Demand-Side Management Strategies for Commercial and Industrial Refrigeration

Martha J. Hewett and Russell W. Landry, Center for Energy and Environment
Sharon Scheckel, Northern States Power Company

Refrigeration is a significant end use in the commercial and industrial sectors, yet has received little attention in DSM programs to date. In this research, we undertook a comprehensive assessment of refrigeration technologies in terms of savings potential, current market penetrations, and acceptability to customers and trade allies. Savings potential was determined through critical review of published research and interviews with researchers, major equipment manufacturers and refrigeration engineers. For the commercial sector, market penetration and customer acceptability were determined through structured interviews with major equipment manufacturers, contractors and supermarket chains, while for the industrial sector, they were determined through focus groups with vendors, design engineers and customers. For the commercial sector, the DSM opportunities identified which were cost effective and had low current market penetrations included unloaders, mechanical subcooling, and external liquid-suction heat exchangers for compressor systems, and high efficiency fan motors and lamps for display cases. For the industrial sector, the DSM opportunities with low market penetration included: close approach condensers, close approach evaporators, floating head pressure below defrost pressure, spray cooling of booster compressor discharge gas with liquid recirculation system bypass, and increased insulation levels. Several DSM strategies other than rebate programs were also identified as being appropriate for encouraging refrigeration energy efficiency.

Some of the measures rebated by current utility programs were found to have high market penetrations already. Others were found to have limited potential due to system interactions which had been inadequately addressed in published analyses. A number of innovative measures face market resistance which can only be overcome by understanding the interrelationships of decision-makers in this sector and meeting their needs for demonstrated savings and reliability.

In both the commercial and industrial sectors, a standardized rebate program with custom adjunct was preferred over a custom program by customers and trade allies. In both sectors, program marketing must target trade allies heavily, both because they have a very strong influence on customers' acceptance of new equipment and designs and because they are better able to grasp the technical aspects of the program. In the commercial sector, a very small number of food wholesalers and retailers control the specifications for almost all new supermarkets and are also crucial to program success.

Introduction

Refrigeration is estimated by EPRI to account for about 16 to 18% of commercial sector electricity use, and has a load profile very similar to the average U.S. electric load profile (Khattar and Knight 1992). The utility for which this work was done estimates that refrigeration accounts for about 10% of its commercial sector sales and about 2% of its industrial sector sales.

In spite of its significance, refrigeration has received little attention in DSM programs to date. A survey of 40 of the 45 utilities which address refrigeration in their DSM programs (Hewett et al. 1993) indicated that only ten of these utilities had standardized rebates for refrigeration, while most simply included it in a catch-all custom program. The ten utilities operated 12 standardized refrigeration rebate programs, eight of which had been started in 1990 or later. A great variety of measures were rebated, and, in contrast to other end uses such as lighting, there was little consistency in measures rebated across programs. Most programs rebated one to six measures.

Thirty-eight utilities operated 51 custom programs which covered refrigeration, though none of these served refrigeration exclusively. Two-thirds of the custom programs had started in 1990 or later. A wide range of measures had been rebated. Of 63 total programs, only 12 had more than ten refrigeration participants.

The utility for which this work was done has operated a refrigeration rebate program since 1990, focused primarily on supermarket refrigeration and covering high efficiency compressors, parallel compressor rack systems, mechanical subcooling, and glass-door retrofits for low temperature refrigerated display cases. As of early 1993, the program had approximately 75 participants. In 1992, the utility began a comprehensive market and technology assessment to identify its key refrigeration customers, identify DSM opportunities and their current market penetrations, and explore customer and trade ally perceptions of various DSM measures, economic criteria, and other factors. This market assessment addressed both commercial and industrial refrigeration.

The commercial portion of the project focused on supermarkets, both because they use about three fourths of commercial sector refrigeration energy (Khattar and Knight 1992) and because they offer more technical potential and fewer institutional barriers than convenience stores. A typical supermarket has annual energy use of 400 MWh or more annually, of which about 60% is refrigeration. A typical new store in the utility's service territory occupies 35,000 to 45,000 square feet. The refrigerated areas include frozen and fresh food display cases, walk-in coolers, and meat, produce and deli preparation areas. The refrigeration compressors are located in a central machine room, and the condensers, almost always air-cooled, may be outside or in the machine room. Older stores may have individual compressors for each display case or case line-up, but newer stores have groups of compressors piped in parallel, each serving a group of loads with the same or similar evaporator temperature (and therefore suction pressure) requirements. Supermarkets have generally used CFC-12 or HCFC-22 for medium temperature applications and CFC-502 for low temperature applications, but are currently switching to HCFC or HFC refrigerants. HCFC-22 is the most heavily used for medium and low temperature applications today, but it is anticipated that new HFC refrigerants will be used as they become more readily available.

Industrial refrigeration end-users represent a diverse market. The food industry-including beverage, vegetable, turkey, dairy and meat processing plants, as well as refrigerated warehouse/distribution centers—is a major market segment for the utility's service territory, and other significant end-users in the market include the chemical industry and indoor ice arenas. These diverse applications exhibit a variety of seasonal usage patterns. Industrial refrigeration systems usually employ ammonia as the refrigerant with HCFC-22 as the second most common refrigerant. The typical industrial refrigeration system has multiple compressors piped in parallel to serve many evaporators that are used to provide process or space cooling at more than one temperature level. The refrigeration system also usually uses one or more evaporative condensers on the roof to reject heat into the atmosphere. Although some systems may be sold as a nearly complete package (especially for smaller applications), most systems are custom designed with each major component purchased separately.

Methodology

The technology and market assessments involved four primary objectives:

1. Identify potential DSM technologies and system design strategies,

2. Assess current market penetration and identify market barriers for each measure,

3. Estimate approximate energy and demand savings potential and costs for each measure,

4. Determine appropriate DSM program characteristics.

The methods and resources used to achieve each of these objectives are described below. Secondary objectives included identifying important refrigeration trade allies and customers and cultivating positive relationships between key industry professionals and the utility.

Identify Potential DSM Measures

Supermarket DSM measures were identified through two complementary approaches. The first involved critical review of published research and discussions with principal investigators of both published research and research in progress (Borhanian 1992, EPRI 1992a, b and c, 1991a and b, 1990, 1989, Hill and Lau 1993, Holtzapple 1989a, b and c, Howell 1993 a and b, Mitchell (pers. comm. 1992), NYSERDA 1992, Copeland 1991, 1992a,b, Tollar 1992).

The second involved very extensive discussions with technical staff for major manufacturers of refrigeration equipment, including compressors, refrigerated display cases, display case doors, condensers and evaporators, refrigerant, and controls and peripheral equipment. This was a necessary complement to the review of published research because of limitations of the available research in terms of DSM measures analyzed, climates in which these measures have been tested or modeled, and assumptions about the configuration of the refrigeration system. Notable among these assumptions are the refrigerants: many of the measures have been tested and modeled by researchers only on CFC or HCFC refrigerants that will be phased out over the coming years. Contacts from the major manufacturers were also able to provide other extremely useful information, as described later.

Since very little published research on industrial refrigeration DSM measures exists, a wide variety of information sources were used. A preliminary list was based on program literature from the sole utility that had already developed an extensive program addressing industrial refrigeration. This list was then modified based on input from two design consultants and a number of manufacturers' representatives. Further additions and changes were made after reviewing reference texts on the subject of industrial refrigeration and articles published in various trade journals and literature. This revised list was then used as a basis for interview questions with trade allies and customers (described further in the next section). Some additional modifications were made based on their input, which was obtained by asking (after discussing technologies on the list) if there are any other energy saving technologies that they use or have heard about.

Assess Current Market Penetration and Identify Market Barriers

Current market conditions have a significant effect on the net cost-effectiveness of DSM programs. Both the market share in new facilities and the market penetration in existing facilities must be assessed to determine which efficient technologies have low enough current rates of utilization to warrant DSM incentives.

The major manufacturers mentioned above were able to provide valuable information on national market shares of a number of technologies and design strategies in new supermarkets.

Information on market shares in new supermarkets in the utility's service territory was obtained through face-to-face interviews with technical staff for the six key food wholesalers and retailers in the area, identified through Progressive Grocer's *Marketing Guidebook* (1992). From discussions with the four major wholesalers we learned that their technical design specifications are used not only for new stores they own or franchise, but also for new stores opened by independent retailers for whom they are the principal wholesaler. The exceptions are two small (8 to 9 store) retail chains who have their own specifications. Thus four wholesalers and two retailers control the technical design of virtually all new supermarkets in the area. These six decision-makers are critically important players in the success of DSM efforts.

The wholesalers had no systematic records and limited sense of the market penetrations of various DSM features in existing supermarkets, except in some cases their corporately owned stores. Market penetrations in existing supermarkets were therefore estimated more approximately, based primarily on face-to-face interviews with the two contractors who represent 90% of the supermarket refrigeration installation/remodeling business in the area and about 50% of the service work. These estimates were supplemented with information from the wholesalers and retailers.

Customers' and trade allies' awareness of various DSM measures and perceptions about them can have a marked effect on the success of DSM programs. Perceptions about a wide range of potential supermarket DSM measures were gathered from all of the sources just mentioned. The opinions of the four major display case manufacturers turned out to be particularly important, since the overwhelming preference of the wholesalers and retailers in the utility's service territory is to buy "turnkey" refrigeration systems designed by these manufacturers, and since nearly all reported that they rely very heavily on these original equipment manufacturers (OEMs) for recommendations on efficiency measures. This probably reflects both the general trend away from retaining extensive inhouse engineering staff in the supermarket industry and the great conservatism about new technologies driven by the overriding concern for preservation of valuable refrigerated merchandise. The retailers also value contractors' opinions highly, since they rely heavily on them to keep equipment operating, so contractors' perceptions of various efficiency measures will also have a major impact on program success.

Because of several characteristics of the industrial refrigeration industry, it was deemed most appropriate to use trade allies-instead of customers—as the main information source regarding market penetration and barriers for the various technologies. The number of the utility's industrial refrigeration end-users was estimated to be several hundred, scattered over a wide variety of industries, and the expense required to identify and interview a representative sample of these customers would have been substantial. On the other hand, there is a relatively small number of contractors and designers that do industrial refrigeration work—both locally and nationally. While many of the existing facilities would not have been constructed recently enough for the customers to provide information relevant to new facility design, the trade allies had knowledge of both current design practice and what can be found in existing plants. A majority of design work is done by a contractor or consultant (rather than by the end-user) so they were expected to have more detailed knowledge about various technologies (and they are in a strong position to influence design choices).

Two main approaches were used in obtaining trade ally input for industrial refrigeration. First, manufacturers' representatives, locally based contractors, and a local consultant were invited to a group meeting. This format was chosen for these interviews so that the participants would tend to be more objective and unbiased, since each representative's competitors would also be involved in the discussion and would be expected to object to any 'questionable' claims. Each meeting participant was sent preliminary program information in advance so that feedback regarding this information could be obtained. The group was asked about typical design practice for many system components and about problems associated with the efficient technologies.

The second approach was to conduct telephone interviews of design/build contractors and design consultants who do industrial refrigeration work throughout the region or the country. Initial discussions with consultants and trade allies had indicated that a large amount of local industrial refrigeration work is done by designers and contractors based outside the utility's service territory, and that the industrial refrigeration industry is made up of a relatively small number of firms which operate regionally, nationally, or internationally. Because of this, it was considered necessary to talk with a number of regional and national firms to get a clear picture of what the typical design of a new facility in the utility's service territory would be. The appropriate person at each firm was asked about the following issues for many of the DSM measures identified: (1) their current design practice, (2) what their experience has been, and (3) why they are not used more.

Trade ally input was also obtained during a short-course on industrial refrigeration that was presented by a variety of industry professionals. Finally, in order to provide a reality check on information provided by the trade allies, plans for a small number of recently built facilities were reviewed to see what options were incorporated into the designs.

Estimate Energy and Demand Savings Potential

The commercial portion of the project specifically excluded any new work to estimate energy and demand savings from refrigeration DSM measures through field testing or modeling. Estimates were therefore assembled from published research, research in progress, and estimates made by manufacturers and other experts.

Cost and savings estimates were made for a number of industrial refrigeration measures that appeared to be good DSM opportunities. A consultant who had worked with other utilities on DSM programs for industrial refrigeration was hired to provide initial estimates of energy and demand savings, as well as incremental costs for a number of DSM measures. The energy and demand savings estimates were based on engineering calculations that took into consideration local weather conditions and assumptions about typical design, the order in which different measures would be applied, and load variations (the estimated load of a cold storage warehouse was applied). Initial estimates of incremental costs for various measures were based on price quotes from various contractors and vendors.

The initial cost and savings estimates were then sent to trade allies prior to the group meeting, and feedback regarding the accuracy of the estimates was obtained during the meeting. In addition, a number of the regional and national firms were asked about costs and savings for various measures during the telephone interviews. Finally, additional calculations and contacts with manufacturers and contractors were made to fill information gaps for technologies that were either not included, lumped together, or had incorrect baseline design assumptions in the initial estimates.

Determine Appropriate DSM Program Characteristics

The utility already operated a commercial refrigeration rebate program which had enjoyed reasonably good participation, so the commercial portion of the project did not focus heavily on DSM program design, though some insights were gathered in the course of other work.

Recommendations for industrial rebate characteristics, as well as program options other than rebates, were developed by synthesizing information from a variety of sources. The goal was to answer such questions as: how strict should the technical requirements be; how should the program be marketed; should the utility have a staff person available to do energy audits or give end-users money to have an audit performed; would electric utility loans to customers have a big impact on participation; should operator, contractor, or designer training be included; what are the industry's typical economic criteria for energy efficiency investments; and should the utility pay for test installations to demonstrate the viability of promising technologies.

One source of information was a survey of existing refrigeration DSM programs and program literature obtained in carrying out the survey (Hewett et al. 1993).

This information was augmented by asking trade allies who had worked with another utility's extensive industrial refrigeration rebate program for their opinions. Two other sources of information that were used to obtain insight into these questions from the utilities' perspective were relevant published papers about industrial DSM programs and discussions with some of the utility's service representatives.

Of most importance, information relevant to program design issues was obtained from discussions with industrial refrigeration trade allies and customers. Besides providing information that is useful in developing a better program, these efforts to obtain and incorporate input from people in the industry cultivated positive relationships with key industry professionals. This should make the program much easier to market successfully. Trade allies were asked questions related to program design issues both during the group meeting and during the individual telephone interviews. Two customer group meetings were also held to obtain input on these same issues, In addition, utility service representatives were asked about various program design considerations.

Results

Commercial Sector

Recommended Measures. Nine technologies were identified for inclusion in the utility's enhanced commercial refrigeration program (Table 1).

Table 1. Measures Recommended for Inclusion in NSP's Commercial Refrigeration Rebate Program

DSM Measure	Energy Savings (1)	Peak Demand Savings (1)	Market Penetration: National, New Constr	Market Penetration: Local, New Constr	Market Penetration: Local, Existing Stores
Compressors and Compressor Systems					
high efficiency replacement compressors (non-CFC only)	16% (2)	not est	92 to 96%	95 to 100%	20 to 25%
uneven parallel rack system retrofits	15% (3)	not est	90%	100%	60%
unloaders on lead compressor of parallel rack system	3 to 5% (2,4)	3% (4)	not est	apparently uncommon	apparently uncommon
Subcooling Strategies					
mechanical subcooling (LT, VLT)	1 to 7% (3,4,5,6)	1 to 6% (4,5,6)	40%	20 to 40%	10 to 15%
internally compounded two-stage compressors with intercooling and subcooling, R22	6% (6)	11 to 12% (6)	low	low	low
large external liquid to suction heat exchangers, LT, VLT	1 to 10% (2,3,4,6)	4% (4,6)	low	0%	<5%
Display Cases					
T8 lamps and electronic ballasts in display cases	not est	not est	low (8)	low	low
high efficiency evaporator fan motors	6% (4)	4% (4)	17 to 20% (7)	20 to 30%	<20%
glass door display cases (MT)	10% (4)	11% (4)	<5%	<5%	<5%

MT = medium temp (fresh food)
LT = low temp (frozen food)
VLT = very low temp (ice cream, juice)
(1) Percent of refrigeration energy use or peak demand.
(2) Manufacturer's estimate.
(3) EPRI 1991a
(4) EPRI 1992a
(5) EPRI 1990
(6) EPRI 1992c
(7) EPRI 1992b
(8) only recently available

Rebates for high efficiency compressors and uneven parallel rack systems were limited to retrofit applications only, due to their high market shares in new stores locally and nationally. Rebates in retrofit applications were retained because the impending mass conversion of supermarkets to non-CFC refrigerants offered a unique opportunity to accelerate upgrades to high efficiency equipment. Rebates were recommended for compressor unloaders, which decrease compressor capacity and improve control of suction pressure under low load conditions.

Subcooling liquid refrigerant (lowering the temperature below the saturation temperature) before it enters the evaporator increases the refrigeration effect (cooling per unit mass of refrigerant), increases efficiency, and decreases flash gas formation. Three subcooling strategies were recommended for rebates based on EPRI field tests and modeling: mechanical subcooling, internally compounded two-stage compressors with intercooling and subcooling, and large external liquid to suction heat exchangers.

Input from trade allies suggests that these subcooling strategies will encounter some marketing obstacles. While two of the four major display cases OEMs promote mechanical subcooling nationwide and use it in most of their low temperature systems, the other two use it in only 10 to 15% of their systems and feel it is not cost-effective in cooler climates, where significant subcooling is achieved naturally in the condenser during much of the year. Local contractors tend to follow the lead of the OEM whose equipment they install, so those working with the latter two manufacturers tend not to use mechanical subcooling. Internally compounded compressors not only are perceived as somewhat more complex than single stage compressors, but also are produced by a manufacturer with a significantly lower overall market share, apparently due to a less extensive distributor network which makes them somewhat less able to provide quick replacement equipment. Large external liquid to suction heat exchangers have been shown to be highly cost-effective in EPRI-funded modeling and field tests, and are currently being rebated by several utilities and used by at least one very large chain on the basis of these results, but the OEMs on a national level do not think the savings are significant. Contractors in this utility's service territory have had problems with these devices in the past and have strong negative opinions of them. To generate significant response to rebates for these subcooling measures, demonstration projects may be necessary to verify savings for local conditions and to overcome negative trade ally perceptions.

Several display case measures were recommended for inclusion in the enhanced program. Typically display cases have used high output and even very high output lamps; display case doors with built in T-8 lamps and electronic ballasts have only recently become available. The efficient lamps reduce lighting energy, reduce the refrigeration energy required to reject the heat generated by the lamps, and are mounted in the door mullion to reduce the need for anti-sweat heaters. These new doors also provide exceptionally even product lighting and are extremely popular with merchandising staff. High efficiency (permanent split capacitor) evaporator fan motors use half the energy of standard (shaded pole) motors, and are currently being rebated by several utilities. Unfortunately, contractors and customers experienced high failure rates with the first generation of high efficiency fan motors for display cases and have moderately to strongly negative opinions of them. Failures have since been greatly reduced by moving the capacitors to a drier location inside the motor housing, and at least two extremely large (1000 to 2000 store) supermarket retailers nationally include them in their standard specifications. Here again, a demonstration projector comparison test may be needed to overcome local market barriers. Reach-in cases for medium temperature applications have sound energy economics and deserve a rebate, but low utilization of these rebates is expected due to merchandisers' resistance.

Future opportunities. A number of technologies were identified for which the economics were uncertain. These included:

- very low head pressure systems,
- alternative compression and subcooling systems for HCFC-22 low temperature applications,
- low relative humidity store design,
- close-approach air-cooled condensers,
- high efficiency glass doors for display cases,
- temperature-terminated defrost,
- floating head pressure operation for stand-alone compressor systems in small stores (with unloaders and balanced port valves),

Very low head pressure (VLHP) systems allow the condensing temperature to float down to 45°F to 60°F in cool weather, reducing the compressor work and improving efficiency. VLHP had been identified as highly cost effective in several studies done for EPRI and is rebated by at least two utilities on this basis. However, these studies did not take into account increases in other fuel use for space heating, due to reduced reclamation of refrigeration waste heat, nor did they take into account the fact that electricity savings may be reduced below those modeled by the need to boost head pressure during defrost cycles. A more recent study for EPRI (1992a) addressed the first of these issues, but contained calculation errors (excluded costs, incorrect savings) which made the technology appear considerably more cost-effective than it appears when these errors are corrected. In addition, the analysis for new construction only compared low head systems to fixed head systems without heat reclaim, though few if any stores are built this way. When compared with fixed head systems with heat reclaim, the corrected analysis shows the fixed head systems to be more cost effective than the VLHP systems. Another information gap is that existing analyses of VLHP have looked only at CFC-502 low temperature systems. The HCFC-22 low temperature compressor systems available vary considerably in their relative performance as a function of head pressure, so VLHP economics need to be analyzed for each of several different HCFC-22 compressor systems available. The baseline level of natural subcooling as a function of climate zone also needs to be better quantified. HCFC-22 and HFC simulations for cold climates and for fixed head, floating head, and low head operation would provide a better basis for decision-making on both head pressure control and HCFC-22 compression and subcooling options. In spite of these problems, VLHP warrants further investigation. There is a recent trend away from heat reclaim in the utility's service territory due to the increasing cost of the additional refrigerant charge required, and local contractors and wholesalers are interested in better information for decision-making.

Recent research has reconfirmed that store humidity has a large impact on refrigeration energy use (Howell 1993a and b). In addition, there is considerable concern about relative humidity among local contractors and customers, and interest in better control of humidity levels. However, the net impact of humidity on store energy use in northern climates is still poorly quantified, due to insufficient information on actual annual humidity profiles in supermarkets in cold climates, and on the air conditioning system energy penalty incurred in achieving low relative humidities. Field data collected by Hill and Lau (1993) indicate that dehumidification is rarely an issue in cooler climates outside the five cooling months, and modeling by John Mitchell (University of Wisconsin, personal communications to M.J. Hewett, 1992) shows annual savings in total store energy use of only about 5 to 6% in climates similar to the utility's service territory. Savings depend on adjustment of anti-sweat heater control and defrost control to take into account the reduced humidity. In addition, cost-effective control requires proper infiltration and ventilation control and proper distribution system design, not just specialized HVAC equipment. It is therefore somewhat difficult to establish rebate qualifying criteria, and savings are hard to assure unless monitoring is done to confirm performance (as is done by at least one utility). The utility is working to close information gaps in this area through its participation in EPRI's heat pipe field tests.

Air-cooled condensers designed to operate at a small difference in temperature between the condensing temperature and ambient air are rebated by another utility which is a leader in refrigeration DSM. While reducing head pressure lowers compressor energy, net savings will only be achieved if fan energy losses can be kept to a minimum. Optimum control of the various fan stages is also a factor in overall energy savings. The utility decided to incorporate this measure in their program based on the other utility's work.

Manufacturers of glass doors for display cases offer a range of door efficiencies, and at least one utility offers a rebate for high efficiency doors. However, major display case OEMs indicated that they do not offer their customers a choice of door efficiencies. The products the OEMs currently use do not meet the requirements of this one utility, and these OEMs' experience is that the more efficient doors do not perform satisfactorily in terms of condensation control. Though not readily available on display cases, the efficient doors are available as separate units for installation on the display side of site-built walk-in coolers commonly used in convenience stores and warehouse stores. The utility doing this project decided to incorporate this measure in their program based on the other utility's work.

Stand-alone compressor systems are not normally operated with floating head pressure, because the large increase in capacity at low loads causes short-cycling. Recent analyses (EPRI 1992a) indicate that floating head combined with compressor unloaders will operate successfully and is cost-effective for stores too small to use parallel rack systems. This may offer an opportunity for significant energy savings at the time of refrigerant conversion for these smaller stores.

A number of technologies which are in the R&D phase or early phases of commercialization should be monitored, so that they can be considered for incorporation if energy savings are demonstrated and products become commercially available. These include:

- screw compressors,
- scroll compressors,
- demand defrost control,
- evaporative condensers for northern climates,
- overall display case rating systems,
- superheat suppression.

The screw and scroll compressors currently under development do not have a design goal to achieve significant energy savings over reciprocating designs, but it is possible that they may. Current research for the New York State Energy Research and Development Authority (NYSERDA) (Borhanian 1992) and ratings by manufacturers should be monitored as they become available.

Demand defrost control has long been a goal for display case OEMs but has never been successfully commercialized due to problems with variable frost loading in cases, sensor technology, cost and other factors. Commercialization of the control recently developed for NYSERDA (1992) and any other demand defrost controls should be monitored.

Evaporative condensers currently available do not appear cost-effective for northern climates (see below). Current research by NYSERDA, aimed at developing a unit specifically for northern climates, should be tracked.

Canada is currently attempting to develop a uniform rating system for commercial refrigeration display cases. An overall rating would provide the most meaningful, consistent basis for rebating display cases, avoiding the inconsistencies that can arise when rebates are given on a component basis. While the process of developing a rating system has been a trying one for the manufacturers, the ultimate result may be of considerable value. The utility will need to monitor the progress of the Canadian effort.

Superheat suppression is available as an add-on to liquid line pumping systems, and engineering calculations indicate small savings (Holtzapple 1989a, b, c).

Measures Not Recommended for Incentives. A large number of items were investigated which proved not to be cost-effective rebate targets. A number of these measures are cost-effective for customers but already have such high market penetration that the societal benefit of a rebate program would be small (Table 2).

Many other measures do not appear to be cost-effective to customers in the utility's climate, based on available research. These include:

- open reciprocating compressor rack systems (Copeland 1992b),
- evaporative condensers,
- remote evaporative subcoolers,
- evaporative precoolers,
- dedicated ambient subcooling coils,
- external liquid to suction heat exchangers for medium temperature applications,
- mechanical subcooling for medium temperature applications,
- conversion to new HFCS for energy savings alone,
- use of outdoor air economizers for winter cooling of walk-in coolers.

Table 2. Measures Not Recommended Due to Current High Market Penetration

	Market Penetration		
DSM Measure	**National, New Constr**	**Local, New Constr**	**Local, Existing Stores**
floating head pressure	70 to 80%	70 to 80%	30 to 40% (1)
refrigeration waste heat recovery for service hot water	not est	>60%	not est
air conditioning waste heat recovery for supply air reheat	not est	90%	not est
gas defrost	60 to 70%	100%	60 to 80%
anti-sweat heater control	not est	>90%	75 to 85% (2)
glass door display cases (LT, VLT)	75 to 85% (3)	70 to 80% (3)	70 to 80% (3)
low TD evaporators for very low temperature cases	100%	100%	not est

(1) Floating head pressure is used in essentially all stores with parallel rack systems. Floating head pressure is more difficult to implement in stores with stand-alone compressor systems (see EPRI 1992a for details).
(2) Percentage given is percent of stores with reach-in cases. Other types of cases do not have significant amounts of controllable defrost heaters.
(3) Percentage given is percent of multideck cases (excludes single deck coffin/bin cases).

Two of these in particular deserve further comment. Evaporative condensers have been recommended in several studies (EPRI 1991a,b, 1992a) for utilities in northern climates. However, these analyses variously overlooked heat reclaim interactions, had computational errors, or looked at overall economics of evaporative condensers with packages of other measures rather than the marginal economics of evaporative condensers versus air-cooled condensers with the same package of measures. In addition, the water costs may have been underestimated. Given local concerns about maintenance, it does not appear that the marginal economics warrant a rebate.

Conversion to the new HFCs is not expected to substantially increase or decrease energy use, if the same equipment is used (Copeland 1991, 1992b, Tollar 1992). It may offer an opportunity to accelerate adoption of efficient technologies.

For specific reasons, a handful of other measures are also low priorities for rebates, including:

- variable speed drive on parallel rack systems,
- strip curtains for walk-in boxes,
- separation of low temperature and very low temperature walk-in freezers,
- high efficiency unit coolers (heat exchangers for walk-in boxes).

Variable speed drives on the lead compressors of parallel rack systems accomplish the same general goal as unloaders (although they also increase energy use at full speed due to converter losses), but at a much higher cost. Display case OEMs have experienced high failures, lifetimes shorter than the payback period, and electronic interference with store scanning systems used for checkout and inventory control and are not at all enthusiastic about them. Upcoming NYSERDA field tests of VSD on rack systems should be monitored. In the meantime, the utility decided to offer rebates to put VSDs on a level playing field with unloader technologies.

Strip curtains for walk-in coolers are cost-effective in principle, but local wholesalers and retailers indicate that they are cut off or tied back by employees so often that they are not worthwhile. Separation of low temperature and very low temperature walk-in freezers could reduce energy use, but customers indicated that the value of floor space is so high that they would not be willing to do it. No third party testing and certification of unit coolers is available, and ratings are reported to be so inconsistent across manufacturers that rebates could not meaningfully be established.

DSM Program Characteristics. As mentioned previously, the utility already operates a commercial refrigeration rebate program which has had good participation, so the commercial portion of the project did not focus heavily on DSM program design. In response to specific questions, trade allies and customers reconfirmed their preference for standardized rather than custom rebates, as long as the standardized rebate program stays abreast of changes in technologies. Reasons for disliking the custom approach included the cost and time involved in assembling documentation for a custom rebate, the uncertainty as to whether a rebate will be given, potential inequities across participants in awarding custom rebates, and the perception that the utility has not taken the time to understand the sector and determine what is worth rebating. Some respondents were interested in a custom program as an adjunct to standardized rebates.

Customers were enthusiastic about the utility's recent offer to review the designs for new stores, but were not very interested in its financing program.

Other key findings relating to program design, discussed in more detail earlier, were (1) that four wholesalers and two retailers control the technical design of virtually all new supermarkets in the area, (2) that the opinions of the four major display case manufacturers are particularly important, since the overwhelming preference of wholesalers and retailers in the area is to buy "turnkey" systems designed by them, and (3) that the opinions of a handful of key contractors are highly valued by retailers, who rely heavily on them to keep equipment operating. To be successful, a supermarket DSM program must work very closely with these small but extremely important groups of customers and trade allies.

Industrial Sector

Potential DSM Measures Identified. More than 50 technologies and design options were identified which affect the energy use of industrial refrigeration plants. While a majority of the measures are applicable to many types of industrial refrigeration facilities, a number of others are applicable only to certain types of facilities, or have relative costs and savings that vary widely for different applications. Although many of the DSM technologies involve more than one part of the system, the measures were categorized into the following groups:

- Condenser technologies,
- Evaporator technologies,
- Compressor technologies,

- Refrigerated space, process, or miscellaneous technologies.

Each of these categories had roughly the same number of measures.

Market Penetration and Barriers for DSM Measures. The determination of current market penetrations provided useful information regarding which measures are already being installed most of the time, which measures are installed in some cases, and which measures are almost never used. Table 3 shows the rough market penetrations for condenser technologies. Based on the market penetration findings, it was recommended that the new construction rebate program have minimum requirements that include a large number of the measures that already have high market penetrations (although exemptions should apply to many of the measures which are not generally applicable). In other words, the design must include these measures before a rebate can be received for anything. Conversely, it was recommended that many of the measures with moderate or low market penetrations be considered for inclusion in a rebate program (if they pass a cost-benefit analysis screening).

Savings and Costs for DSM Measures. Table 4 shows a sample of the energy savings, demand savings, and cost data for measures that were recommended for rebate program consideration. Customer and utility cost-benefit analysis was beyond the scope of this project, but was subsequently performed by the utility for a number of measures. It should be noted that the values vary with local climate conditions and applications (the values in the table are for a cold storage warehouse/distribution center). One of the key factors is the temperature of the refrigerated space (or process being cooled). An example of this effect can be seen in Table 4 for close approach evaporative condensers.

The wide variation in costs and savings for different applications suggests that the utility take one of two approaches: (1) Offer a 'custom' rebate program where the rebate for each facility is based on the costs and savings evaluated for that particular application; or (2) Have a prescriptive program that has different rebate amounts for different temperature levels (either a table with values for different temperature levels or a sliding scale calculated using a formula). While using a custom program would require less up-front work by the utility (to do cost-benefit analysis and prepare literature), it would require more work later on—by both the utility and the customer or designer—to review the design and determine the appropriate rebate amount for each project. Another factor is that although a custom program's flexibility allows it to take into account application-specific circumstances, it can also be perceived as unfair because different facilities could get different rebate amounts for installing the same measure.

DSM Program Characteristics. One of the most important results regarding rebate program design is that for a program to effectively move the market towards

Table 3. New Construction Market Penetration for Condenser Measures

DMS Measure	Market Penetration
Floating head pressure	high
Automatic purger on negative pressure system	high
Evaporative condenser (as opposed to air-cooled)	high
Winter operation of evaporative condenser	medium
Automatic purger on positive pressure system	medium low
High stage desuperheating	medium low
Close approach condenser	low
Floating head pressure below defrost pressure	low
Ozone water treatment	low
Spray cooling of booster discharge with liquid bypass	low
High efficiency fan and pump motors	low
External booster desuperheating	low

Table 4. Incremental Savings and Costs for Selected Industrial Measures

DSM Measure	Space Temperature	Annual Energy Savings	Demand Savings	Incremental Cost	Unit (Per)
Extra ceiling insulation (R-60 vs. R-40)	-15°F	722 kWh	0.15 kW	$2,400	1000 sq ft
Extra wall insulation (R-50 vs. R-35)	-15°F	469 kWh	0.29 kW	$5,600	1000 sq ft
Extra vessel insulation (R-28 vs. R-17)	-15°F	1,746 kWh	0.33 kW	$1,500	1000 sq ft
Quick close doors	-15°F	46 kWh	0	$188	door sq ft
Second low temperature suction	-20°F	725 kWh	0.21 kW	$500	Ton*
Close approach evaporative condenser(s)	-15°F	182 kWh	0.13 kW	$175	Ton*
Close approach evaporative condenser(s)	40°F	91 kWh	0.06 kW	$150	Ton*
External booster desuperheating	30°F**	220 kWh	0.04 kW	$67	Ton*

* One ton of refrigeration is equivalent to 12,000 Btu/hr.
** The intermediate saturated suction temperature, not space temperature, is 30°F.

more energy efficient design, a prescriptive (or standardized) approach is needed and the options and requirements must be specified beyond the current level of understanding of many customers and utility customer-service representatives. A very detailed prescriptive program is needed to make it clear to designers exactly what will be rebated and to what level. Without this clarity, designers may be more hesitant to incorporate greater energy efficiency into their designs because they may not feel assured that the customer will receive a certain rebate amount. Unfortunately, this level of detail will make the program beyond the technical understanding of many facility managers and utility service representatives.

Although having such detailed specifications may appear to be a significant barrier to program marketing, this can be overcome through two complementary approaches. First, a strong emphasis should be placed on marketing the program through trade allies (as opposed to marketing through utility service representatives or direct customer contact). As indicated earlier, there is a relatively small number of trade allies serving the industrial refrigeration sector so the design and retrofit decisions of a large number of customers can be affected with lower utility effort if the cooperation and active support of these trade allies is obtained. Understanding detailed program requirements should not be a barrier to marketing for competent industrial refrigeration consultants and contractors who will have the incentive of selling some of the rebate program measures to their customers. The second, complementary approach is to market the program to the customers' key decision makers without discussing the technical details of the program. If a customer expresses initial interest, then the customer can have someone with the proper expertise (in-house engineer, contractor, consultant, or a utility representative) determine the measures applicable to the plant and develop recommendations. At that point the customer's decision maker(s) should have sufficient information about the economics to make a decision about whether or not to participate.

A second key recommendation is that design assistance in the form of an audit program should be provided. The program should partially pay for an audit performed by a consultant or contractor that the customer chooses from a list of pre-qualified firms. Although the benefits of having a utility staff expert available to perform industrial refrigeration audits were considered, this was not recommended because: (1) the work load would probably not justify a dedicated full-time employee; (2) very extensive training would be needed for a current employee to develop the expertise; (3) customers expressed a desire to be able to make their own choice of auditor; (4) the utility may be perceived as taking away business from consultants if it does not let customers make their own choice.

There were several other findings related to program design. Training for operators should be actively supported, but training for contractors and designers should be limited to telling them about the program and how to use it. It was also found that many operators may need preliminary skill development before going through the standard industrial refrigeration training program that is currently available (Hallowell et al. 1989). A custom rebate option for measures not covered also needs to be included. The rebate for custom measures should buy down the simple payback to two years. The availability of loans is not very important for this market, but could be useful if the utility offers a package that is a very substantial improvement over market interest rates. However, such a program would likely have a very high number of free riders in the industrial refrigeration market. Measures were also identified that could benefit from a utility-sponsored test installation that demonstrates their reliability and savings.

Conclusions

Commercial and industrial refrigeration offer a number of good DSM opportunities. The phase-out of CFC refrigerants offers a unique opportunity to capture savings in the commercial market and in a subset of the industrial market. Some cost-effective measures face marketing obstacles in the form of negative trade ally or customer perceptions, which must be overcome through demonstration installations or other strategies. A number of measures currently rebated by utilities appear to have market penetrations too high to warrant continued incentives. Other technologies were identified that could potentially be good DSM opportunities, but for which the level of available information is insufficient to warrant their widespread promotion.

It is recommended that standardized rebate programs coupled with minimum design requirements be the primary method of serving these markets. Several DSM strategies other than rebate programs were identified as being appropriate to encourage refrigeration energy efficiency including: funding demonstration installations of specific technologies, contributing to cooperatively funded research, subsidizing audits, and encouraging operator training.

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