DEMONSTRATION OF ADVANCED INTEGRATED HVAC&R SYSTEMS IN A LOBLAWS SUPERMARKET IN CANADA

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ABSTRACT

A demonstration project of innovative refrigeration system technologies has been underway in a Loblaws supermarket in Canada with the technical support of the CANMET Energy Technology Centre-Varennes (CETC-Varennes) from Natural Resources Canada. The technology implementation allows the reduction of greenhouse gas emissions by approximately 75% and energy consumption by approximately 25% compared to a typical supermarket. The principal innovation at this 10,000 square-meter (102,000 square-feet) Loblaws is the installation of a secondary-loop refrigeration system integrated with the building's heating and ventilation system. The objective of the secondary-loop system is threefold: to reduce refrigerant charge and therefore leaks, to facilitate heat recovery, and obtain a better quality of cold to limit food spoilage. For instance, heat recovery provides for all heating and hot water demand and allows the elimination of the furnace. The project detail and the performance analysis will be presented.

Key Words: ***Supermarket, refrigeration, secondary-loop, secondary fluids, integrated HVAC&R***

1 INTRODUCTION

Natural Resources Canada's CANMET Energy Technology Centre – Varennes (CETC-Varennes) has established a major program in refrigeration. This program involves research, development, and deployment activities undertaken in partnership with universities, refrigeration stakeholders (manufacturers, suppliers, consultants, end-users), utilities, and energy management federal and provincial organizations.

The deployment activities were launched in September 2003 under the Refrigeration Action Program for Buildings (RAPB) funded through the Climate Change Plan for Canada, whose goal is to reduce greenhouse gas (GHG) emissions in Canada—in keeping with the Government's commitment under the Kyoto Protocol. The principal goals of the RAPB are to reduce GHG emissions by 1.6 Mt of CO_2 equivalents a year and the energy consumption by 1,700 GWh equivalent per year by 2012, in Canadian supermarkets, skating-ice and curling rinks. The strategy to achieve these goals is based on the development of constructive partnerships, information and capacity building activities and demonstration projects.

In the supermarket sector, the first demonstration project has been carried out with Loblaw, a major chain of supermarkets in Canada. The project aimed at reducing the energy consumption as well as greenhouse gas (GHG) emissions, while improving product quality and customer comfort, through the implementation of an innovative refrigeration system integrated to the heating, ventilation and air conditioning (HVAC) equipment and advanced control strategies. The project has enabled Loblaw to build an environmentally friendly supermarket, the first of its kind in Canada.

2 BACKGROUND

Supermarkets are the most energy intensive buildings in the commercial sector in Canada, with an energy consumption of approximately 1,000 kWh per square meter per year. This is due to the fact that although supermarkets are heated, ventilated and air-conditioned like any other building, they also have refrigeration systems to keep food products cold or frozen — and refrigeration accounts for about half of the buildings' total energy consumption. Moreover, the refrigeration systems of most supermarkets use large quantities of synthetic refrigerant (roughly 1,000 to 2,000 kg of HCFC or HFC per store), which circulates under pressure, from the mechanical room to the refrigerated display cases, through kilometers of piping with hundreds of brazed joints. This is a source of significant leakage, which accounts for 10 to 30 % of the total refrigerant charge per year. Although the HFC refrigerants currently used to replace CFC and HCFC are harmless to the ozone layer, they are nevertheless powerful GHGs that are 1500 to 3000 times more damaging than CO_2. Refrigerant losses from supermarkets therefore have a significant impact on global warming.

The refrigeration system in a supermarket is generally designed as an isolated process intended to produce cold and most of the heat extracted from refrigerated display cases is released into the environment. Nevertheless the amount of heat rejected is much larger than the energy needs of the store and could meet its heating and hot water requirements most of the time, even in the coldest winter days. Another drawback of most of the Canadian supermarket refrigeration systems is that the heat is released at temperatures above 40°C. This temperature level is normal for the hot weather in the southern United States but could be much lower in the cold Canadian climate, leading to a significant reduction in the energy consumption.

3 DEMONSTRATION PROJECT

CETC-Varennes and Provigo/Loblaws cooperated closely on this demonstration project to implement the following strategies at Repentigny:

- Refrigeration system and synthetic refrigerants confined to the mechanical room;
- Secondary fluids on cold and heat rejection loops of both low and medium temperature refrigeration systems;
- Package refrigeration units confined in the mechanical room insuring minimal refrigerant charge and leaks;
- Semi-hermetic compressors;
- Plate-type evaporators and plate-type condensers;
- Only four thermal expansion valves located in the mechanical room;
- No evaporator pressure regulator required to operate the refrigeration system;
- Heat recovery from the condenser with a secondary loop to provide almost all the space heating demand;
- Variable condensing temperature by the modulation of the secondary loop heat rejection temperature according to the outside temperature in order to minimize the overall supermarket energy consumption while meeting the refrigeration and space heating loads of the supermarket;
- No furnace for space heating.

3.1 Refrigeration System – Cold Side

The nominal capacity of the low temperature refrigeration is 200 kW, and 400 kW for the medium temperature system. Both refrigeration systems use R507A, a HFC refrigerant blend.

As shown in Figure 1, two secondary fluids that have no environmental impact — potassium formate for low temperatures (around -28°C) and propylene glycol for moderate temperatures (around –6°C), are cooled by the refrigerant through a heat exchanger. These fluids circulate through pipes from the mechanical room to the refrigerated display cases at low pressure, thus reducing the possibility of leaks.

Subcooling of the low temperature liquid line by 30ºC corresponding to 55 kW of cooling at design conditions is performed by the medium temperature system through a plate-type evaporator. The desuperheat of the low temperature unit is recovered with a double wall heat exchanger. The defrosting of the display case evaporators is performed by a small flow of warm glycol circulating in a three-pipe system.

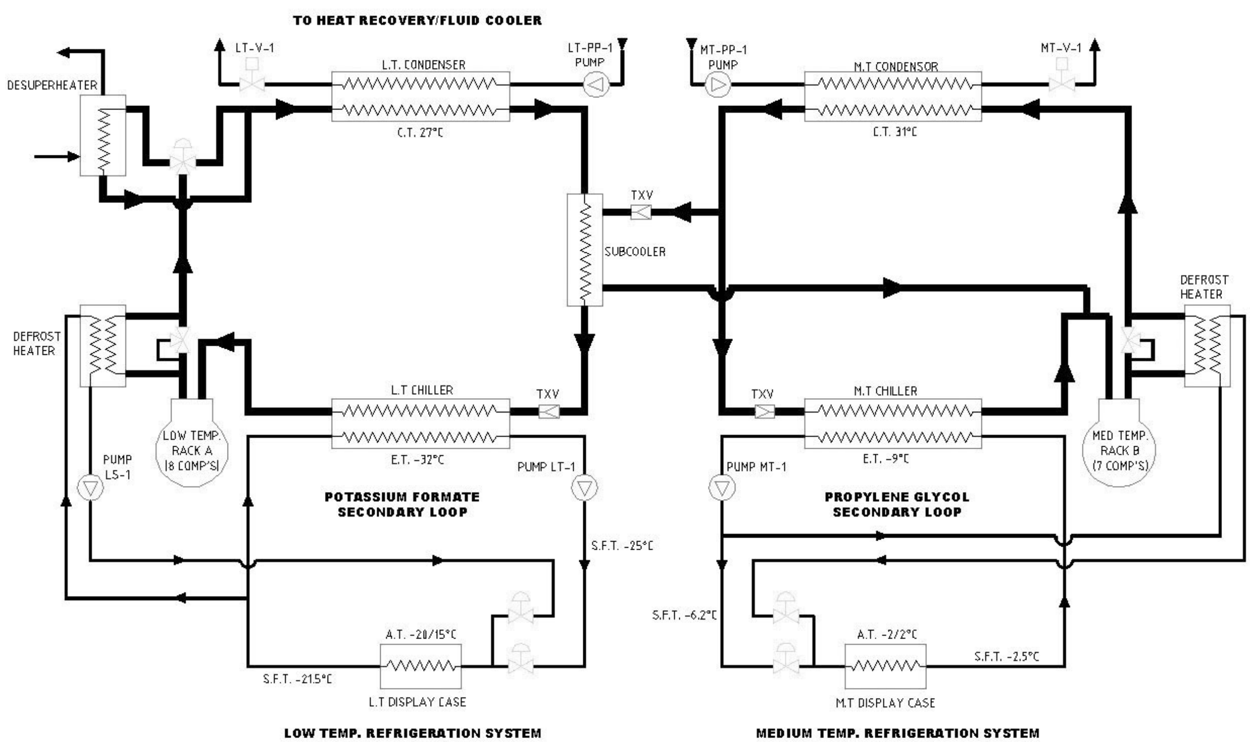

Fig. 1. Cold side of the low and medium temperature refrigeration systems

3.2 Refrigeration System – Hot side Heat Recovery and Upgrade for Heating Purposes

The heat rejection loops of the low and medium temperature refrigeration systems are independent. The use of ethylene glycol as secondary fluid, on those loops, makes it easier to recover the heat from the condenser and the superheat energy from the compressor, to meet the air heating and the hot water needs of the building.

The heat load (up to 220kW) rejected by the low temperature system is recovered and upgraded by seven water loop heat pump units. This strategy leads to a lower heat rejection temperature and therefore improves the energy efficiency of the main refrigeration system.

The heat load (up to 250kW) rejected by the medium temperature loop is recovered by an air coil located in a rooftop unit. The cold fresh supply air and the space return air are mixed at the heat recovery coil. The secondary fluid temperature is varied strategically in order to match the space heating demand. Therefore the refrigeration system of the medium temperature loop acts as a heat pump.

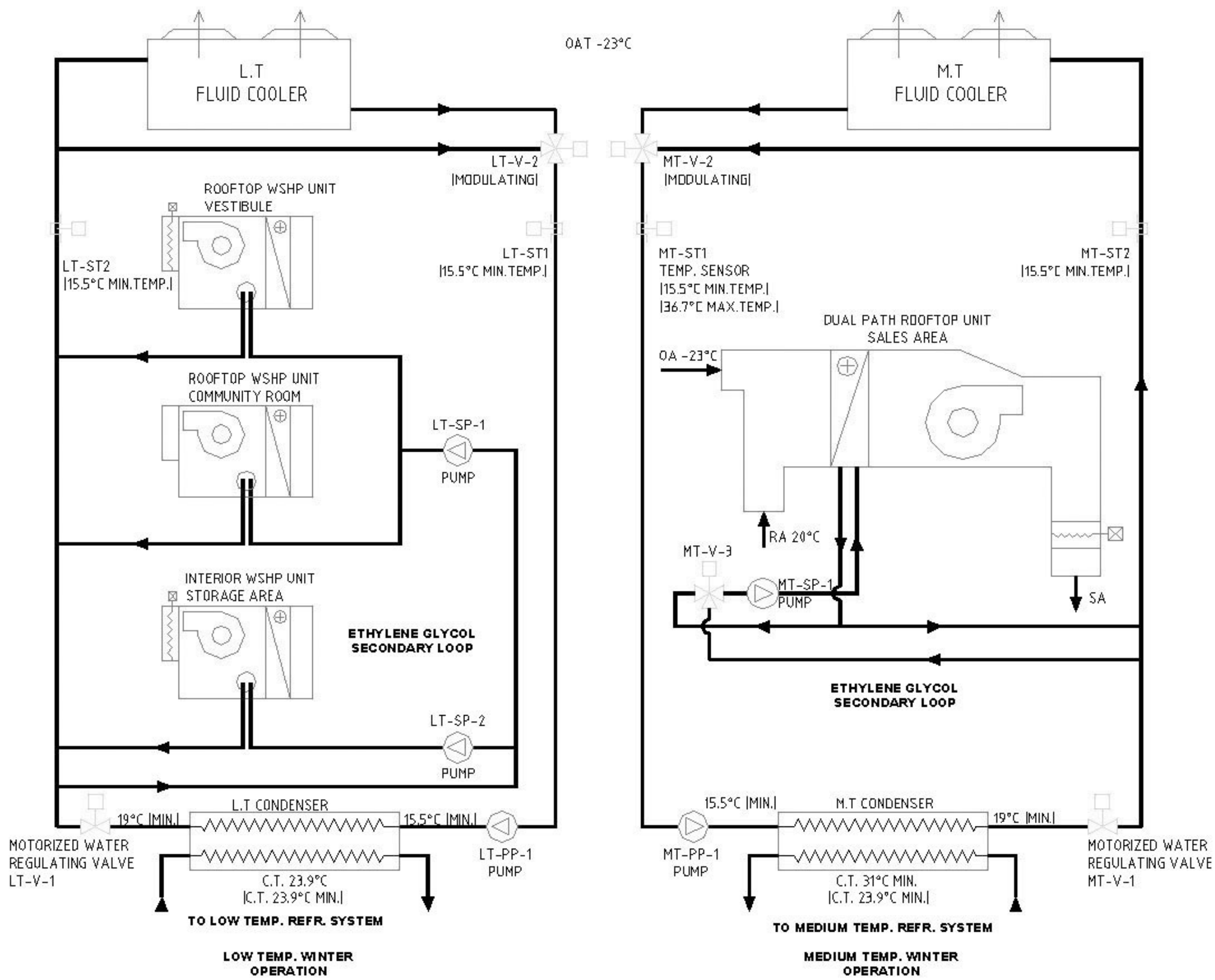

Fig. 2. Hot side of the low and medium temperature refrigeration system

4 HEAT RECOVERY OF LOW AND MEDIUM TEMPERATURE REFRIGERATION SYSTEM

4.1 Operation and Control Strategies

The operation of the HVAC&R integrated system is optimized by the control system in order to take advantage of the Canadian climate. The main control variable is the condensing temperature — and its optimization is based on two criteria: building heat load (recovery) and outside temperature.

5 EXPECTED IMPACTS

The integrated secondary-loop HVAC&R system (Figures 2 and 3) allows a reduction of approximately 80 % in the amount of synthetic refrigerant compared to a conventional supermarket system. The project is expected to reduce total supermarket energy consumption by 18 % and GHG emissions by about 75 % relative to conventional supermarkets of equivalent size. The GHG emission reduction comes from both energy savings and synthetic refrigerant leak decrease. It is equivalent to the total GHG emissions of 430 family-size cars per year. The system has also other benefits: ease of operation and maintenance, more stable food temperatures (resulting in improved product quality and longer shelf life time) and added comfort for the customers.

6 RESULTS AND PERFORMANCE

The 10,000 square-metre (102,000 square-foot) Loblaws supermarket in Repentigny opened on April 28, 2004, and the integrated HVAC&R system has been operating successfully since then. The HVAC&R system operator indicated that the start-up of the whole system has been an easy task. A detailed monitoring of the integrated system is performed on a continuous basis with more than two hundred sensors scanned each minute. CETC-Varennes has been analyzing the system performance for at least a complete year.

6.1 Winter Conditions

The following tables show the system performance under winter conditions for a 24-hour operation on December 20, 2004. The average outdoor temperature was -22.6ºC, the indoor temperature 20.9 ºC, and the indoor relative humidity 15%.

Table 1. Refrigeration and heating system energy consumption - December 20, 2004

	Units	Low temp system	Medium temp system	Total
Compressor consumption	kWh	1 570	1 536	3 106
Outdoor Fluid cooler	kWh	0	0	0
Pump cold side	kWh	168	127	295
Pump condenser	kWh	122	533	655
Heat pump consumption	kWh	775	0	775
Heat recovery coil pump	kWh	0	65	65
Auxiliary heating	kWh	322	0	322
Total consumption	**kWh**	**2 957**	**2 261**	**5 218**

The low temperature compressor unit worked at 85% of its nominal capacity and the medium temperature unit at 55 %. The energy consumption for space heating was reduced by 88%, thanks to the heat recovered from the refrigeration system. Even at –26°C outdoor temperature, only 3% of the heating load was supplied by the auxiliary heating unit (for the shipping/receiving dock). The total energy consumption (5218 kWh) is the sum of the energy consumed by the refrigeration compressors, heat pumps (including fans), circulation pumps, and auxiliary heating units.

Table 2. Space heating and refrigeration load - December 20, 2004

	Units	Low temp system	Medium temp system	Total
Total Space Heating Load	kWh	3 366	5 973	9 339
Total Refrigeration Load	kWh	3 449	5 176	8 625
Total load	**kWh**	**6 815**	**11 149**	**17 964**

We have defined a specific COP for the supermarket ($COP_{supermarket}$).

$$\mathbf{COP_{supermarket}} = \frac{\textbf{Total space heating and refrigeration load}}{\textbf{Total energy consumption for heating and refrigeration}}$$

Table 3. Saved energy and COP improvement - December 20, 2004

	Units	Low temp system	Medium temp system	Total
Saved space heating energy	kWh	2 269	5 908	**8 177**
Supermarket COP		2.3	4.9	**3.4**
Supermarket COP DX without heat recovery		1.4	1.5	1.5

$COP_{supermarket}$ is a good indicator of the efficiency of the supermarket, in order to compare different technologies and strategies. The calculated COP for this supermarket is more than 2.4 times the COP of a similar supermarket using a multiplex DX system and a furnace for space heating (this factor varies with the outdoor temperature).

6.2 Summer Conditions

Under summer conditions the secondary fluid refrigeration system consumes 10% more than a standard multiplex system because of the extra pumping power. The saturated evaporating temperature is lower by 3°C for the low temperature unit but almost the same for the medium temperature unit. The saturated condenser temperature for the secondary-loop system is typically 1°C higher than the temperature in a standard DX system. In the Montreal area the temperature exceeds 18°C for only 1500 hours per year, and therefore this small increase in energy consumption under summer conditions (which corresponds to less than 5% of the total supermarket energy consumption in a year) is significantly overshadowed by the heating season benefits. It is possible to increase the energy performance during summer conditions by working on the pumping power required for circulating the secondary fluids. The pumps in place were probably oversized.

7 CONCLUSION

The preliminary results obtained up to now show that this demonstration project of advanced integrated HVAC&R systems in the Repentigny Loblaws supermarket is successful. These results demonstrate that: 1) the use of secondary loops on the cold and hot sides of a refrigeration system are promising alternatives to direct expansion systems, in order to reduce synthetic refrigerant charges and leaks in supermarkets; 2) the use of a secondary loop on the hot side of the refrigeration system offers a better potential and flexibility for heat recovery and upgrade; 3) it is possible to match the whole heating (heating and hot water) requirements of supermarkets by recovering the heat rejected by the refrigeration system (even during the coldest days of the Canadian winter) and therefore to eliminate the use of auxiliary heating devices such as furnaces. The detailed monitoring of the supermarket performance is going to continue until summer 2005. The final project report will present also a detailed financial evaluation of the project, investments, and operation costs, as well as a qualitative evaluation of customer comfort and produce shelf life.

This demonstration project is a huge step towards the increase of the energy and environmental performance of Canadian supermarkets. Other demonstration projects, featuring new operating strategies and secondary loops have already been planned under the Refrigeration Action Plan for Buildings. In the long term, the use of secondary loops will facilitate the adoption of natural refrigerants (ammonia, carbon dioxide, hydrocarbons...) in supermarkets.

Finally, it is interesting to note that the substantial environmental benefits to be achieved through this new approach to the design of refrigeration systems should not imply in any additional costs, since the energy savings will offset the extra investment costs within an acceptable time frame.

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