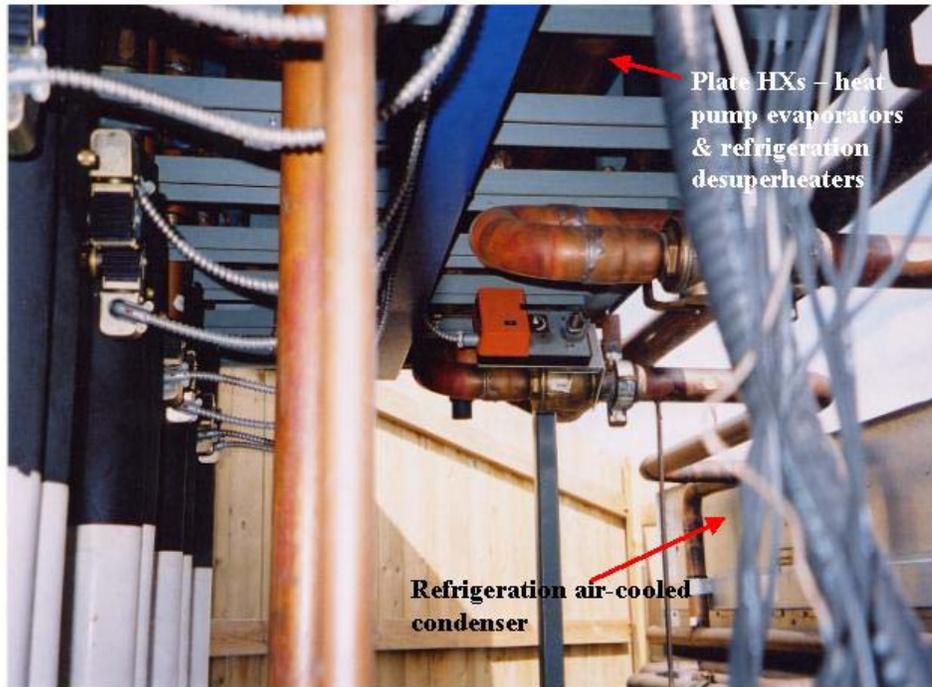


Figure 4 – Plate heat exchangers (HX) for heat pump evaporators and refrigeration desuperheaters and subcooler at Canadian test store.

Denmark. A propane/CO₂ cascade plant is being tested in a small store. Propane is used as the high temperature refrigerant (-14/+30°C) while carbon dioxide is used at the low temperature level (-32/-11°C). Data indicate that energy use of the test plant is about the same as that of R404A DX plants in other stores of the same chain. It is estimated that the additional cost for a propane/carbon dioxide cascade plant for a medium sized Danish supermarket (30 kW freezing load and 60 kW cooling load) will be about 15% of the total installation.

Sweden. Sweden's work for the Annex is part of their national program Eff-Sys under a project "Energy Efficient Solutions for Supermarkets in Theory and Practice." They have developed a computer model (Cybermart) for system predesign and have carried out field measurements in four supermarkets to validate the model. Sweden's analyses indicate that well designed advanced secondary loop systems do not compromise energy efficiency compared to conventional DX systems. The analyses also show that two-loop secondary systems with subcooling of the low temperature loop are more efficient than cascade systems.

United Kingdom. Four research activities have been completed. These include 1) an evaluation of combined heat and power, and combined cooling, heating, and power schemes for supermarkets, 2) a comparison of various secondary systems with standard DX systems, 3) an investigation of the effect of various store conditions on case performance, and 4) analytical and experimental investigation of three defrost methods and alternative control strategies.

United States. A 3720 m² supermarket based on the layout in Figure 1 was simulated and TEWI and energy consumption estimates were made for a baseline air-cooled multiplex refrigeration system and advanced systems, Table 1. Total refrigeration load was 328 kW with a refrigerant charge of 4.15 kg/kW load. The distributed compressor, low-charge multiplex, and secondary loop systems (with four independent secondary loops) all achieved estimated annual energy savings of about 11%. Use of evaporative heat rejection was the principal driver for these energy savings - baseline system energy consumption was 8.2% lower with an evaporative condenser. The lowest TEWIs were achieved by the distributed system and the secondary loop systems with CO₂ emission reductions of about 13 - 14 million kg, or 57 - 60%. The low-charge multiplex system had estimated TEWI reductions of about 24% or 43% depending upon the refrigerant loss assumption.

System	Condensing	Charge, kg/kW	Primary Refrigerant	Leak (%)	Annual kWh	TEWI (million kg of CO ₂)		
						Direct	Indirect ^a	Total
Multiplex	Air-Cooled (baseline)	4.15	R404A /R-22 ^b	30 (15)	976,800	13.62 (6.81)	9.52 (9.52)	23.14 (16.33)
	Evaporative	4.15		30	896,400	13.62	8.74	22.36
Low-Charge Multiplex	Evaporative	2.77	R404A /R-22 ^b	30	863,600	9.08	8.42	17.50
				15	863,600	4.54	8.42	12.96
Distributed Compressors	Water-Cooled, Evap. Tower	1.24	R404A	5	866,100	1.00	8.44	9.44
Secondary Loop	Evaporative	0.69	R507 ^c	10	875,200	1.13	8.54	9.67
				5	875,200	0.56	8.54	9.10
	Water-Cooled, Evap. Tower	0.27	R507 ^c	5	959,700	0.23	9.36	9.59
				2	959,700	0.09	9.36	9.45
Results for Washington, DC location – 15 year service life								

^aConversion factor = 0.65 kg CO₂/kWh

^b1/3 R404A (low temp.), GWP = 3260; 2/3 R22 (medium temp.), GWP = 1700

^cR507, GWP = 3300

An analysis of an integrated water source heat pump and distributed compressor refrigeration system showed about 13% operating cost savings compared to a baseline air-cooled multiplex refrigeration system with conventional rooftop HVAC units.

Two systems are under field test – a distributed compressor system with water source heat pumps and a low-charge multiplex DX system.

CONCLUSIONS

Analyses carried out under Annex 26 have shown that both energy savings (over 10%) and TEWI reductions (up to 60%) are possible with low-charge refrigeration systems as compared to conventional multiplex DX systems. Use of evaporative heat rejection approaches (condensers or cooling towers) to reduce condensing temperatures is a key to obtaining maximum energy savings. Integration of heat pumps with the refrigeration system to recover heat rejected by the refrigeration system for space heating can yield overall cost savings of 10% compared to conventional approaches. In general further efforts to reduce TEWI for advanced low-charge systems would benefit more from reduction in energy usage (through efficiency increases or load reductions) than from further reduction in refrigerant charge and losses.

The total value of the Annex research work is about \$5 million US. This represents a leveraging of each participant's funds of up to 10:1.

REFERENCES

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- [2] Lundqvist P., ed 2000. Proceedings of the IEA Annex 26 Workshop: Advanced Supermarket Refrigeration/Heat Recovery Systems, IEA Heat Pump Centre, Sittard, The Netherlands. (Cd-rom format only).

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