Revised Draft Analysis of U.S. Commercial Supermarket Refrigeration Systems

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U.S. EPA's Stratospheric Protection Division

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1. Executive Summary

This report presents a wide range of data collected on five types of supermarket refrigeration systems: direct expansion, secondary loops, distributed, low-charge multiplex, and advanced self-contained systems. In many cases, varying or even conflicting information was obtained from the published literature and/or industry experts. Table ES-1, below, summarizes the results of this data analysis.

Table ES-1. Summary of Key Attributes of Supermarket Systems, Based on ICF Analysis

	Baseline	Alternative Technologies			
	Direct Expansion (DX)	**Secondary Loop**	**Distributed**	**Low-Charge Multiplex**	**Advanced Self-Contained**
Estimated Penetration of Technology into New/ Remodeled U.S. Supermarkets	60% to 80% (~70%)	3% to 5% (~4%)	18% to 35% (~26%)	Minimal	Minimal
Common Refrigerants	R-22, R-502, R-404A, R-507A	R-404A, R-507A	R-22, R-404A, R-507A	R-404A, R-507A	R-134a, R-404A, R-507A
Average Leak Rates During Use	15% to 35% (Old systems: 25%; New systems: 15%)	< 2% to 15% (Literature: <2% to 5%; Industry: 10% to 15%)	5% to 25%	25%	Literature: 1%; Industry: 10%
Comparison of Alternatives to Baseline (DX)					
Typical Charge Size		10% to 50%	12% to 60%	30% to 60%	5% to 10%
Change in Direct Emission Reduction		- 44% to -99% (HFCs); -100% (ammonia, HCs)	- 75% to -95%	NA	NA
Change in Energy Consumption		- 5% to +15%; 0% to +20%	- 8% to +16%; 0% to +10%	- 12%	+7%
Change in Capital Cost		+10% to +25% (capital costs are on the higher end of this range for systems using natural refrigerants)	0% to +33%	0%	0%
Change in Installation Cost		-4% to +10%	-25% to +15%	0%	0% to +15%
TEWI Reduction		42% to 61%	38% to 60%	24% to 44%	56%

NA = Not available.

2. Introduction

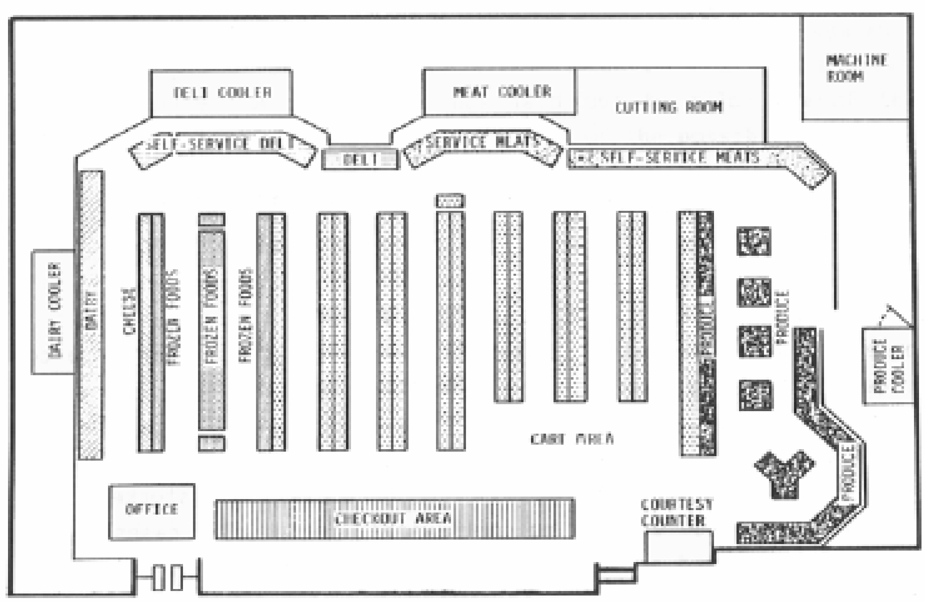
Supermarkets are defined as retail food stores with sales greater than $2 million. In 2004, the Chain Store Guide estimated that there were over 31,000 supermarkets in the United States. The top 20 supermarket chains, with 18,276 stores, hold 77% of total retail groceries sales in the U.S (Chain Store Guide, 2004).

Published estimates of the average supermarket size in the United States vary widely. UNEP (2003) estimated that the average supermarket in the United States is 43,000 ft^2; more recent industry estimates concur, indicating that the average store size is currently about 45,000 ft^2. However, a 2002 study by Arthur D. Little (ADL) estimated that newly constructed supermarkets in the United States are 60,000 ft^2, and this will be the average size of all supermarkets in 8 to 10 years.

Annual energy use in supermarkets ranges from 100,000 kWh/year to 1.5 million kWh/year, depending on store size. Refrigeration energy consumption in a typical supermarket is estimated to comprise 30% to 50% of total energy consumption, or up to 65% for small supermarkets (ADL, 2002; Baxter and Walker, 2003; IPCC/TEAP, 2005). According to IEA (2003), compressors and condensers account for 60% to 70% of refrigeration energy consumption, while display and storage cooler fans, display case lighting, evaporator defrosting, and anti-sweat heaters account for the remainder (IEA, 2003).

Figure 1, below, presents the typical layout of a supermarket with the refrigerated display cases and storage areas located around the store's perimeter.

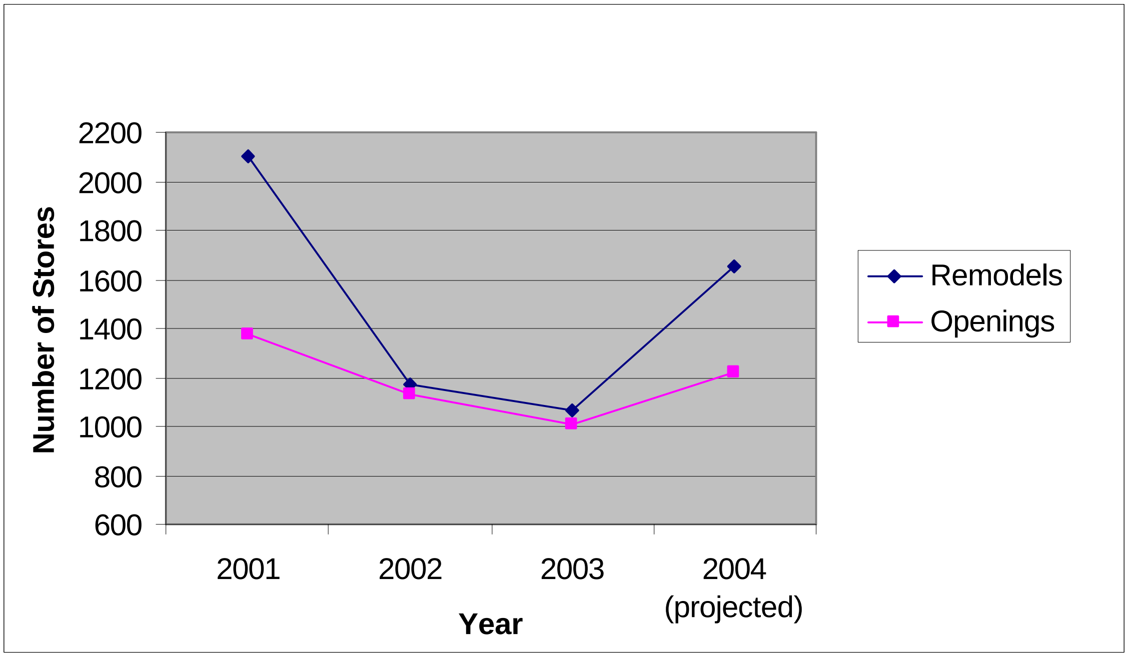
Figure 1. Typical Supermarket Layout



Source: ADL (1996).

Approximately 4,000 new supermarket refrigeration systems are purchased each year, with about 60% being for new store applications and 40% for remodels (Humphrey, 2000). One industry expert estimated that of his company's sales of DX systems, 70% of sales are for new store applications, while 30% are for remodels. Depending on the supermarket chain, supermarket remodeling occurs every seven to ten years (Humphrey, 2000), although the life span of refrigeration equipment is estimated to be between 10 and 20 years (IPCC/TEAP, 2005). The trends for new supermarket construction and remodeling in the United States over the last several years are presented in Figure 2, below.

Figure 2. U.S. Trends for New Supermarket Stores and Remodels



Source: Chain Store Guide (2001, 2002, 2003, 2004).

Currently, nearly all supermarket refrigeration equipment in use contains either HCFCs (R-22) or HFCs (R-404A and R-507A). The estimated market breakout by refrigerant type, as provided by two U.S. industry sources, is presented in Figure 3.

Figure 3. Estimated Breakout of In-Use Supermarket Equipment, By Refrigerant Type

Refrigerant	Percent of In-Use Equipment	
	Manufacturer A	Manufacturer B
CFCs	5%	0%
HCFC-22	65%	40%
HFCs[a]	30%	60%

[a] Includes R-404A and R-507A. According to industry estimates, R-404a is used in a larger portion of systems than R-507A.

There are many types of refrigeration systems in use in U.S. supermarkets, many of which are customized to fit particular stores' needs. These systems vary in many aspects, including store layout, refrigerant type, and refrigerant charge size.

This paper describes the most common, conventional type of supermarket refrigeration systems in use—the direct expansion (DX) system—as well as four alternative technologies that are still being improved upon and, increasingly, penetrating the U.S. market. These systems provide the potential to reduce consumption and emissions of ozone depleting substance (ODS) or greenhouse gases (GHGs) and, in some cases, energy consumption. These four technologies include:

- Secondary loop systems;
- Distributed systems;
- Low-charge multiplex systems; and
- Advanced self-contained systems.

These systems are often able to operate with a lower refrigerant charge and non- ODS refrigerants. Other innovations in these systems, described in later sections of this paper, can also help to reduce refrigerant emissions.

The remainder of this report is structured as follows:

- Section 3 discusses traditional DX systems;
- Section 4 details secondary loop systems;
- Section 5 provides information on distributed systems;
- Section 6 presents information on low-charge multiplex systems;
- Section 7 discusses advanced self-contained systems;
- Section 8 presents a TEWI analysis, comparing the direct and indirect warming impacts of each of the supermarket systems for which quantitative data is available;
- Section 9 presents the information on efficiency and cost penalties associated with R-22 supermarket retrofits;
- Section 10 provides the references used in this report; and
- Appendix A provides best practices for performing R-22 retrofits.

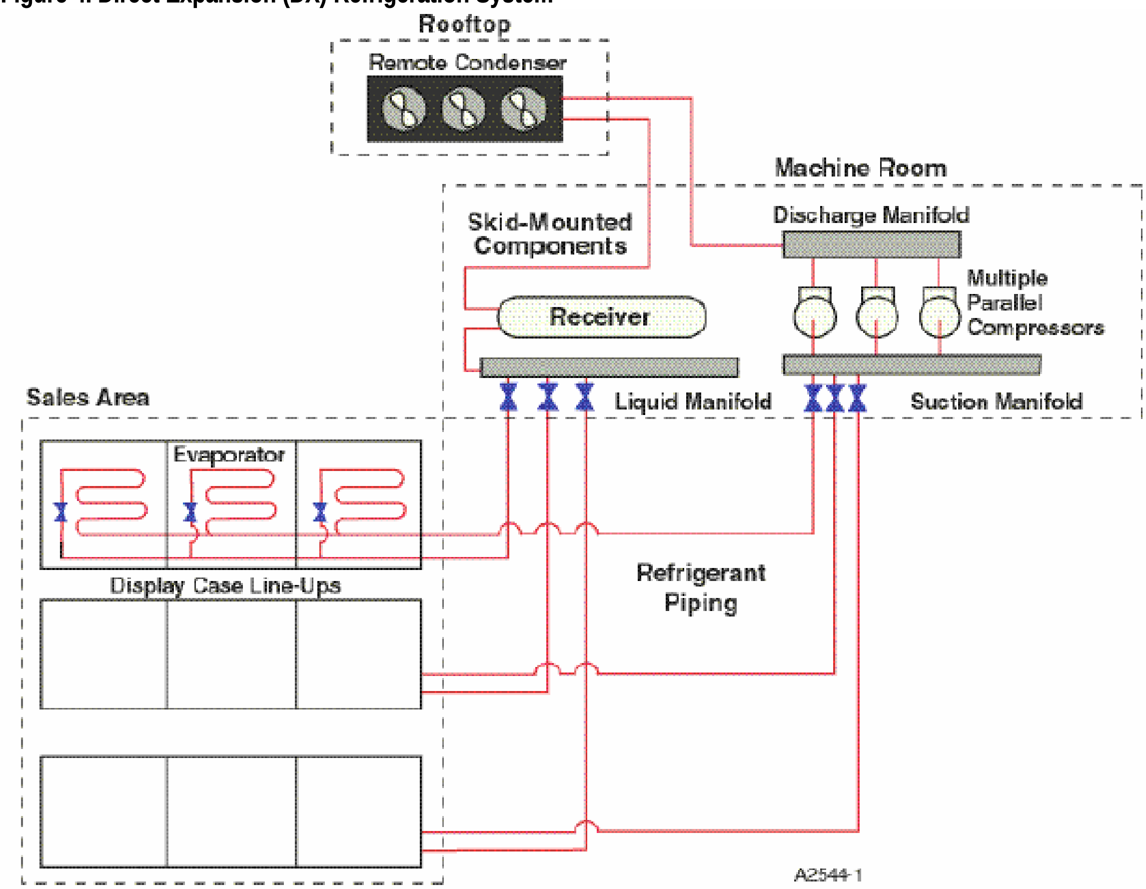
In each of the technology discussions (Section 3 through 7), brief system descriptions are provided, as are estimates of the systems' market penetrations in the United States, common refrigerants, typical charge sizes and leak rates, direct emissions, energy consumption, and capital and installation costs.

3. Direct Expansion (DX) Systems

3.1. Description

In a direct expansion (DX) system, the compressors are mounted together and share suction and discharge refrigeration lines that run throughout the store feeding cases and coolers. The compressors and condensers are located in a separate machine room, either in the back of the store or on its roof, to reduce noise and regulate heat rejection. These multiple compressor racks operate at various suction pressures to support display cases operating at different temperatures (Baxter and Walker, 2003; Powell, 2003). The hot gas from the compressors is piped to the condenser and converted to liquid. The liquid refrigerant is then piped to the receiver and distributed to the cases and coolers by the liquid manifold. After cycling through the cases, the refrigerant returns to the suction manifold and the compressors (Southern California Edison and Foster-Miller, Inc., 2004). Figure 4, below, presents the layout of a typical DX system in a supermarket.

Figure 4. Direct Expansion (DX) Refrigeration System



Source: IEA (2003).

3.2. Penetration of Technology

DX systems have traditionally been the most commonly used commercial refrigeration systems in the United States. In 2002, Powell estimated that DX systems were installed in 90% of supermarkets (Powell, 2002). In 2005, one equipment manufacturer estimated that 79% of new commercial refrigeration systems sold by his company are DX systems, while another manufacturer provided a lower estimate of 60%. <u>Thus, DX systems represent an estimated 60% to 80% of new market sales in the United States.</u>

3.3. Refrigerant Type and Charge Size

R-22 has been the most commonly used refrigerant in DX systems, with R-502 often used for low-temperature applications. However, R-404A and R-507A are increasingly penetrating the U.S. market as an alternative for both R-22 and R-502 (IPCC/TEAP, 2005; Powell, 2001; Powell, 2002). As shown in Figure 5, U.S. equipment manufacturers provided varying estimates of the breakout of refrigerant types that are used in DX systems sold today.

Figure 5. Estimated Breakout of Refrigerant Types Used in New DX Systems Sold Today[a]

Source	Refrigerant		
	HCFC-22	HFC-404A	HFC-507A
Manufacturer A	10%	60%	30%
Manufacturer B	33%	33%	33%[b]
Manufacturer C	50%	50%	0%

[a] These estimates are provided for each individual manufacturer, not for the U.S. market as a whole.

[b] Use of R-507A is reportedly increasing the fastest.

Charge size depends not only on store size, but also on the specific equipment and applications used (e.g., number of racks, low/medium/high temperature applications), which varies from store to store. Estimated charge sizes of DX systems, based on published literature and industry information obtained for this report, are shown in Figure 6.

Figure 6. Estimated Charge of DX Systems

As a Percent of Floor Area	Store Size (ft^2)	Charge Size of a DX System (lbs)	Comments	Source
4%	45,000	2,000	Using only medium-temperature equipment	Manufacturer A
6%	60,000	3,600		ADL (2002)
6% - 7%	45,000	2,866 to 3,086		Manufacturer C
7.5% - 10%	60,000	4,500 to 6,000	Using 3 racks	Manufacturer B
8% - 14%	35,000	3,000 to 5,000		Southern California Edison and Foster-Miller, Inc. (2004)

<u>According to the above sources, DX charge sizes can range between 4% and 14% of supermarket square footage.</u>

3.4. Typical Leak Rates and Direct Emissions

Figure 7, below, presents estimated leak rates provided in published literature and by industry sources contacted for this report. As shown, leak rates can vary widely; the reduction in leakage from DX systems can be explained by a number of steps taken by equipment manufacturers and users to minimize leakage, including: designing the system for tightness, practicing maintenance procedures for early detection and leakage repairs; training personnel; and recovering refrigerant at end-of-life (IPCC/TEAP, 2005).

Figure 7. Estimated Annual Leak Rates of DX Systems

Annual Leak Rates	Comments	Source
5% to 10%	Based on two studies performed in Germany	Birndt et al. (2000), Haaf and Heinbokel (2002)
3% - 22% (18% average)	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
12.4%	Based on a field test	Southern California Edison and Foster-Miller, Inc. (2004)
15%	Newer equipment	IEA (2003)
15% - 35%	Multiple factors for such a high leak rate were cited, including poor installation and maintenance	Manufacturer B
20% - 35%		Bivens and Gage (2004)
25%	After equipment has been in service for several years	Manufacturer A, Manufacturer B, Manufacturer C
$\geq$ 30%	Older equipment	IEA (2003)

Estimates of annual leak rates for DX systems range from 3% to 35% for in-use equipment, with the higher annual leak rates (25%) being more characteristic of older equipment and the lower ones (15%) being more characteristic of newer equipment.

3.5. Energy Consumption

DX systems consume significant amounts of energy due to the long pipe runs between the display cases and compressor racks, which result in pressure drops and suction gas heating. In addition, compressor run times are increased, increasing compressor energy consumption (Southern California Edison and Foster-Miller, Inc., 2004). However, DX systems have less thermal resistance, and no separate fluid pumping equipment, giving them an efficiency and cost advantage compared to alternative systems (IPCC/TEAP, 2005). According to ADL (2002), a typical DX system in a 60,000 ft^2 supermarket is estimated to consume approximately 1.2 million kWh/year. According to an industry expert, a 45,000 ft^2 store will consume 1.45 million kWh/year.

3.6. Capital and Installation Costs

One U.S. equipment manufacturer estimated that, for a store that is 60,000 ft^2, where 3 racks are required, total capital cost is about $165,000 (i.e., $55,000 per rack). The cost of food cases would be in additional to this. According to another equipment manufacturer, the installation cost of a DX system in a 30,000 ft^2 store is approximately $130,000, or $4.33/$ft^2$. In addition, the cost of DX systems will depend on the type of refrigerant used; currently, the initial cost of an HFC DX system is estimated to be two to three times more than the cost of an R-22 system.

4. Secondary Loop Systems

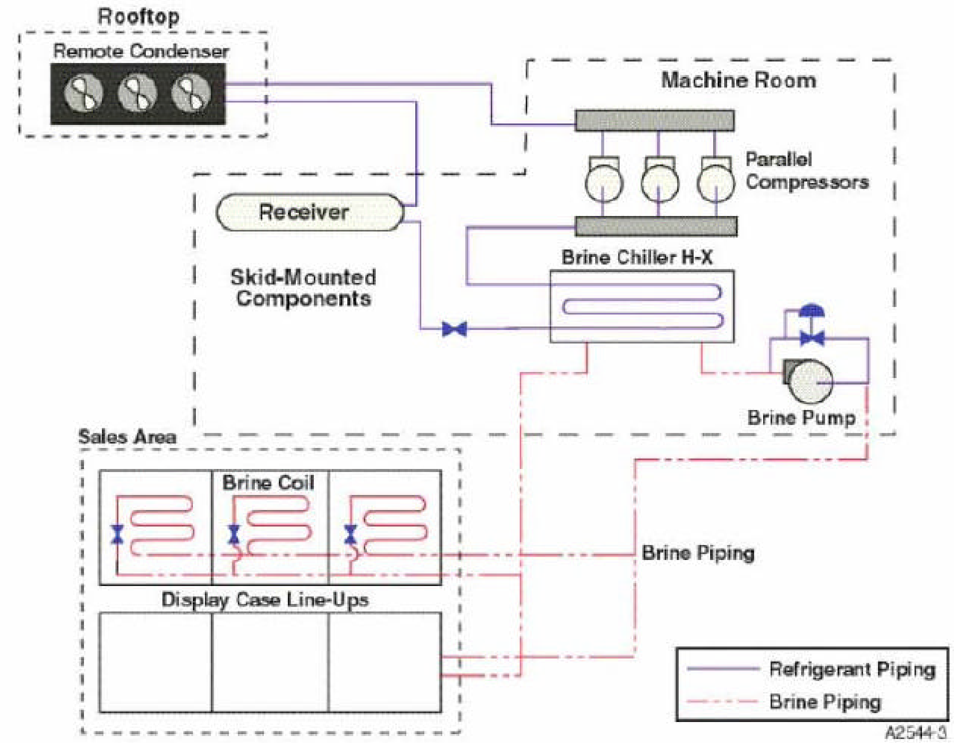
4.1. Description

In secondary loop systems, two liquids are used. The first is a cold fluid, often a brine solution, which is pumped throughout the store to remove heat from the display equipment. The second is a refrigerant that is isolated from the equipment cooled and passes through a heat exchanger to be cooled (EPA, 2004). Secondary loop systems can operate with two to four separate loops and chiller systems depending on the temperatures needed for the display cases. Secondary loop systems may use either reciprocating or screw compressors, although high-efficiency screw compressors have greater energy savings potential (Southern California Edison and Foster-Miller, Inc., 2004).

The two main disadvantages associated with secondary loop systems are a loss of energy efficiency and higher capital costs (EPA, 2004; IEA, 2003). One benefit to secondary loop systems is that they have improved temperature control compared to conventional direct expansion systems. This is an important advantage in the United States, which has recently tightened its regulations on temperature control for refrigerated products such as meat, poultry, and fish (EPA, 2004; IEA, 2003).

Figure 8 presents a diagram of a secondary loop refrigeration system.

Figure 8. Secondary Loop Refrigeration System



Source: Southern California Edison and Foster-Miller, Inc. (2004).

4.2. Penetration of Technology

One U.S. equipment manufacturer estimated that approximately 5% of its new supermarket sales are secondary loop systems.[1] Another manufacturer estimated that sales of secondary loop systems represent only about 3% of its new supermarket sales. Based on this data, the total market penetration of secondary loop systems into new or remodeled stores is estimated to range from 3% to 5% in the United States.

4.3. Refrigerant Type and Charge Size

According to U.S. equipment manufacturers interviewed for this report, secondary loop systems use primarily R-404A (about two-thirds) and R-507A (about one-third). No secondary loop systems are known to have been sold with R-22 or ammonia within the United States.

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[1] Supporting this estimate, one supermarket chain in the U.S. reported that 5% of its systems are secondary loop systems (Godwin, 2005).

In Europe, however, ammonia secondary loop systems are in use. In addition, CO_2 has also been gaining market share as a secondary coolant (IPCC/TEAP, 2005). Although one industry expert noted that CO_2 has lots of potential for use in low-temperature applications, currently, safety issues prevent the widespread use of CO_2 in the United States (Beeton, 2005).

Because the primary refrigerant does not need to circulate throughout the store, secondary loop systems can operate with a significantly lower refrigerant charge than DX systems. Thus, the charge size of a secondary loop system is estimated to be 10% to 25% of the charge in a DX system (ADL, 2002; Bivens and Gage, 2004; IPCC/TEAP, 2005; IEA, 2003) while other estimates range from 30% to 50% of the charge size of a DX system (Godwin, 2005; Southern California Edison and Foster-Miller, Inc., 2004).

Figure 9, below, presents a summary of the estimated charge size estimates for secondary loop systems provided by various sources. Variations in charge size estimates are likely associated with differences in secondary loop equipment and, potentially, different baseline comparisons (i.e., differences in the size of "conventional" DX systems).

Figure 9: Charge Size of a Secondary Loop System as a Percentage of the Charge Size of a DX System

Charge Size as a Percentage of DX Systems	Store Size (ft^2)	Actual Charge Size (lbs)	Comments	Source
1% -1.5%	35,000	300 to 500	Based on theoretical calculations made in preparation for field study. Field study required additional charge to provide heat reclaim for hot water and space heat.	Southern California Edison and Foster-Miller, Inc. (2004)
10% - 15%	NA	NA		IEA (2003)
11%	60,000	396		ADL (2002)
15% - 25%	NA	NA	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
30% - 40%	NA	NA	Based on a case study of a chain store in North America	Godwin (2005)
40%[a]	45,000	1,200		Manufacturer A
~50%	42,000	1,400	Based on a case study of a supermarket in California	Southern California Edison and Foster-Miller, Inc. (2004)

NA=Not Available
[a] Medium temperature only.

Based on the data presented above, although theoretical calculations indicate that secondary loop systems could require a charge of as little as 1% of DX systems, according to several case studies, secondary loop systems actually require a charge of between 10% and 50% of DX systems.

4.4. Typical Leak Rates and Direct Emissions

Secondary loop systems have lower annual leak rates than DX systems because they have a reduced number of connecting joints where leaks can occur (Bivens and Gage, 2004; EPA, 2004). In addition, secondary loop systems use pre-manufactured pipes that are often made of plastic instead of copper; therefore, they do not require brazing (EPA, 2004). Estimates of annual leak rates for secondary loop systems ranged from less than 2% to 15%, as presented by Figure 10. Based on the more recent data available from U.S. systems, this range may be closer to 10% to 15% in the United States.

Figure 10. Estimated Annual Leak Rates of Secondary Loop Systems

Annual Leak Rate	Comments	Source
U.S. Data		
2% - 5%		ADL (2002)
5%		IPCC/TEAP (2005)
10%		Manufacturer A
12%	This system uses glycol (ethylene or propylene) as cooling fluid to remove heat from food products in cases.	Manufacturer B
14.8%		Southern California Edison and Foster-Miller, Inc. (2004)
International Data		
< 2%	Based on a study of supermarkets in Sweden.	Engsten and Lindh (2004)

The combination of these reduced leak rates and the lower charge sizes results in significant direct emission reductions (Bivens and Gage, 2004; EPA, 2004). Indeed, secondary loop systems are estimated to experience total direct emissions reductions of 44% to 99% relative to DX systems (see Figure 11).

Figure 11. Estimated Direct Emissions of Secondary Loop Systems Relative to DX Systems

Direct Emissions Relative to DX Systems	Comments	Source
- 44%	This estimate is based on a comparison field study of a secondary loop system with an annual leak rate of 14.8% (compared to 12.4% for DX), and a charge size equal to 11% of a DX system.	Southern California Edison and Foster-Miller, Inc. (2004)
- 50% to -90%	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
- 75%		Godwin (2005)
- 98.5%	Assumes a 2% to 5% reduction in annual leak rate (compared to 15% for DX) and that the charge size is equal to 11% of a DX system.	ADL (2002)

4.5. Energy Consumption

Most studies have found that secondary loop systems require more energy than conventional DX systems. Reasons for increased energy use include (Southern California Edison and Foster-Miller, Inc., 2004):

- The use of display cases containing evaporators designed for DX systems. The evaporator coils have heat transfer characteristics that are not appropriate for use with a secondary fluid.
- Operation of the refrigeration system reducing the efficiency of the refrigeration compressors.
- The viscosity of the glycol-water mixture used in many secondary loop systems, which is much higher than that of water alone, increasing the fluid friction and pumping power.

Estimates of the energy consumption of secondary loop systems relative to DX systems are shown in Figure 12.

Figure 12. Estimated Energy Consumption of Secondary Loop Systems Relative to DX Systems

Energy Consumption Relative to DX System	Store Size (ft^2)	Comments	Source
0% to +20%	NA	Estimates are for secondary loop systems with ammonia, hydrocarbons, or HFCs Estimate is based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
+5% to +20%	NA	Data reported from 77 supermarkets with secondary loop systems in Germany	Haaf and Heinbokel (2002)
+10% to +15%	NA		UNEP (2003)
+15% to +20%	45,000		Manufacturer B
+17%	60,000		ADL (2002)

NA = Not Available

Based on this data, average secondary loop systems in use consume 0% to 20% more energy than DX systems.

However, energy savings are possible with *advanced* secondary loop systems. For example, the following design features can lead to energy savings:

- Close coupling between the chiller evaporator and the compressor suction to reduce pressure drop and refrigerant gas overheating (Southern California Edison and Foster-Miller, Inc., 2004);
- Improved pump capacity control and use of a low viscosity secondary fluid to reduce the energy use involved in circulating the secondary fluid (Southern California Edison and Foster-Miller, Inc., 2004);
- Design of display cases and fixtures for secondary loop systems to reduce heat transfer penalties (Southern California Edison and Foster-Miller, Inc., 2004);
- Subcooling of the primary refrigerant with the secondary fluid and then use of the secondary fluid to defrost the heat exchangers in display cases (IEA, 2003).
- More efficient defrost (IPCC/TEAP, 2005);
- Better part load characteristics (IPCC/TEAP, 2005);
- Improved expansion device performance (IPCC/TEAP, 2005); and
- Use of high-efficiency evaporative condensers (IEA, 2003).

Using these improved design features, secondary loop systems can lead to energy savings of 5% to more than 15% compared to DX systems, as presented by Figure 13.

Figure 13. Estimated Energy Consumption of Advanced Secondary Loop Systems Relative to DX Systems

Energy Consumption Relative to DX Systems	Store Size (ft^2)	Comments	Source
- 4.9%	42,000	Achieved in a field test of an advanced secondary loop system	Southern California Edison and Foster-Miller, Inc. (2004)
-10%	40,000	Compared to a DX system with an air-cooled condenser;	Baxter (2003)
> -14.9%	42,000	Energy Prediction made by Southern California Edison and Foster-Miller, Inc., 2004	Southern California Edison and Foster-Miller, Inc. (2004)

4.6. Capital and Installation Costs

Capital and installation costs of secondary loop systems vary widely depending on the types of primary and secondary refrigerants used, as shown in Figure 14.

Figure 14. Estimated One-Time Costs of Secondary Loop Systems using HFC Refrigerants Relative to DX Systems

Type of Cost	Cost Relative to DX System	Primary Refrigerant	Secondary Refrigerant	Comments	Source
HFC Secondary Loop Systems					
Capital	+10%	NA	NA	Based on a study of one supermarket chain in North America	Godwin (2005)
	+10% to +25%	HFCs		Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
	+17.5%	HFC	Not specified (secondary coolant or brine)		EPA (2004)
Capital and Installation	+ 6.8%	R-404A	Glycol		Rohrbach (2005)
	+15%[a]	NA	NA		UNEP (2003)
	+15%	R-404A or R-507A	Propylene glycol or potassium formate brines		IEA (2003)
	+15% to +35%[b]	NA	NA	Based on a study of 77 supermarkets in Germany	Bivens and Gage (2004)
Installation	+10%	NA	NA		Godwin (2005)
	-4%	NA	NA		Manufacturer A
Maintenance	-20%	R-404A	Glycol		Rohrbach (2005)
	-40% to +50%	NA	NA		Godwin (2005)
Secondary Loop Systems Using Natural Refrigerants					
Capital	+25%	Ammonia	NA		EPA (2004)
Capital[c]	+30%	Hydrocarbons	NA	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)

NA = Not Available.

[a] This cost refers to the "initial cost," which this analysis assumes to include both capital and installation costs.

[b] This cost refers to the "installed costs," which this analysis assumes to include both capital and installation costs.

[c] This cost is assumed to be a capital cost, though the literature is not clear.

The higher capital and/or installation costs associated with secondary loops can be offset by lower operating and maintenance costs due to decreased charge sizes, decreased leak rates, faster defrost, lower maintenance needs, and longer shelf lives, potentially resulting in significant cost-savings over time (EPA, 2004; IEA, 2003; Southern California Edison and Foster-Miller, Inc., 2004).

Figure 15, below, compares the maintenance costs associated with repairs to five DX and five secondary loop systems in a major Midwest supermarket chain from April 2002 to April 2004. Overall, the secondary loop systems showed a decrease in the costs of labor, parts, refrigerant, and maintenance relative to the costs for DX systems. The secondary loop systems did, however, show a 20% increase in the cost of energy.[2]

Figure 15. Comparison of the Costs Associated with Repairs to DX and Secondary Loop Systems in a Major Supermarket Chain (April 2002 – April 2004)

Store #	Labor ($)	Parts ($)	Refrigerant ($)	Refrigerant (lbs)	Secondary Fluid ($)	Secondary Fluid (gal)	Energy ($)	Maintenance ($)
DX Systems (5 Stores)								
#1014	16,490	14,080	948	834			322,232	32,352
#1067	17,336	19,236	3,360	4,420			383,729	44,352
#1162	17,420	6,703	1,596	1,275			519,326	26,994
#3039	13,060	5,107	1,968	1,765			432,620	21,900
#4075	18,231	12,534	996	1,410			414,224	33,171
TOTAL	**82,537**	**57,659**	**8,868**	**9,704**			**2,072,131**	**158,768**
Secondary Loop Systems (5 Stores)								
#12	19,048	3,814	1,200	200	545	47	515,804	24,854
#1149	17,539	12,271	0	0	9,143	610	503,710	39,562
#1150	10,250	5,600	2,100	350	0	0	524,280	18,299
#1693	19,252	5,503	750	125	417	30	462,358	26,077
#3159	14,878	12,742	2,550	425	321	40	492,175	30,956
TOTAL	**80,966**	**39,929**	**6,600**	**1,100**	**10,426**	**727**	**2,498,327**	**139,747**
Change Relative to DX	**- 1.9%**	**- 30.8%**	**- 25.6%**	**- 88.7%**			**+ 20.6%**	**- 12.0%**

The total cost to purchase and install secondary loop equipment can range from 6.8% to 35% more than DX systems. Capital costs alone can range from 10% to 25% more than DX systems, with capital costs for systems using natural refrigerants (e.g., ammonia, hydrocarbons) being slightly higher than for HFC systems. In addition, estimates of installation costs range from 4% *less* to 10% *more* than DX systems (for both HFC and natural refrigerants). These increased one-time costs can be offset by lower annual costs; maintenance costs associated with secondary loops is 20% to 50% less than DX systems.

5. Distributed Systems

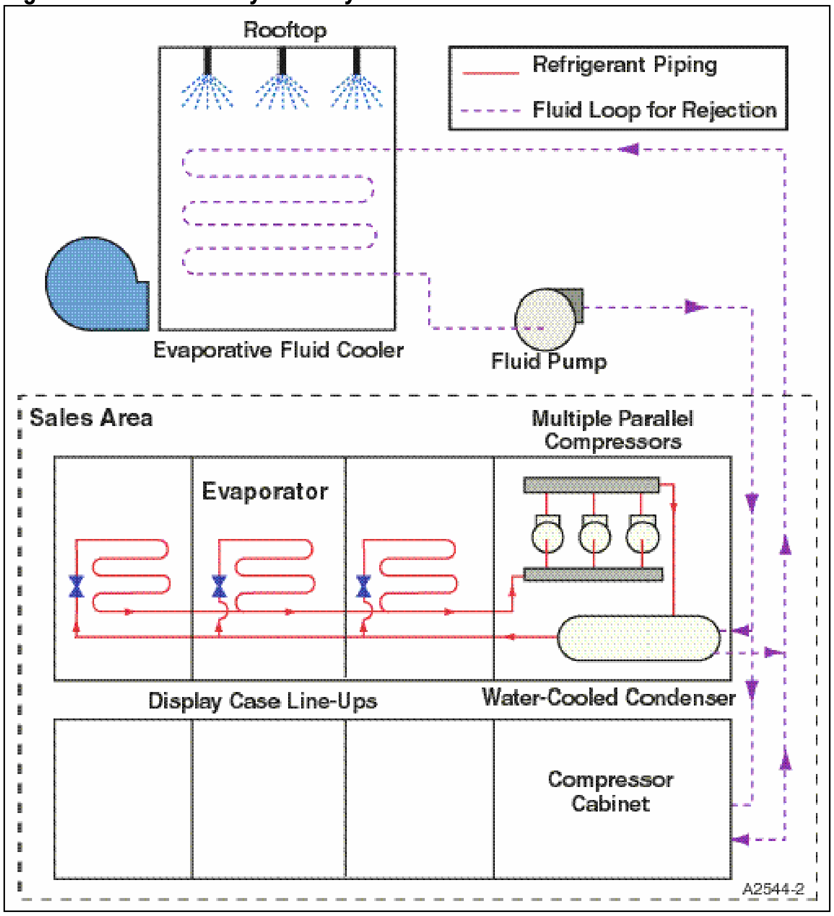
5.1. Description

Unlike DX systems, which have a central refrigeration room containing multiple compressor racks, distributed systems use multiple smaller rooftop units that connect to cases and coolers, using considerably less piping (Powell, 2003; Baxter and Walker, 2003). The compressors in a distributed system are located throughout the store near the display cases they serve. Thus, distributed systems typically use scroll compressors, which have lower noise and vibration levels than other compressors.

[2] Because all the supermarkets used in the study are in the same geographical region, this analysis assumes that per unit costs of labor, parts, refrigerant, and energy are equal. However, data is currently unavailable on the size of each of these supermarkets, which could undermine the comparability of these data.

The compressors are connected by a water loop to the cooling units on the roof or outside of the store (EPA, 2004). Figure 16 presents the layout of a distributed system.

Figure 16. Distributed System Layout



Source: IEA (2003)

5.2. Penetration of Technology

UNEP (2003) noted that, although distributed systems had been developed about 5 years prior, they still did not constitute a significant share of the global market. However, recent information indicates that distributed systems are gaining an important share in the United States' market. Indeed, according to two U.S. equipment manufacturers, distributed systems account for 18% of one company's sales and 35% of the other's sales. <u>Thus market penetration of distributed systems is estimated to range from 18% to 35%.</u>

5.3. Refrigerant Type and Charge Size

Distributed systems use R-22, R-404A and R-507A (ADL, 2002; IPCC/TEAP, 2005). Figure 17 presents estimated market percentages of each refrigerant used in distributed systems, as estimated by two U.S. equipment manufacturers.

Figure 17. Estimated Breakout of Refrigerant Types Used in New Distributed Systems Sold Today[a]

	Refrigerant		
	HCFC-22	HFC-404A	HFC-507A
Manufacturer B	0%	75%	25%
Manufacturer A	10%	60%	30%

[a] Estimates shown are for individual manufacturers, not for the U.S. market as a whole.

Because distributed systems require less piping than DX systems, less refrigerant is needed (Powell, 2003; Baxter and Walker, 2003). Estimates of the charge size of distributed systems range from 12% to 60% of conventional DX systems, as presented in Figure 18.

Figure 18. Estimated Charge Size of Distributed Systems as a Percentage of DX Systems

Charge Size as a Percentage of DX Systems	Store Size (ft^2)	Estimated Charge Size (lbs)	Comments	Source
12%	60,000	600	Using water-cooled condensers	Manufacturer B
19%	60,000	960	Using air-cooled condensers	Manufacturer B
25%	42,000	900		ADL (2002)
25%	35,000	300 to 500	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
33%	NA	NA	High-efficiency scroll compressors are able to operate at lower condensing temperatures than conventional reciprocating compressors; tests performed by the Department of Energy's Oak Ridge National Laboratory (ORNL)	ACHR (1999)
30% - 35%	NA	NA		IEA (2003)
50% - 60%	NA	NA	Using separate rooftop condensers for each cabinet	IEA (2003)

NA = Not Available

5.4. Typical Leak Rates and Direct Emissions

The use of distributed systems in place of DX systems can potentially reduce ODS emissions because smaller refrigeration units are distributed among the refrigerated and frozen food display cases. Through this set-up, distributed systems significantly reduce the refrigerant inventory and minimize the length of refrigerant tubing and the number of fittings that are installed in direct expansion systems, further reducing refrigerant leakage.

Available data indicate that annual leak rates for distributed systems can range from 5% to 25%, as presented in Figure 19.

Figure 19. Estimated Annual Leak Rate of Distributed Systems

Annual Leak Rate	Source
<5%	ADL (2002)
5% -7%	IPCC/TEAP (2005)
<8%	Manufacturer B
25%	Manufacturer A

When changes in both annual leakage and charge size are considered, as well as emission reductions at end of life, estimates of direct emission reductions associated with distributed systems can range from 75% to 90% compared to DX systems. This lower bound estimate of 75% is based on the draft IPCC/TEAP report (2005), while the upper bound estimate of 90% is based on ADL (2002).

5.5. Energy Consumption

The amount of energy used by a distributed system depends on what type of compressor is installed in the system. Scroll compressors are generally less efficient at the evaporating and condensing temperatures needed in commercial refrigeration. However, scroll compressors, unlike reciprocating compressors, do not have valves. Thus, they can operate at lower condensing temperatures, increasing their efficiency and reducing energy consumption (Powell, 2003; Baxter and Walker, 2003).

Literature sources disagree on the energy impact of distributed systems relative to DX systems. As presented in Figure 20, distributed systems have been found to be more energy efficient (by about 8% to 16%) in some cases, but less efficient (by 0% to 10%) in others.

Figure 20. Estimated Energy Consumption of Distributed Systems Relative to DX Systems

Energy Consumption Relative to DX Systems	Source
-8%	ADL (2002)
10% to -16%	ACHR (1999)
0% to +10%	IPCC/TEAP (2005)

5.6. Capital and Installation Costs

The capital costs of distributed systems are estimated to be from 0% to 33% higher than DX systems, as shown in Figure 21.

Figure 21. Estimated Capital Costs of Distributed Systems Relative to DX Systems

Costs Relative to DX Systems	Comments	Source
0% to +10%	Based on a sample of 1,700 supermarket systems in the U.S. and several European countries	IPCC/TEAP (2005)
+8% to +10%		Manufacturer B
+33%		EPA (2004)

The installation costs of distributed systems have been found to range significantly based on published literature and industry estimates. As shown in Figure 23, installation costs have been found to be from 25% *lower* to 15% higher than DX systems.

Figure 22. Estimated Installation Costs of Distributed Systems Relative to DX Systems

Costs Relative to DX Systems	Comments	Source
+15%	"Installed cost"[a]	IEA (2003)
- 8% to +10%	Installation costs are less, primarily because less refrigerant is needed.	Manufacturer B
-25%	Less piping is required, resulting in reduced costs for materials, time, and labor.	Powell (2003)

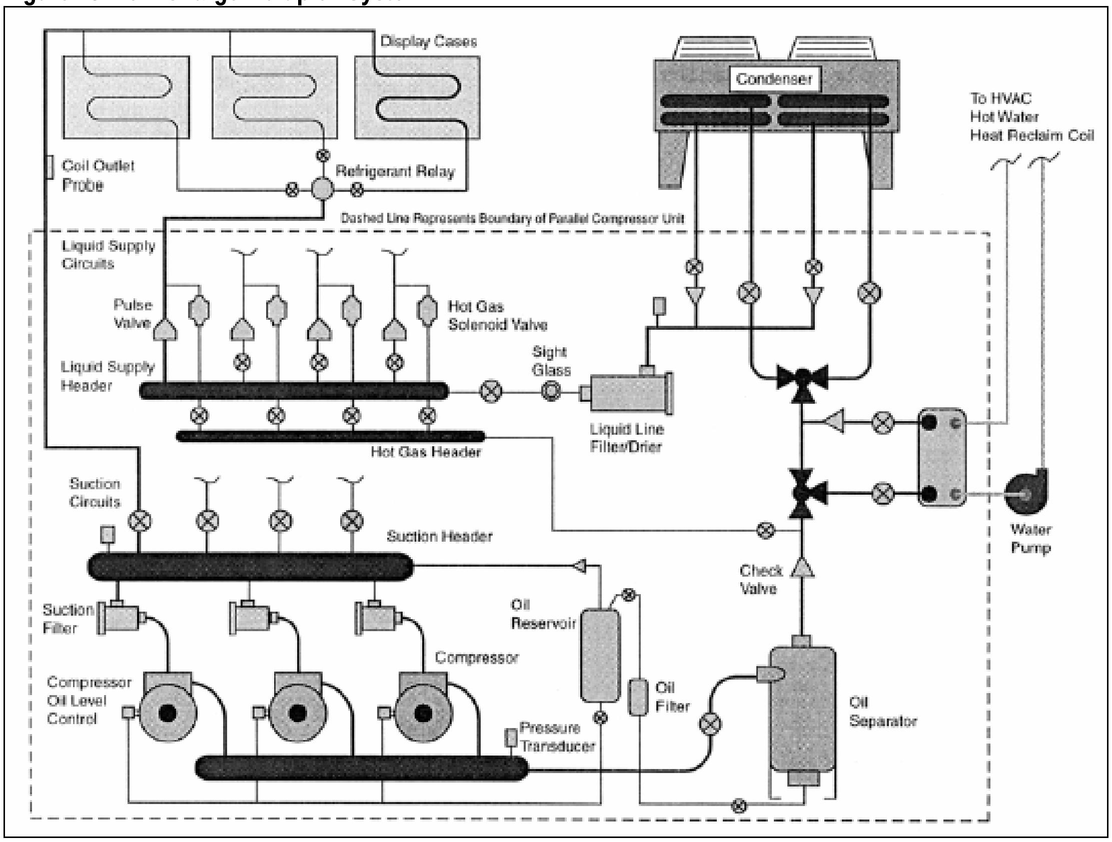
[a] This analysis assumes that this cost includes both capital and installation costs.

6. Low-Charge Multiplex Systems

6.1. Description

Low-charge multiplex refrigeration systems can use several different control systems to reduce the amount of refrigerant charge needed and the amount of energy required to operate the system. In one type of control system, a control valve that operates a bypass from the condenser liquid line maintains a constant differential between the high and low pressures of the system. This limits the refrigerant charge to the amount needed to service all display case evaporators with no additional charge needed for the receiver, as presented in Figure 23 (Baxter and Walker, 2003; IEA, 2003). A mixture of vapor and liquid refrigerant is sent to each display case lineup and storage room, controlled by the compressor rack. The evaporators are operated by valves that control refrigerant flow and evaporation (IEA, 2003). The refrigerant liquid bypassed by the valve is expanded and evaporated through heat exchange using the discharge manifold. This vapor is then piped to the suction manifold to be recompressed and returned to the compressor (Baxter and Walker, 2003).

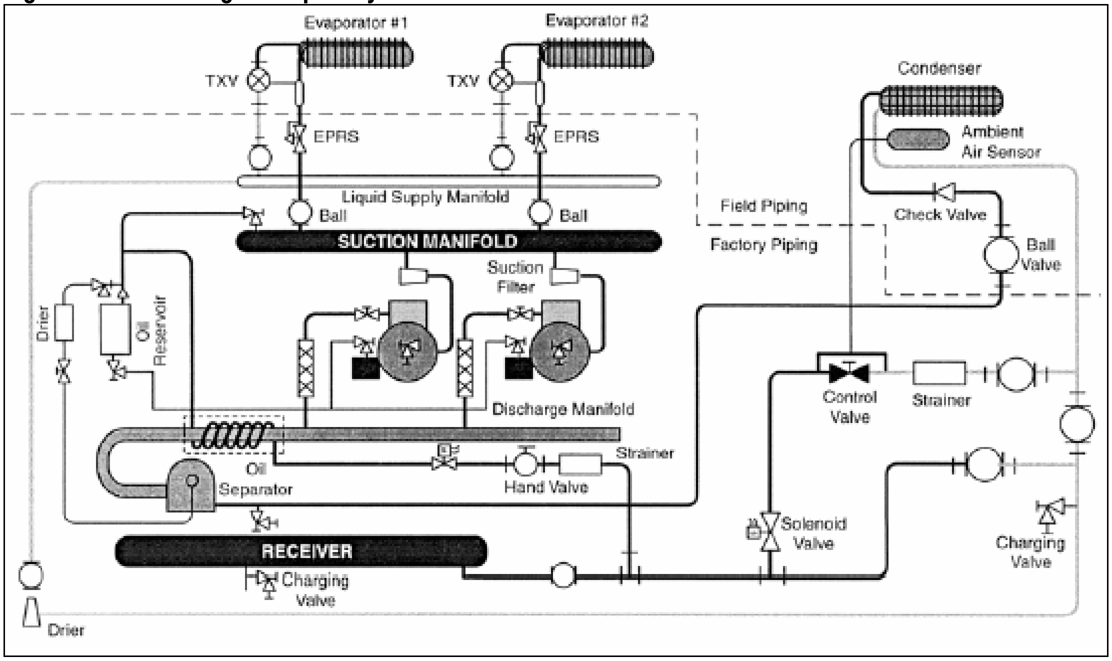
Figure 23. Low-Charge Multiplex System



Source: IEA (2003).

In another type of control system, the refrigerant charge is reduced by minimizing the refrigerant contained in the receiver during operation (see Figure 24). The control valve and ambient temperature sensor act together to maintain a constant temperature difference between the condenser outlet liquid and the ambient air. After the liquid refrigerant passes through the control valve, it is vaporized via heat exchange with the discharge manifold. The receiver stores any liquid refrigerant that is not vaporized (IEA, 2003).

Figure 24. Low-Charge Multiplex System



Source: IEA (2003).

6.2. Penetration of Technology

According to one U.S. equipment manufacturer, very few of these systems have been sold in the U.S., thus they comprise a negligible portion of new supermarket system sales.

6.3. Refrigerant Type and Charge Size

One U.S. equipment manufacturer that produces low-charge multiplex systems for the Canadian market, estimated that approximately two-thirds of the low-charge multiplex systems it sells contain R-404A, while the remaining third contain R-507A. According to this manufacturer, only a few of these systems have been sold in the U.S.

Regarding charge size, available estimates suggest that low-charge multiplex systems require only between 30% and 66% of that of DX systems, as shown in Figure 25.

Figure 25. Estimated Charge Size of Low-Charge Multiplex Systems Relative to DX Systems

Charge Size as a Percentage of DX Systems	Comments	Source
~30%	In systems where charge is reduced to the minimum amount needed by the evaporators	IEA (2003)
66%	In systems where the refrigerant inventory is minimized in the receiver	Baxter (2003), IEA (2003)

6.4. Typical Leak Rate and Direct Emissions

According to one industry contact, low-charge multiplex systems have an annual leak rate of 25%, similar to that of DX systems. No leak rate or direct emissions estimates for these systems were found in the literature reviewed.

6.5. Energy Consumption

A field study performed by Oak Ridge National Laboratory (ORNL) estimated that the low-charge multiplex system used 11.6% less energy than the DX system (Baxter, 2003). The control option that minimizes charge for the system evaporators is estimated to be as energy efficient as traditional DX systems. Moreover, the control option that minimizes refrigerant inventory in the receiver can produce some energy savings because the system compressors are able to operate at lower condensing temperatures than normal (IEA, 2003).

The use of a bypass control valve allows compressors to operate at very low head pressures, offering some energy-saving potential. Because the condenser fans can consume all the compressor energy savings in order to maintain the low head pressure, a "fan control strategy" is very important. Variable-speed condenser fans are recommended to achieve the lowest fan energy consumption while maintaining the desired low head pressures (Baxter and Walker, 2003).

6.6. Capital and Installation Costs

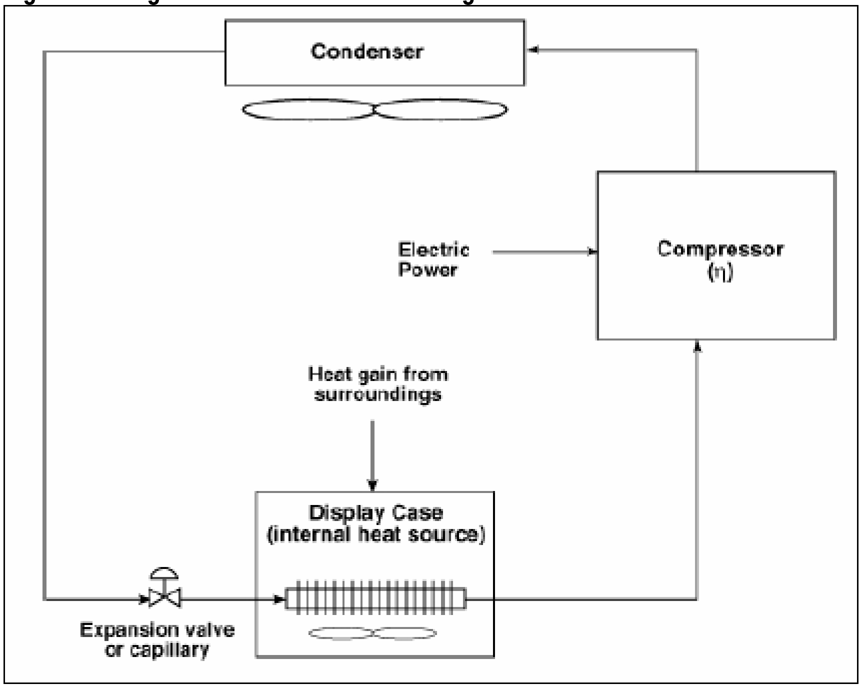
Low-charge multiplex systems using either control option are estimated to have the same installation costs as DX systems (IEA, 2003).

7. Advanced Self-Contained Systems

7.1. Description

Equipment considered to be self-contained includes beverage vending machines, beverage merchandisers, beer coolers, undercounter refrigerators, refrigerators for commercial food service, ice machines, and drinking water coolers (ADL, 2002). In advanced self-contained refrigeration systems, the refrigeration compressors and water-cooled condensers are located in the display cases. A glycol loop rejects heat from the display cases and carries it to the store's exterior. The recent introduction of horizontal scroll compressors into the market (vertical scroll compressors were not suitable for use in display cases) permit more widespread use of self-contained systems (Baxter and Walker, 2003). Foam insulation is used in most equipment to keep temperatures inside the equipment low (ADL, 2002). Figure 26 depicts the typical refrigeration circuit in a self-contained unit.

Figure 26. Diagram of a Self-Contained Refrigeration Circuit



Source: ADL (1996).

7.2. Penetration of Technology

Due to the high upfront costs associated with manufacturing self-contained systems, there are currently very few supermarkets comprised entirely of self-contained equipment in use in the United States. One equipment manufacturer noted that his company has only produced a few of these systems, and estimated that there were less than 10 in operation throughout the entire United States. Therefore, U.S. penetration of this technology is assumed to be minimal (<1%).

7.3. Refrigerant Type and Charge Size

Although self-contained equipment has historically contained R-22, today, advanced self-contained refrigeration systems used internationally typically use R-404A and R-134a (IPCC/TEAP, 2005).

Total charge size in a given supermarket could be as low as 5% to 10% of the charge size of a DX system, if self-contained systems are used for all refrigeration needs (IEA, 2003). For individual types of equipment, charge size can range from 0.3 kg to several kilograms (ADL, 2002).

7.4. Typical Leak Rate and Direct Emissions

Refrigerant emissions in advanced self-contained equipment are minimized by the use of brazed joints connecting the refrigerant tubing and refrigeration system components (ADL, 2002). It is estimated that advanced self-contained systems have a leak rate of approximately 1% (Baxter, 2003; Bivens and Gage, 2004). In addition, according to ADL (2002), because all the components are in the same unit, there is a minimal amount of tubing, further reducing refrigerant emissions. However, more recent information obtained from a U.S. industry contacts suggests that average in-use leak rates of these systems are much higher—about 10% annually.

7.5. Energy Consumption

Much of the energy consumption of self-contained equipment is related to frequent door openings, large beverage cool down loads, and ice maker throughput. A study performed by ORNL indicated that advanced self-contained systems consume 7.3% more energy than do traditional DX systems (Baxter, 2003). Self-contained systems are often less energy efficient per kW of cooling power than centralized systems as they usually reject heat into the store, which then increases the store's demand for air-conditioning and, in turn, increases total energy costs (IPCC/TEAP, 2005).

To reduce energy consumption of these systems, a study performed by ADL (2002) recommended the integration of heat reduction from individual units in a water circuit (IPCC/TEAP, 2005). In addition, the following measures are suggested to improve system efficiency (Baxter and Walker, 2003):

- Maintain the capacity control of the compressor.
- Regulate the condensing temperature to maintain a limited range.
- Ensure that the compressor capacity does not surpass the required refrigeration load to avoid excessive compressor cycling.
- Ensure a close link between the compressor and the case evaporator to reduce the pressure drop at the compressor suction and limit the heat gain to the suction gas.

7.6. Capital and Installation Costs

A study conducted by IEA (2003) estimates that a store that uses only self-contained equipment is associated with approximately the same capital cost as a DX system, but with installation costs that are up to 15% higher. In contrast, one U.S. industry representative claimed that there are "very high" upfront costs associated with self-contained systems, although no quantitative estimates were provided.

8. Total Equivalent Warming Impact (TEWI)

The use of supermarket refrigeration equipment generates "indirect" emissions of greenhouse gases (primarily carbon dioxide) from the generation of power required to operate the equipment. These indirect emissions can significantly reduce—if not, outweigh—the direct emission savings that can result from some alternative technologies. Hence, energy efficiency has a major impact on the total greenhouse gas emissions of an application.

Total Equivalent Warming Impact (TEWI) measures the environmental impact of greenhouse gases resulting from operation, service and end-of-life disposal of the equipment. It combines the effects of both the direct emissions of refrigerants and the indirect emissions resulting from energy consumption by the burning of fossil fuels and the generation of electricity for cooling. The calculation of TEWI is based on the global warming potentials (GWPs), developed by the Intergovernmental Panel on Climate Change (IPCC), which use CO_2 as a reference gas (Sand et al., 1997).

8.1. TEWI Comparisons

Eight TEWI studies have been reviewed and assessed for this report:

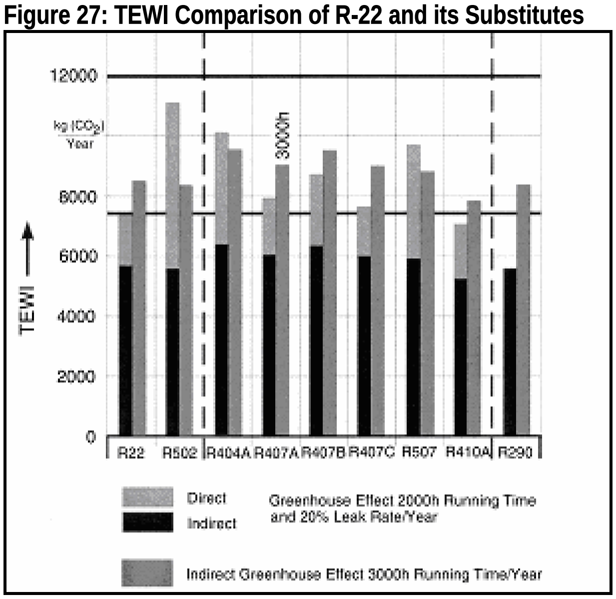
1. Arnemann, M., D. Gebhardt, and H. Kruse. 1995. "Experiementelle Bewertung neuer Kältemittelgemische als Ersatz für R-22 und R-502 [Experimental assessment of new refrigerant mixes as substitutes for R-22 and R-502]." *Die Kälte- und Klimatechnik* (2): 66. As cited in Kruse, Horst, 2000. "Refrigerant Use in Europe." *ASHRAE Journal*.
2. Sand, James R., Steven K. Fischer, and Van D. Baxter. 1997. "Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies." U.S. Department of Energy and Alternative Fluorocarbons Environmental Acceptability Study.

3. International Energy Agency. 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1- Executive Summary." Compiled by Van D. Baxter, Oak Ridge National Laboratory. April.
4. EPA. 2004. "Analysis of Costs to Abate International Ozone-Depleting Substance Substitute Emissions." Office of Air and Radiation (6205J), EPA 430-R-04-006. June. *[Note: this analysis is based on data from ADL (2002).]*
5. Baxter, Van D. 2003. "Advances in Supermarket Refrigeration Systems." U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN.
6. Baxter, Van D. and David H. Walker. 2002. "Field Testing of an Advanced Low-Charge Supermarket Refrigeration System." Paper presented at the New Technologies in Commercial Refrigeration Conference, University of Illinois at Urbana-Champaign, Urbana, IL. 22-23 July.
7. Bivens, Donald and Cynthia Gage. 2004. "Commercial Refrigeration Systems Emissions." Paper Presented at the 15th Annual Earth Technology Forum, Washington, DC. 13-15 April.
8. Intergovernmental Panel on Climate Change/Technology and Economic Assessment Panel. 2005. Draft of IPCC/TEAP Special Report on Ozone and Climate, Chapter 4: Refrigeration.

These studies, each of which is discussed below, have demonstrated that, although indirect emissions can significantly reduce the net environmental benefit associated with alternative systems used in supermarket refrigeration, alternative systems still represent net greenhouse gas improvements over conventional DX systems.

The study conducted at the Research Centre for Refrigeration and Heat Pumps in Hanover, Germany using R-404A, R-407A, R-407B, R-407C, R-507A, R-410A, and R-290 (propane), determined that only R-410 and R-290 have an improved TEWI compared to R-22, with similar performance in terms of energy efficiency. The other refrigerants were shown to have a 5% to 15% higher energy consumption. Figure 27 presents the results of this study (Arnemann et al., 1995, as cited in Kruse, 2000).

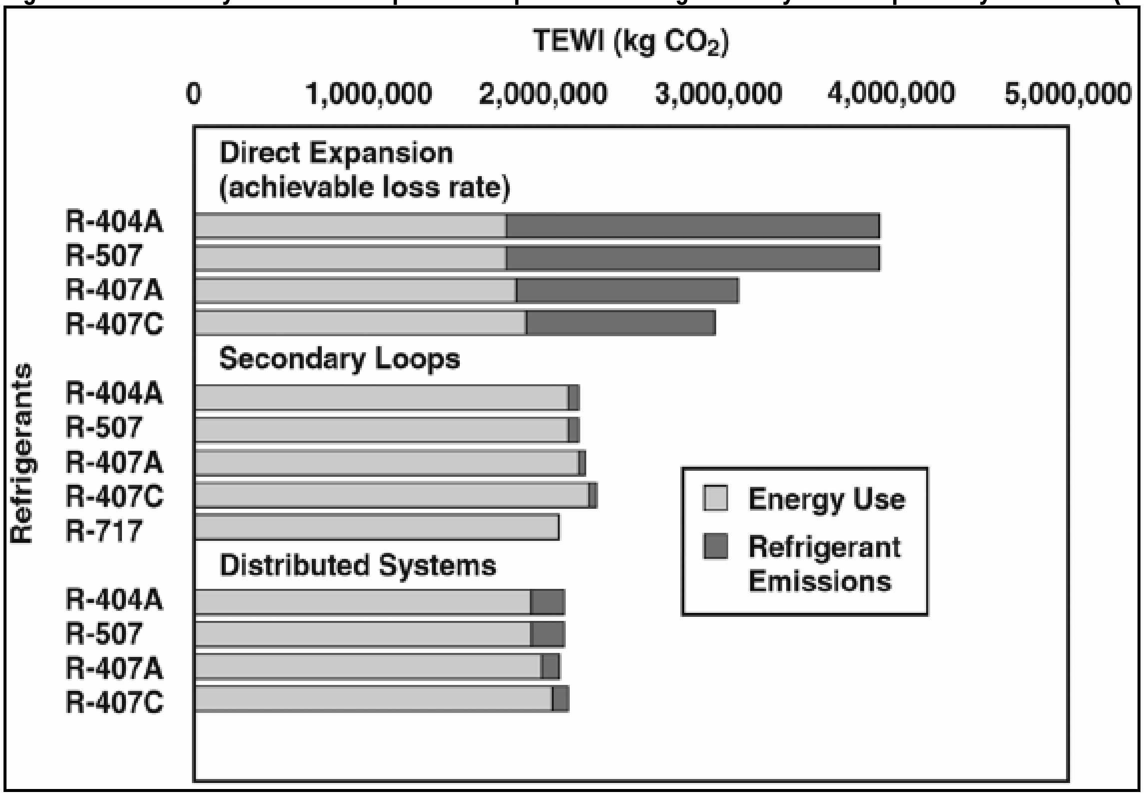
Figure 27: TEWI Comparison of R-22 and its Substitutes



Source: Kruse (2000).

Figure 28 presents the results of a study conducted by Sand et al. (1997) (also discussed in the IEA (2003) report), comparing DX, secondary loop, and distributed systems, each with a variety of different refrigerants in North America, including ammonia (R-717) in secondary loop systems. As shown, both secondary loop and distributed systems offer considerable TEWI reductions compared to the DX systems, especially when careful attention is paid to optimizing design and operational efficiency. The large refrigerant charge and high direct emission rate of DX systems result in high TEWI values, with direct refrigerant loss accounting for about half of the total emissions (IEA, 2003).

Figure 28: TEWI Analysis of Low Temperature Supermarket Refrigeration Systems Reported by Sand et al. (1997)



Source: IEA (2003).

EPA (2004) includes a TEWI analysis comparing distributed, HFC secondary loop, and ammonia secondary loop systems to a conventional DX system, based on data provided in ADL (2002). As shown in Figure 29, all alternative systems were found to result in net emission savings compared to conventional DX systems, with the distributed option resulting in the lowest net emissions, due to its lower energy consumption (despite larger charge size and leak rate compared to the secondary loop systems).

Similar results for distributed and HFC secondary loop systems are reported by Baxter (2003) (as also cited in IEA (2003)). Baxter (2003) compared not only distributed and secondary loop systems, but also low-charge multiplex and advanced self-contained systems, all of which were tested in a Washington, DC location, assuming a 15-year service life. As shown in Figure 30, the analysis indicates that alternative systems can reduce net greenhouse gas emissions by 20% to more than 60% compared to the baseline DX system. Of all alternatives, secondary loop systems with evaporative condensers were found to achieve the greatest emission reduction, even when using fluorocarbon refrigerants. In addition, although self-contained systems have the smallest leak rates, their higher energy use leads to higher net emissions than secondary loop and distributed systems. However, Baxter (2003) found that self-contained systems could potentially achieve the same TEWI reductions as distributed systems, if more efficient, small compressors and/or other improved system components are developed to help reduce system energy use. (Baxter, 2003)

Figure 29: TEWI Results for 60,000 ft² Supermarket, as Reported in EPA (2004) and Based on ADL (2002)

	Centralized Direct Expansion System (Base)	Distributed System	Ammonia Secondary Loop System	HFC Secondary Loop System
Charge Size (kg)[a] (% change)	1,633	408 (- 75%)	180 (- 89%)	180 (- 89%)
HFC Leak Rate (% of charge/yr)[a]	15%	4%	0%	2%
Direct Emissions (kg/yr)	245	16	0	4
Change in Direct Emissions (kg/yr)	N/A	(229)	(245)	(241)
Change in Direct Emissions (TCE/yr)[c]	N/A	(204)	(218)	(214)
Energy Consumption- kWh/yr[a] (% change)	1,200,000	1,100,000 (- 8%)	1,400,000[d] (+ 17%)	1,400,000[d] (+ 17%)
Indirect Emissions (TCE/yr)[e]	198	182	231	231
Change in Indirect Emissions (TCE/yr)	N/A	(17)	33	33
Change in Indirect Emissions (TCE/yr) per ton of cooling capacity[b]	N/A	(0.02)	0.05	0.05
Change in Net Emissions (TCE/yr)	**N/A**	**(221)**	**(185)**	**(181)**
Net Electricity Cost ($/yr)[f]	N/A	($4,000)	$8,000	$8,000

Note: Totals may not sum due to independent rounding.

N/A = not applicable.

[a] Based on ADL (2002).

[b] Assumes that conventional direct expansion systems require 5 pounds (or 2.27 kg) of refrigerant per ton of cooling capacity (EPA, 2004). For a 60,000 sq. ft. store using 3,600 lbs refrigerant (ADL, 2002), this translates to 720 tons of cooling capacity

[c] Assumes the refrigerant is R-404A (ADL, 2002).

[d] Recent technological advances on secondary loop refrigeration systems for supermarkets suggest that, with the use of improved technological features and design/manufacturing/contractor experience, these systems can lead to significant reductions in energy consumption (Baxter, 2003; EPA, 2004); however, these reductions are not assumed in this analysis.

[e] Assumes a national average emissions factor of 0.606 kg CO_2/kWh (EPA, 2004).

[f] Assumes average energy costs for United States between 1994-1999 (of approximately $0.04/kWh) based on EPA (2004).

Source: EPA (2004).

Figure 30: TEWI Analysis on Supermarket Refrigeration Conducted by Baxter (2003)

	Baseline (DX)	Low-Charge Multiplex		Distributed	Secondary Loop				Advanced Self-Contained
Condensing Type	Air-Cooled	Evaporative		Water-Cooled, Evaporative	Evaporative		Water-Cooled, Evaporative		Water-cooled, evaporative
Charge - kg/kW (% change)	4.15	2.77 (- 33%)		1.24 (- 70%)	0.69 (- 83%)		0.27 (- 93%)		0.14 (- 97%)
Primary Refrigerant	R-404A/ R-22[a]	R404A/ R-22[a]		R-404A	R-507A[b]		R-507A[b]		R-404A
Leak Rate	30%	30%	15%	5%	10%	5%	5%	2%	1%
Energy Use- kWh/year (% change)	976,800	863,600 (- 12%)		866,100 (- 11%)	875,200 (- 10%)		959,700 (- 2%)		1,048,300 (+ 7%)
TEWI Reduction[c]		**24%**	**44%**	**59%**	**58%**	**61%**	**57%**	**58%**	**56%**

[a] 1/3 R-404A (low temperature), GWP = 3260; 2/3 R-22 (medium temperature), GWP = 1700.

[b] R-507A, GWP = 3300.

[c] Relative to baseline.

Baxter and Walker (2002) compared a distributed system using R-404A to a DX system using both R-22 and R-404A (for different racks), and determined that the distributed system achieved a TEWI reduction of 38% over the baseline DX system. In addition, the distributed system consumed 12% less energy than DX system.

Bivens and Gage (2004) found that distributed systems can lead to even greater TEWI reductions compared to DX systems—achieving a 47% reduction. However, unlike previous studies, this analysis found that distributed systems consume the same amount of energy as DX systems—not less. Bivens and Gage (2004) also compare secondary loop and low-charge multiplex systems to DX systems, and conclude that secondary loop systems can achieve TEWI reductions of between 42% and 47%, and low-charge multiplex systems can achieve reductions of 46%.

Similar to Bivens and Gage (2004), the IPCC/TEAP draft report (2005) also reports that the energy consumption of distributed systems is equal to or greater than conventional DX systems. Figure 31 presents a comparison of the direct emission reductions, and energy usage of alternative supermarket refrigeration systems, as compared to the baseline DX system, as provided in the draft IPCC/TEAP report.

Figure 31: TEWI Data Reported in Draft IPCC/TEAP Report (2005)

	Baseline (DX)	HFC Secondary Loop	Ammonia Secondary Loop	Distributed (HFC)
Refrigerant	R-22	R-404A	Ammonia	R-404A
Direct Emission Reduction		50% to 90%	100%	75%
Change in Energy Usage		0% to +20%	0% to + 20%	0% to +10%
TEWI Reduction Relative to DX		35% to 60%		

Additional data may be available in the near future; one manufacturer and a supermarket chain are conducting a study comparing the costs of DX and secondary loop systems. Another manufacturer is also developing a TEWI analysis and expects to have results available in several months.

9. Retrofitting R-22 Supermarket Equipment

9.1. System Efficiency

In addition to replacing ODS refrigeration equipment with alternative technologies, alternative refrigerants can also be used to retrofit or "convert" existing ODS (e.g., R-22) systems. However, many ozone-friendly substitutes for R-22 result in a reduction in cooling performance and energy efficiency, which represents a major economic barrier to ODS alternatives. For example, Spletzer and Rolotti (2004) conducted a performance study of R-22 retrofits converted to R-404A, R-407C, R-417A, and R-507A for use in medium-temperature refrigeration loop, and found that:

- R-417A produced the largest losses in refrigerating capacity of any of the retrofits.
- R-407C produced a better capacity match and had the closest capacity of any of the alternatives at the 30ºF box temperature condition. It also produced the highest efficiencies of the retrofit refrigerants.
- R-404A and R-507A performed similarly and produced the highest capacities, on average, of the retrofits.

Honeywell (Gartland, 2005) also conducted a performance study of R-22 systems converted to R-404A, R-407C, R-422A, and R-417A (medium-temperature only). The study found that:

- All refrigerants showed efficiency loss at high ambient temperature in the medium-temperature application.
- Only R-404A showed a capacity increase in the medium-temperature application.
- All refrigerants showed a slight decrease in efficiency in the low-temperature application.
- R-404A had the best capacity in the low-temperature application.

The results of this study are summarized in Figure 32.

Figure 32: Results of Performance Study of R-22 Systems Retrofitted with HFC Refrigerants, Conducted by Honeywell (Gartland, 2005)

	R-404A	R-507A	R-407C	R-417A	R-422A
Capacity (relative to R-22)	Similar	Similar	Lower capacity at lower temperatures	Considerably lower capacity	~10% decrease at low temperatures
Mass Flow (relative to R-22)	~45% higher	~45% higher			55% higher
Temperature Glide	Very low	Very low	8 -12°F	5 -8°F	2 - 4°F
Pressure	~20% higher	~20% higher	~10% higher		~20% higher
Lubricant Used	Synthetic lubricants	Synthetic lubricants	Synthetic lubricants	Oil return issues with mineral oil use	Reduced oil return when used with mineral oil

Beeton (2005) noted that, while R-422A (One Shot® refrigerant) may be a viable alternative, R-404A is currently the most efficient retrofit refrigerant for R-22. One large supermarket chain (Bigg's) has performed two retrofits, converting a low-temperature rack and a medium-temperature rack from R-22 to R-422A. The low-temperature rack ran between 70% and 95% of capacity on R-22, and between 60% and 90% of capacity with extended periods below 50% of capacity after being retrofitted with R-422A. The medium-temperature rack ran between 50% and 80% of capacity when using R-22 and consistently below 50% with R-422A. Due to the reduction in capacity, the number of compressors needed to maintain the suction pressure target is reduced, which in turn will lead to lower energy costs associated with compressor operation (ACHR News, 2005).

9.2. Retrofit Cost

According to one industry expert, costs to retrofit R-22 retail food equipment to ODS alternatives can run very high:

- Retrofitting R-22 to R-407c/R-417a: $20,000-$60,000, depending on store size
- Retrofitting R-22 to R-404a/R-507A: $40,000-$90,000, depending on store size (requires up to 200 expansion valve changes)

The above cost estimates were supported by one U.S. equipment manufacturer who estimates R-22 retrofit costs for a store of 30,000 ft^2 to be between $50,000 and $70,000. However, another U.S. equipment manufacturer estimated retrofit costs for a larger supermarket (between 60,000 ft^2 and 65,000 ft^2) to be above this range—between $85,000 and $105,000.

9.3. Retrofit Procedures

Appendix A provides a checklist for conducting equipment retrofits.

10. References

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Appendix A: Best Practices for Retrofitting R-22 Equipment

A. Checklist

This checklist is intended to be used before conducting a retrofit.

- Conduct preliminary leak check, with special attention to any mechanical joints, valves and fin surfaces. NOTE: REPAIR ALL LEAKS!
- Record baseline data on original system performance.
- Choose lubricant. NOTE: Because HFC refrigerants are not miscible or soluble with mineral oil compressor manufacturers require synthetic oils, such as Polyol Ester-POE.

B. Procedure

The following steps should be followed when retrofitting a supermarket refrigeration system from R-22 to an HFC refrigerant:

1. Isolate the R-22 refrigerant charge to the receiver.
2. Drain as much of the old lubricant from the system as possible, including from the compressor sump, oil reservoir, and oil separator. If large amounts of mineral oil remain, it may clog the system and cause the efficiency of the heat exchangers to decline (Engsten and Lindh, 2003).
3. Replace oil filters and filter driers when performing oil changes.
4. Measure the amount of oil removed, add back an identical quantity of new oil. NOTE: The new oil chosen must be approved by the compressor manufacturer.
5. Run the system with R-22 for at least 24 hours. NOTE: Systems running for an extended period may require fewer oil changes.
6. Repeat steps 1 through 4 until the residual oil is less than 5%, testing using lab analysis or a refractometer.
7. Evaluate expansion devices using the process described below in Section C.
8. Recover R-22 in the system.
9. Pull vacuum.
10. Evaluate pressure controls, including high pressure cut-outs, fan cycling controls, and pressure relief devices.
11. Recharge system with HFC refrigerant.
12. Check system for leaks.

C. Valve Rebuilds (for systems built before 1995)

Systems built before 1995 will most likely require new gaskets and “o”- rings (elastomers)

1. Rebuild all Evaporator Pressure Regulators (EPRs);

2. Rebuild all solenoid valves;

3. Rebuild hold back valves;

4. Rebuild heat reclaim valves;

5. Evaluate TXVs and new refrigerant for proper capacity and superheat. Replace whole valve or power head if necessary. NOTE: Existing R-22 valves may be under-sized for higher mass flow refrigerants R-507A, R-404A and R-422A;

6. Replace "o"- rings on the receiver float, and receiver optic switch;

7. Replace nylon gasket on Roto Lock fittings. NOTE: Complete steps 6 and 7 prior to pulling a vacuum.

D. System “Rack”

1. Replace schraeder caps and schraeder cores on high side. NOTE: All schraeder caps should be brass.

2. Replace liquid line filters on conversion date.

3. Replace suction felts or cores on conversion date .

4. Use brass sealing caps on ball valves and compressor service valves.

5. Set holdback valves on the condenser drain leg.

6. Set EPRs to manufacturer’s parameters before setting any superheats.

7. Set mechanical sub-coolers to rack manufacturers’ parameters. Verify stable operation before setting any superheats.

8. Set TXV superheats to 8º-10º for medium temperature applications and 5º-7º for low temperature applications. NOTE: With blended refrigerants use DEW values for superheat measurements.

E. Tips

Keep the following items in mind when performing a retrofit:

- Perform the final oil change on conversion date;
- Run a defrost cycle on all circuits prior to oil changes in order to aid oil removal;
- Replace oil separator filters on conversion date;
- Dispose of used oil properly;
- Recover R-22 and pull vacuum;
- Complete all work outlined under rack system before recharging;

- Most HFCs have lower densities than R-22 so use proper charge amount; for example, when using R-404A, 87% of the size of the R-22 charge is required;

- All 400 series refrigerants must be liquid charged; and

- Always use proper personal protection equipment when handling refrigerants and oils.

R-404A requires a higher pressure and many of the systems components must be changed. The molecules of R-404A are also smaller than those of R-22, so the system must be much tighter to prevent leaks. In addition, the POE oil that R-404A requires may eat through seals and membranes, leading to higher leak rates.