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SECONDARY LOOP SYSTEMS FOR THE SUPERMARKET INDUSTRY

White Paper — September 2007

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Overview

Objective

The objective of this white paper is to promote the use of secondary loop systems as a method to minimize the emission of refrigerants that have been shown to damage the environment. In doing so, the benefits of secondary loop systems in comparison to other alternatives will be evaluated. This analysis will show that secondary loop systems are not only environmentally friendly, but they have a low initial cost, simplified piping, low cost of operation and are easy to maintain.

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Background Information

Introduction

Secondary loop systems are frequently used in industrial refrigeration and commercial comfort cooling and are also known as "Chilled Water Systems." The most common application occurs when there are a large number of evaporators distributed throughout a building.

The supermarket industry has begun to adapt this design to their medium temperature refrigeration systems. This design protects the environment by reducing greenhouse gases that contribute to global warming. It has a low installation cost, is easy to service and maintain and has a low cost of operation.

There are approximately 35,000 supermarkets in the United States.[1] A single store may contain up to 5,000 pounds of refrigerant to cool and freeze food and may experience leak rates of up to 30 percent.[2] In addition to harming the environment, leaks negatively impact the profitability of supermarkets, as it is costly to clean systems and replace lost refrigerant. Environmental damage and high refrigerant costs are the primary drivers for the increased interest in alternative approaches to the traditional direct expansion system for supermarket refrigeration.

Market Drivers

The number of new and remodeled supermarkets in the United States is being driven by consumer trends toward increased freshness and convenience. Various industry sources show a typical remodel cycle of 7-10 years. Over half of store remodels were as a result of company policy (i.e. standard remodel schedule). In 2005, nearly 1,000 new stores opened and another 1,500 existing stores were remodeled.

As the number and size of supermarkets and the consumer trend toward fresher and more convenient foods increases, the demand for refrigeration will continue to increase. Refrigeration selection is impacted by the following key issues currently facing the supermarket industry:

- Increasing concern about product safety
- Increasing concern about environmental issues
- Increasing interest in improved energy efficiency
- Governmental regulations (State and Federal)
- Total cost of ownership/cost efficiency
- Opportunities for strategic differentiation

All of these industry drivers are driving supermarkets toward new alternatives for refrigeration systems.

Current Situation

A typical supermarket refrigeration system includes refrigerated display cases and walk-in coolers and freezers. These fixtures are direct expansion (DX) and connect to a central refrigeration system that is located either in an equipment room or on a rooftop. Most often, the central refrigeration system consists of several sets of rack-mounted compressors. Each compressor serves a specific portion of the store's refrigeration load and there are typically separate racks for medium and low temperature applications. The average life of a refrigeration system is 15 years; however, supermarket refrigeration systems are overhauled every 8 years on average, which coincides with the typical store remodel cycle.

The interconnecting piping can contain a charge of between 3,000 to 5,000 pounds of refrigerant. The most common refrigerants used are R-22, R-404A and R-507. Studies consistently report leak rates of up to 30 percent for older systems and up to 15 percent for newer systems. Refrigerant leaks are due to a wide variety of factors, including: vibration, thermal cycling, quality of valve materials and quality of connections.[4] A breakdown of the reports of refrigerant release locations is shown below in Figure 1.

Figure 1

Release Locations	Percentage of Total Occurrence
Condenser Valves and Connections	17.2%
Hot Gas Defrost Valves	16.6%
Other Piping Connections	12.8%
Expansion Valves	10.4%
Liquid Line Valves	6.7%
Other System Valves	10.3%
Evaporator Coil	3.9%
Sight Glasses	2.9%
Other	19.2%
Total	100%

Figure 1: Typical refrigerant release locations[5]

The ideal solution is an efficient design, which minimizes the amount of refrigerant required and at the same time, protects the environment by reducing the number of refrigerant leaks. Of all possible alternatives, a secondary loop system is deemed the optimal solution to address all of these issues. This design can reduce the volume of refrigerants by up to 90 percent and restrict the location of the DX refrigerant to the machine room. Additional benefits are that the systems are simpler to maintain and also provide improved food product quality. [6]

What is a Secondary Loop System

A secondary loop refrigeration system incorporates two different refrigerants to provide cooling. In all systems, the primary loop is a traditional direct expansion design that uses a phase change refrigerant such as R-404A and a compressor to circulate the refrigerant. This primary fluid is typically restricted to the machine room. A heat exchanger is used to transfer energy from the primary loop to the secondary loop. In most applications, the refrigerant in the secondary loop is a benign single-phase fluid that is circulated by a pump throughout the store to the individual evaporators. Propylene glycol has proven to be the most suitable secondary fluid as it is non toxic, non flammable, does not contribute to global warming and provides optimal performance compared to other secondary fluid alternatives. The secondary fluid absorbs energy by increasing in temperature as it passes through refrigerated cases and unit coolers in the refrigerated spaces.

One of the fastest growing applications of a secondary loop system is on the evaporator side of the refrigeration system. This design is often applied in a supermarket but could just as easily be applied to a storage warehouse. This application is nearly identical to a chilled water loop used in comfort cooling, except the system is designed for lower evaporator temperatures and uses a water and glycol mixture instead of just water. Propylene glycol is usually used with food applications, as it is non toxic. For simplicity reasons, this paper will focus on secondary loop systems used on the evaporator side of the refrigeration system.

Figure 2 is a schematic representation of this type of secondary loop. The primary loop consists of a compressor (1) and an air-cooled condenser (2). The liquid refrigerant flows from the condenser to a heat exchanger (3), which is the primary system evaporator, and is controlled by an expansion device (4).

The refrigerant leaves the heat exchanger as a superheated vapor and is circulated back to the compressor. This heat exchanger (3) is the evaporator for the primary refrigeration loop. The other side of the heat exchanger is the secondary loop. Heat is removed from the fluid and the fluid temperature is reduced. A pump (5) is used to circulate the secondary loop refrigerant to the display cases and walk-in coolers. A solenoid valve is provided at the entrance to each heat exchanger to regulate the flow of refrigerant in response to room temperature. The secondary loop refrigerant cools the refrigerated space by absorbing heat thus increasing the fluid temperature. Typical changes in fluid temperature range from 4°F to 8°F, depending upon the room temperature. Finally, the secondary loop refrigerant is returned to the pump (5) and the process is repeated.

Figure 2

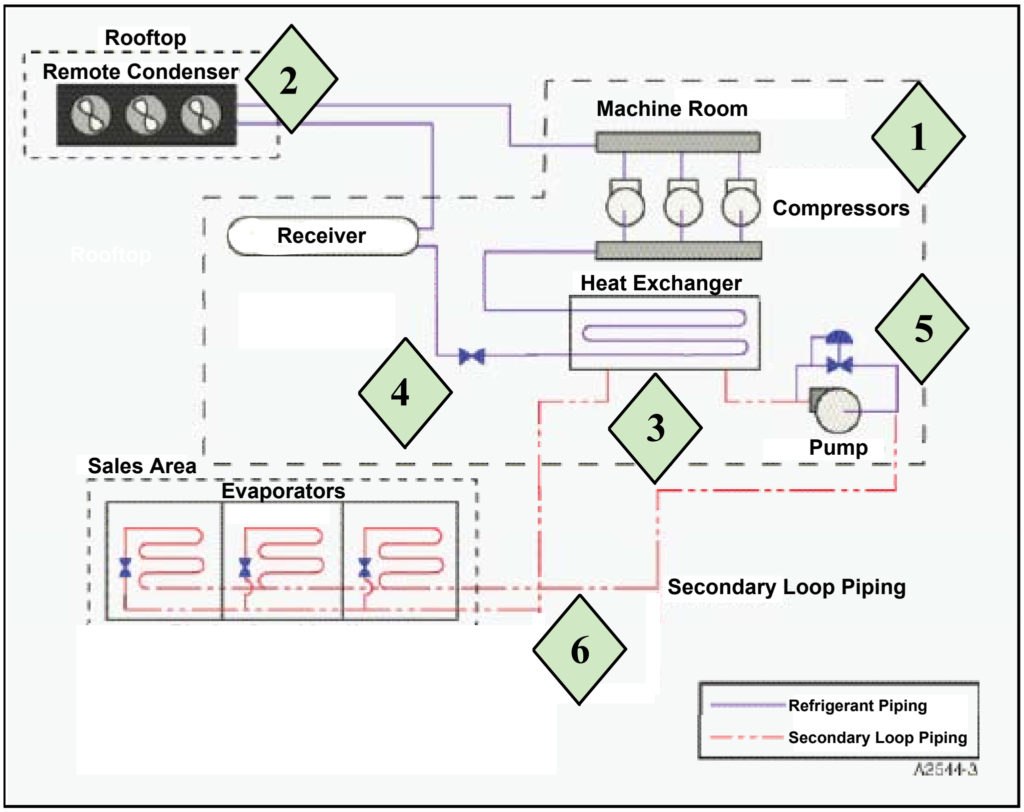

Figure 2: Schematic of a Secondary Loop System

Two-Phase Secondary Loop

There is a variant of the secondary loop, which uses a two-phase mixture as the refrigerant. This variant takes advantage of the high latent heat required to change the phase of the refrigerant from liquid to solid. The higher the percentage of refrigerant undergoing a phase change, the higher the energy stored per pound of refrigerant. This reduces the flow rate (GPM) required for the same cooling capacity. The concentrations of the fluids are closely regulated so as to operate at a point of minimum flow resistance (viscosity). The combination of reduced flow and low flow resistance combine to reduce the power required for circulation.

One example is ice slurry, which consists of water and ice and is close to the consistency of slush. A type of antifreeze, such as glycol or ethanol, is included when the fluid temperature is lower than 32°F. In this design, the heat exchanger is modified so that it will change a portion of the secondary coolant from liquid water to ice. This solution is either piped to a storage tank, for thermal storage, or pumped directly to the evaporators. The piping is also modified so the individual evaporators can be piped in series or parallel.

A unique advantage of ice slurry systems is their surprisingly low pumping requirement. The flow resistance occurs at the boundary of the ice slurry and the inside wall of the pipe. At this interface, the pipe temperature is slightly warmer than the fluid, but sufficiently warm to melt a thin layer of ice adjacent to the pipe. This thin film of fluid acts as a lubricant, allowing the ice slurry to flow with less power and a smaller pump.

Benefits of Secondary Loop

As previously mentioned, a typical supermarket requires 3,000 to 5,000 pounds of refrigerant,[7] most of which is located in the piping between the compressor and the individual refrigeration evaporators. A secondary loop confines the direct expansion refrigerant to the machine room. The lines connecting the compressor to the evaporators are filled with a benign water and glycol mixture. This can reduce the amount of refrigerant needed for operation by as much as 90 percent.[8] A secondary loop system eliminates opportunities for DX refrigerant leaks near food because this refrigerant is restricted to the machine room.

Figure 3

Category	Traditional DX System	Secondary Loop System
Refrigerant Charge	Up to 5,000 lbs	Less than 500 lbs
Refrigerant Location	At case and in machine room	Machine room only
Leak Impact	High — due to large system charge	Low — due to low system charge
Refrigerant Emissions	Up to 30%	Less than 5%
Box Temperature	Greater temperature fluctuations due to greater TD	More stable box temperature

Figure 3: Comparison Between Traditional DX Systems and Secondary Loop Systems

Lower Initial Cost

It is a common misconception that secondary loop systems have a higher installed cost than standard direct exchange (DX) systems due to the cost of the pumps and increased temperature differential between the compressor and saturated evaporator temperature. Secondary loop systems installed in the 1990s often had 30 percent higher initial cost and 30 percent lower operating efficiency than centralized direct expansion systems.[9] This is no longer the case for the following reasons:

Simplified Piping

There is a cost savings due to reduced halocarbon refrigerant and in the reduction in length of interconnecting pipe. In secondary loop systems, expensive copper pipe can be replaced by much less expensive plastic pipe. There is often an elimination of refrigeration components required, especially in systems that use hot gas defrost. The simplified piping also contributes to the initial cost savings. The interconnecting field piping for a direct expansion system has to be designed to ensure oil return to the compressor. Piping is simplified as there is no need for oil return.[10]

Circulating Pump

The cost of the circulating pump for the secondary loop has also been dramatically reduced with new designs. Systems designed in the past were based on a 2°F rise in the secondary loop fluid. Current design practice is to use a temperature rise of 4°F to 8°F.

Since the refrigerant flow rate is directly related to the change in fluid temperature, a two to four fold reduction in flow rate (gallons per minute or GPM) can be realized, thereby reducing the pump horsepower required by an order of magnitude.[11]

Fewer Components

Supermarkets often have medium temperature walk-in coolers in the 28ºF to 32ºF range. Unlike walk-in coolers in the 35ºF to 40ºF range, a positive means of defrost is required. Secondary loop systems can use a "warm fluid defrost," using fluid at 50ºF[12] to defrost the coil instead of electric resistance defrost heaters or hot discharge gas. Hot gas systems today require a hot gas solenoid valve, suction stop valve and check valve for each circuit, and usually use a system discharge pressure regulator to ensure sufficient pressure for a quick defrost. All of these components are eliminated with a secondary loop system.

Lower Cost of Operation

There is increasing evidence that secondary loop refrigeration systems are as efficient and in some cases more efficient than direction expansion systems. A field trial by the California Energy Commission conducted over a nine-month period resulted in energy savings of 4.9 percent for a secondary loop system vs. a baseline direct expansion system.[13] A portion of the energy savings was attributed to the higher suction temperature required to maintain adequate product temperature for the secondary loop system vs. the baseline system.

Excerpt from "Investigation of Secondary Loop Supermarket Refrigeration Systems"

In a comparison of single-deck meat cases it was found that "the multiplex display case had to operate at a lower rack Saturated Suction Temperature (SST) to maintain adequate product temperature. A comparison of multi-deck produce cases showed that both systems operated at similar SST, but the secondary loop system had more uniform product temperature.[(2)]

There are also indications that the minimum refrigeration condensing temperature for medium temperature racks can be reduced from 70ºF Saturated Discharge Temperature (SDT) to 50ºF SDT as a result of the short liquid lines to the refrigeration evaporator. This reduction in head pressure would increase the compressor EER from 16 BTUH/Watt to 23 BTUH/Watt, or an increase of 40 percent.[(i)]

Prepared By: Southern California Edison and Foster-Miller, Inc.

Ease of Maintenance

The secondary loop system requires less maintenance than a traditional direct expansion system. The simplified piping is easier to understand and troubleshoot, making it easier to install and repair — by less experienced technicians. There is no need to adjust Thermostatic Expansion Valves (TXV). The systems are also easier to service since they are located in the machine room and not at each evaporator. The number of refrigerant leaks in field piping are reduced and are easier to locate and clean when they do occur. Issues with oil return and logging are eliminated so there is no need for oil traps and suction risers.

Conclusion

The secondary loop refrigeration system is an environmental friendly design that can reduce the amount of refrigerant that can leak into the environment by as much as 90 percent. The design has many other important benefits as well. Field trials have demonstrated a reduction in the need for defrost periods, improved product quality and reduced shrink rate. The system design is simpler than a multiplex direct expansion system and is easier to service and maintain. The combination of reduced refrigerant charge and lower cost field piping, offset the additional cost of the pumps and additional heat exchanger. New state of the art designs minimize the pump power and have a SST equal to or higher than baseline direct expansion systems.

For more information about secondary loop systems for medium temperature applications visit www.thecoldstandard.com or (800) 537-7775.

Footnotes

[1] *Directory of Supermarket, Grocery & Convenience Store Chains 2005, Chain Store guide*

[2] *Palmer, John and Alison Crompton. "IEA Annex 26: Advanced Supermarket Refrigeration Heat Recovery Systems — UK Summary of Final International Report, May 2003.*

[3] *www.arap.org/adlittle/8.html*

[4] *Directory of Supermarket, Grocery & Convenience Store Chains 2005, Chain Store guide*

[5] *Ibid*

[6] *Georgi S. Kazachki, Ph.D. and David K. Hinde September 2006 "Secondary Coolant Systems for Supermarkets", ASHRAE Journal*

[7] *Ramin T. Famamarzi, P.E., David H. Walker, P.E. March 2004 "Investigation of Secondary Loop Supermarket Refrigeration Systems" Consultant Report by Foster-Miller, Inc. California Energy Commission 500-04-013*

[8] *Ibid*

[9] *Boyko, J. 1997. "A Secondary Look at Secondary coolant Systems", SPECS/97- Refrigeration Engineering Workshop I.*

[10] *Georgi S. Kazachki, Ph.D. and David K. Hinde September 2006 "Secondary Coolant Systems for Supermarkets", ASHRAE Journal*

[11] *Ibid*

[12] *Erdman Anthony Case Studies November 2007. Internet posting, http://www.erdmananthony.com/case_studies.asp?id=33*

[13] *Ramin T. Famamarzi, P.E., David H. Walker, P.E. March 2004 "Investigation of Secondary Loop Supermarket Refrigeration Systems" Consultant Report by Foster-Miller, Inc. California Energy Commission 500-04-013*

About the Authors

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