CLIMATE-CHANGE IMPACT OF SUPERMARKET REFRIGERATION SYSTEMS

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ABSTRACT

Climate change impact of a refrigeration system, also termed Life Cycle Climate Performance, refers to all of the warming impacts from use of the system throughout its lifetime, expressed in terms of carbon dioxide-equivalent emissions. These include carbon dioxide emissions from fossil fuel power plants to generate power to operate the system, plus refrigerant emissions during operation of the system, during system maintenance, during end-of-equipment-life refrigerant recovery and/or disposal, plus other emissions during refrigerant manufacturing and transport. At historical supermarket annualized refrigerant emission rates of 30% of system charge per year, refrigerant emissions share of LCCP can amount to over 60% of the total. This paper will provide a progress report on supermarket refrigerant emission reduction programs, including system design options for reduced LCCP.

Key Words: ***supermarket, refrigerant emissions, LCCP, DX, indirect systems, cascade systems.***

1 INTRODUCTION

Centralized supermarket refrigeration systems consist of a series of compressors and condensers located in a remote machinery room, providing a cooling medium to display cabinets and cold storage rooms in other parts of the building. The size of systems can vary from cooling capacities of 20 kW to more than 1 MW, as used in larger supermarkets. Refrigerant charge sizes can range from 100 to 2,000 kg. The most common form of centralized system is termed direct expansion (DX), in which refrigerant circulates throughout the system as the cooling medium. Specific units can be dedicated to low temperature or medium temperature evaporators. Centralized systems had refrigerant emissions in the 1980's reported up to 35% of charge on an annual basis (Fisher et al. 1991, AEA 2003, Pedersen 2003). The high emission rates were due to system design, construction, operation, maintenance, and refrigerant recovery/disposal practices followed with no awareness of potential environmental impact. Refrigerant emissions are a contributor to climate change impact, as described in the following paragraph.

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Additional perspective for climate change impact of supermarket refrigerant emissions can be found in the publication by Palandre et al. 2004, which describes databases for worldwide refrigeration and air conditioning systems and refrigerants including refrigerant sales, system refrigerant inventories, and refrigerant emissions expressed in units of mass and carbon dioxide-equivalents. Supermarket refrigeration systems represent a major part of the category of commercial refrigeration in the publication. They report commercial refrigeration annualized refrigerant emissions rate of 30% of systems inventory in 2002, and on a carbon dioxide equivalent basis, this represents 41% of the total emissions from the worldwide sectors of air conditioning and refrigeration. Sector carbon dioxide-equivalent emission data are in Table 1. With commercial refrigeration having the largest carbon dioxide-equivalent refrigerant emissions of all the air conditioning and refrigeration sectors, studies on emission reduction for this sector are an important step toward lower climate change impact.

Table 1. Sector shares of refrigerant emissions expressed in CO_2 equivalent

Sector	% Share of Emissions
Commercial Refrig.	41
Mobile A/C	35
Stationary A/C	13
Industrial Refrig.	6
Domestic Refrig.	4
Transport Refrig.	1

1.1 Refrigerant Emission Studies

Refrigerant emission studies have been reported by several countries, with important learnings for reduction in system emissions. The countries include Germany, The Netherlands, United States, Sweden, Denmark, and Norway.

In Germany, two articles have reported supermarket systems refrigerant leakage studies and emission rates. A research project ”Tightness of Refrigeration Systems”, was conducted by the Institut fur Luft- und Kaltetechnik , commissioned by the Forschungsrat Kaltetechnik which is Research Council for Refrigeration Technology (Birndt et al 2000). Statistical methods were used to select the refrigeration systems to be evaluated, such that representative data could be generalized to all commercial refrigeration systems in Germany. 42 refrigeration systems were selected in Hesse, and 20 systems in Saxony. Refrigerant leak points were identified, and leak rates quantified by use of halogen leak detectors. There were several findings which provided important insight to refrigerant leakage characteristics.

- No leaks were identified in 40% of the systems.
- 14% of the found leaks contributed 85% of the refrigerant losses.
- 83% of the found leaks occurred in the assembly joints, such as flanged and screw joints, plus service valves and sight glasses.

From this information, it was obvious that a few “bad” systems caused most of the leakage, and some of their major conclusions to improve system tightness were:

- careful assembly of flanged joints and separable connections
- use improved service valves
- whenever maintenance is performed, a follow-up leak test is required
- use proper leak test procedures and correct evaluation of leak data

For the 19 centralized refrigeration systems built between 1991 to 1999, and having charge sizes of 60 to 300 kg, the leakage data indicated annual refrigerant loss rate of 9% of charge.

The second article (Haaf and Heinbokel 2002) reported on supermarket refrigeration systems using HFC refrigerant R404A in direct expansion for medium and low temperature refrigeration. Data were taken on systems installed in Germany after 1995 with improved technologies for leak tightness, plus reduction of refrigerant fill quantities by 15%. The average leakage rates were determined to be 5% of charge, which is a reduction from earlier years’ values of 10% of charge annual rates.

In the Netherlands, emissions have been significantly reduced through national mandatory regulations established in 1992 for CFCs, HCFCs, and HFCs, assisted by an industry initiated certification model which was given the designation of STEK. The Dutch regulations consist of several elements (Gerwen and Verwoerd 1998) with the following listed as examples:

- New systems and modifications of existing systems must fulfil detailed technical requirements to improve tightness.
- Flared joints are forbidden.
- Overpressure protection designed such that refrigerant emission to the ambient is minimized.
- System commissioning procedures include pressure and leakage tests.
- Each system has a log book for recording system failures, refrigerant additions, maintenance activities, and leak detection test results.
- Periodic system inspections conducted, including leak tightness. Systems with refrigerant charge exceeding 1000 kg equipped with automatic detection systems combined with automatic shut-off valves.
- Decommissioning includes reclaim and recovery of refrigerant.
- Companies carrying out maintenance and installation work must be certified and their personnel qualified.

The STEK organization was founded in 1991 on the joint efforts of the government and trade and industry groups in the refrigeration and air conditioning industries. The aim of STEK was to promote skillful handling of refrigerants and reduce/prevent refrigerant emissions. In 1992, the Dutch Minister of Housing, Spatial Planning, and the Environment (VROM) transferred the responsibility to STEK for the certification of companies and qualification of personnel, including an inspection and verification system. Only companies with a STEK certificate may carry out work on a refrigeration system.

The success of the Dutch regulations and the STEK organization in reducing refrigerant emissions was demonstrated with results from a detailed study in 1999 of emission data from refrigeration and air-conditioning sectors. For commercial refrigeration, annual refrigerant emissions (emissions during leakage plus disposal) were 3.2% of the total bank of refrigerant contained in this sector (Hoogen and Ree 2002).

In the United States, a report by the Environmental Protection Agency (Troy 1997) extensively detailed options for reducing supermarket refrigerant emissions, with estimates of expected emission reductions for options related to equipment design, construction practices, preventive maintenance, regular leak checking, and refrigerant accounting programs. Emission reduction programs and experiences were described for four supermarket organizations in the United States, indicating the potential for emission reductions down to about 15% of system refrigerant inventory per year. It is expected that the estimate would not include catastrophic events such as a fork-lift vehicle collision with refrigerant piping.

Reports of refrigerant emissions for 2001 and 2002 from two supermarket chains located in the western and eastern United States (Bivens 2004) showed annual refrigerant losses of 18% and 22% of system refrigerant inventory.

Another source of United States refrigerant emissions data was the South Coast Air Quality Management District (SCAQMD), a four county region consisting of Los Angeles and Orange counties and parts of Riverside and San Bernardino counties, representing a population of 15 million people in southern California. SCAQMD requires biannual reporting from facilities which have systems containing 22.7 kilograms (50 pounds) or more of CFC and/or HCFC refrigerants. The reports must include the charge size, refrigerant type, and annual refrigerant usage for each system in the facility. Data were available for 223 supermarkets having 1164 refrigeration systems in 2000 and 1217 refrigeration systems in 2001, with systems charge sizes up to 1285 kg (Gage 2004). Although the reporting requirements did not apply for systems using HFCs, 5% of the systems reported in 2001 and 2001 used R-404A. The percentage of systems using HCFC-22 declined slightly from 58% in 2000 to 56% in 2001.

Figure 1 shows the percentage of systems in each group which reported no refrigerant usage (and thus no leaks) in a given year. Over the two-year period, the percentage of systems requiring no refrigerant addition was closely related to system refrigerant charge size. Seventy-seven percent of the smaller charge size systems (23-137 kg) required no refrigerant additions, 65% of the medium charge size systems (138 – 455 kg) required no refrigerant additions, and 44% of the larger charge size systems (456 – 1285 kg) required no refrigerant additions. This gradation is as might be expected, as the larger charge-size supermarket refrigeration systems have longer piping runs, more assembly joints, more valves, and therefore more opportunities for refrigerant leakage.

On a total system basis, the average emission rates were 13% for 2000, and 19% for 2001. For the small number of R404A systems reported, the average emission rates were 9% in 2000 and 8% in 2001. If it can be assumed that R404A is used only in the newer systems, these lower rates may be an indication of more leak-tight design and construction.

Since the average emission rates include those systems with no emissions (as shown in Figure 1), on a per system basis the leaking systems have significantly higher loss rates than the averages. This observation amplifies the importance of periodic checking with leak detectors, representing a significant opportunity to identify and repair high leakage rate sources.

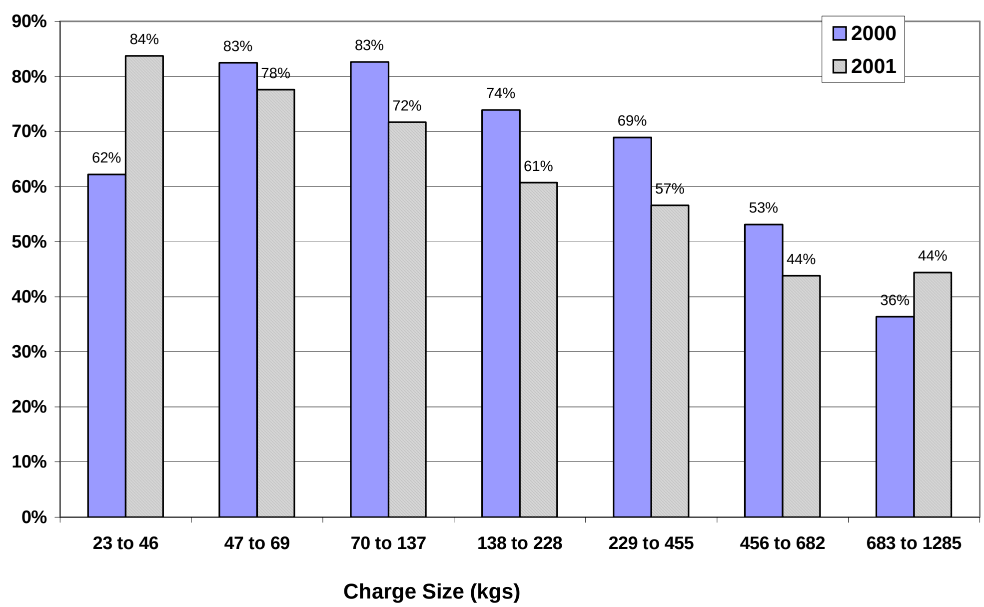

Fig. 1. Percentage of systems with no refrigerant addition.
(California South Coast Air Quality Management District)

In Sweden, a large supermarket chain provided refrigerant fill data from the time period of 1993 to 2002, with annual refrigerant losses decreasing from 14.0% in 1993, to 12.5% in 1998, and to 10.4% in 2001 (Lundqvist 2004). The lower emissions were partly attributed to increased application of indirect cooling systems (secondary loop heat transfer fluids) in supermarkets. The annual leakage experiences with the several refrigerants are shown in Fig. 2. Additional analysis of the data was provided by Engsten and Lindh 2004. They found that 40-50% of the stores would have no refrigerant leakage during a year's period, and 25% of the stores accounted for 70-80% of the leakage. 5% of the stores had annualized leakage rates of over 40% of system charge. Stores with smaller leakage amounts were generally operating with indirect cooling systems. These data highlight the great differences between the best and worst cases of refrigerant leakage, and are similar to findings of the German study (Birndt 2000).

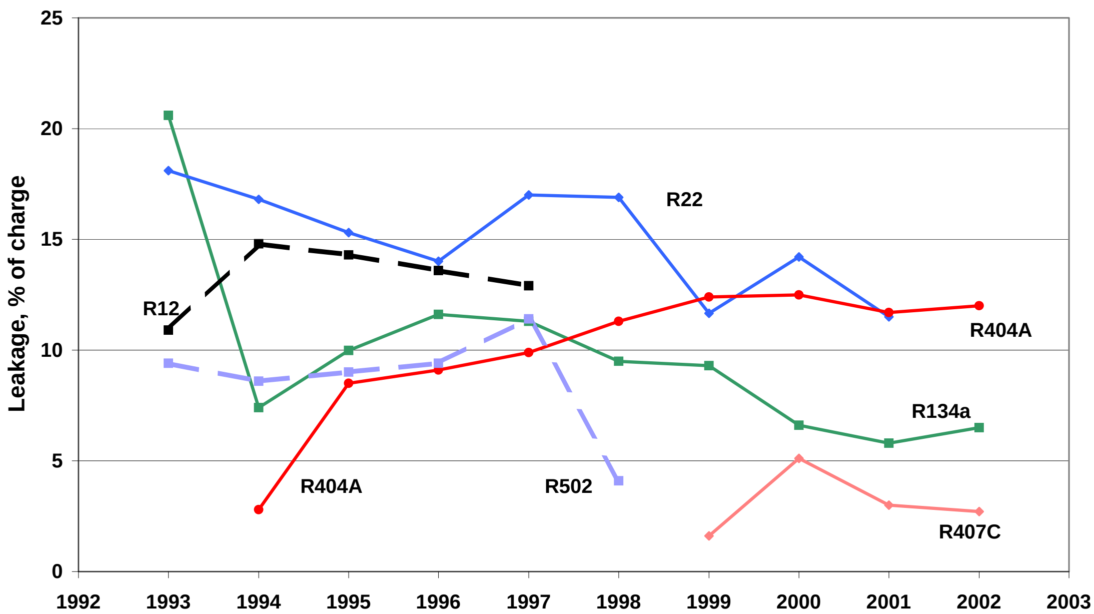

Fig. 2. Swedish supermarket company annual refrigerant leakage as % of system charge.

In Denmark, the Danish Environmental Protection Agency reports that new commercial refrigeration systems have become more leak-proof through quality improvement efforts of three refrigeration associations. Whereas refrigerant losses were earlier 20-25% of refrigerant charge per year, the new systems are at approximately 10% loss per year (Pedersen 2003).

In Norway, a Norwegian company of 220 supermarkets provided refrigerant fill data for the time period of 2002 – 2003, showing annual refrigerant losses of 14% of the total bank of refrigerant contained in their supermarkets (Neksa 2004). Indirect systems with secondary loop heat transfer fluids are increasingly used in Norway.

1.2 Refrigerant Emissions – Perspective and System Design Options

Refrigerant emissions data for commercial refrigeration systems as reported in the previous section vary from 3% to 22% of refrigerant inventory on an annual basis. The four sets of United States data for three regions of supermarkets in the time period of 2000-2002 showed emissions rates of 13%, 18%, 19%, and 22%. Reported European supermarket annual leak rates are at lower values, from 3% in The Netherlands, to 5-10% in Germany, 10% in Denmark and Sweden, and 14% in Norway.

The global refrigerant emissions rate for commercial refrigeration systems was reported at 30% of system charge per year (Palandre et al. 2004), in contrast to the lower values reported above. We expect there are several reasons for the differences. The United States and European data sets are not of sufficient size to be representative of all supermarket systems in the United States and Europe, and some companies not reporting may have higher emission rates. The short time period of some of the data sets may have resulted in non-representative refrigerant losses during end of equipment life refrigerant recovery. Finally, refrigerant recovery is not uniformly practiced in all parts of the world (UNEP 2002).

Studies described above have identified the main sources of refrigerant emissions, with recommendations for improved design, installation, and maintenance procedures, including more frequent use of leak detectors. A comprehensive description of practices and procedures to reduce inadvertent release of refrigerants has been published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. as ANSI/ASHRAE Standard 147-2002 (ASHRAE 2002).

There are additional routes to lower refrigerant emission rates which involve system design changes, such as distributed direct systems, indirect systems, and cascade systems. With the distributed system design, compressors are located in sound-proof boxes near the display cases, resulting in shortening of refrigerant circuit lengths and reduction of refrigerant charge by 75% versus the centralized DX system. Condensing units can be air or water cooled. With the close coupled system design, refrigerant emissions were assumed to be 4% of system charge on an annual basis (ADL 2002). Energy consumption is reported to be similar to that of the centralized DX systems (IEA 2003).

With the indirect system design (also termed secondary loop system), the refrigeration system cools a heat transfer fluid which is circulated to the display cases and cold storage rooms. This design permits refrigerant charge reduction of 75-85%. Fluorocarbon-based refrigerants are used in these systems, and if the refrigeration system can be located in a controlled-access room away from the customer sales area, indirect systems may also use flammable and/or toxic refrigerants, depending on systems safety design and safety regulations. Refrigerant emissions can be reduced to 4% of charge per year (ADL 2002) due to reduced refrigerant piping lengths and number of connecting joints. A publication on experience with indirect systems reports additional investment costs and lower energy efficiency than with DX systems (Haaf and Heinbokel 2002). Another publication (IEA 2003) indicates that well designed indirect systems may have energy efficiency close to that of direct systems.

Another version of the DX system is a cascade system with HFC refrigerant in the medium temperature stage and carbon dioxide as refrigerant in the low temperature stage. The condenser of the carbon dioxide stage is in heat transfer with the evaporator of the medium temperature stage. These systems have been tested in Europe since 2000, with system cost and energy efficiency similar to that of the centralized DX systems (Haaf and Heinbokel 2002). Depending on system design, HFC refrigerant charge reduction is about 50%, and annual emission rates about 5% of charge.

1.3 Supermarket Refrigeration System Energy Efficiency

LCCP of supermarket refrigeration systems can also be reduced by lowering energy consumption. Examples of designs for reduced energy consumption are floating condenser temperatures in which the condensing temperature follows the ambient temperature, evaporator design for more efficient defrosting, more efficient compressors, and economizer/compressor systems (Beeton 2003).

Another way to reduce the effect of supermarkets on the environment is to utilize heat recovery from refrigeration system condensers (IEA 2003, Engsten and Lindh 2004). A commercial demonstration program of an integrated heating, ventilation, air conditioning and refrigeration system is described on the website of National Resources Canada (NRC 2003). A 10,000 m^2 supermarket located in Repentigny, Canada is operating with a secondary loop refrigeration system integrated to the heating and ventilation system. The heat rejected by the refrigeration system condensers is recovered for heating demands of the store. This integrated system has reduced total energy consumption of the store by 18% compared with other recent supermarket installations, and a reduction of 75% in greenhouse gas emissions versus other store designs.

1.4 Supermarket Refrigeration Systems LCCP

The components of LCCP were included in calculations for a supermarket system reported by A. D. Little (ADL 2002). We have taken the basic example described in the report, and added several design options for supermarket systems. A 5,575 square meter (60,000 square foot) supermarket was analyzed using utility emission rate of 0.65 kg CO2 per kWh, yearly refrigeration energy consumption of 1.2 million kWh, and 15 year equipment life. A centralized DX system operating with R404A (or R507A) charge of 1636 kg and refrigerant emission rate of 30% per year was initially assumed. Refrigerant manufacturing GWP, 100 year ITH, was taken as 18, for a total GWP of R404A of 3278.

Several system design changes beyond the baseline system were evaluated for LCCP.

- DX system with 5% annual leak rate as demonstrated in Germany and The Netherlands.
- DX system with 5% annual leak rate and refrigerant charge size reduced 40% by critically charging the system.
- DX system with 5% annual leak rate, critically charged with refrigerant R404A, and energy consumption 10% lower than baseline DX system.
- Distributed system with 4% annual leak rate and energy consumption same as DX system; refrigerant charge size 25% of DX.
- Secondary loop system with 4% annual leak rate; primary refrigeration system charge size 11% of DX, energy consumption 15% higher than DX system, R404A primary refrigerant
- Secondary loop system as previous, but with ammonia or hydrocarbon as primary refrigerant
- Secondary loop system same as two previous, but with energy consumption only 5% higher than DX system.

The varying conditions chosen for the options in the LCCP table are based on literature reports. As one example, Haaf and Heinbokel 2002 have reported data from 77 supermarkets installed with secondary loop systems. The secondary loop systems had installed costs 15-35% higher than DX systems, and energy consumption 5-20% higher than DX systems.

Table 2. LCCP of supermarket refrigeration system design options

		Energy	**LCCP, million kg CO2**		
Configuration	**Leak Rate**	**Consumption**	**Indirect**	**Direct**	**Total**
DX, 1636 kg R404A	30%	Baseline	11.7	24.2	35.9
DX, 1636 kg R404A	5%	Baseline	11.7	4.0	15.7
DX, 982 kg R404A	5%	Baseline	11.7	2.4	14.1
DX, 982 kg R404A	5%	-10%	10.5	2.4	12.9
Distr, 409 kg R404A	4%	Baseline	11.7	0.8	12.5
Sec Lp,180 kg R404A	4%	+15%	13.5	0.4	13.9
Sec Loop, NH3 or HC	4%	+15%	13.5	0	13.5
Sec Lp,180 kg R404A	4%	+5%	12.3	0.4	12.7
Sec Loop, NH3 or HC	4%	+5%	12.3	0	12.3

It is recognized that the LCCP values in Table 2 are based on several assumptions such as utility fuel source and CO_2 emissions rate, and overall system design and performance. There can be differences due to country-specific utility fuel sources, and the state of refrigeration system technology such as laboratory or commercial system demonstrations. The main purpose of the Table is to illustrate the potential magnitude of changes in LCCP for several improvement options. The data show that LCCP can be reduced by over 60% with the options.

Research is underway in many countries to reduce LCCP of supermarket refrigeration systems, with expectations for additional improvements in the systems described above, in cascade systems, more energy-efficient refrigeration system designs, and in integrated refrigeration, heating, ventilating, and air conditioning systems. Tests of carbon dioxide as the only refrigerant in commercial refrigeration systems are also underway (Schiesaro and Kruse 2002, Girotto, et al. 2003).

2 CONCLUSIONS

Refrigerant emission rates from a limited number of supermarket organizations in the United States and Europe were in the range of 3%-22% of refrigerant system inventory on an annualized basis, contrasted with the worldwide estimate of 30% for commercial refrigeration systems. The lower emissions were a result of programs directed toward design of tighter systems, and more attention to installation and preventive maintenance procedures, leak checking, and refrigerant accounting. Additional refrigerant emission abatement options include use of distributed, secondary loop, and cascade systems. System energy efficiency improvement options promise decreased energy consumption of 10-20%. Initial investment costs, operating costs, and energy consumption are important factors in considering the several system options. LCCP calculations show the importance of energy efficiency, refrigerant charge size, and refrigerant emissions in reducing the climate change impact of supermarket refrigeration systems, with opportunities to reduce climate change impact by over 60%.

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