Cool Energy Savings Opportunities in Commercial Refrigeration

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Abstract

The commercial sector consumes over 13 quads of primary energy annually. Most of this consumption (two-thirds) meets the energy needs of lighting and heating, ventilation, and air-conditioning. The largest consuming group of the remaining one-third is commercial refrigeration at about one quad annually (990 trillion Btu), valued at over $7 billion per year to the commercial sector consumer. Potential energy savings are estimated to be about 266 trillion Btu, with consumer savings valued at about $2 billion. This study provides the first known estimates of these values using a "bottom-up" approach.

We evaluated numerous self-contained and engineered commercial refrigeration systems in this study, such as: supermarket central systems, beverage merchandisers, ice machines, and vending machines. Typical physical characteristics of each equipment type were identified at the component level for energy consumption. This information was used to form a detailed database from which we arrived at the estimate of 990 trillion Btu energy consumption for the major equipment types used in commercial refrigeration. Based on the implementation of the most cost-effective technology improvements for the seven major equipment types, we estimated an annual potential energy savings of 266 trillion Btu. Much of the savings can be realized with the implementation of high-efficiency fan motors and compressors. In many cases, payback can be realized within three years.

Introduction

Most energy conservation programs in the commercial sector have focused on lighting and HVAC equipment because these applications account for about two-thirds of commercial sector energy use (see Figure 1). Commercial refrigeration represents about 20% of the remaining energy use of the commercial sector. A recent in-depth study by Arthur D. Little (ADL) funded by the DOE's Office of Building Equipment (OBE) was done in order to help quantify commercial refrigeration energy use and to assess the potential for energy savings. The information is being used by OBE to guide planning for national efforts aimed at energy conservation.

Most people have some familiarity with commercial refrigeration equipment, since this equipment is used mostly for display, storage, and vending of food in supermarkets, convenience stores, and restaurants. The range of equipment includes display cases, refrigerated vending machines, beverage merchandisers, ice machines, and storage refrigerators and freezers. Commercial storage units come in a range of sizes including "walk-in", "roll-in", and "reach-in". The refrigeration systems serving this equipment can be contained within the unit (as for a vending machine), or can have varying levels of complexity. Supermarket refrigeration systems, for instance, include sales-floor display cases, storage walk-ins, remotely-located compressor rooms, roof-mounted condensing units, and heat recovery coils located in air-conditioning units or water heating systems.

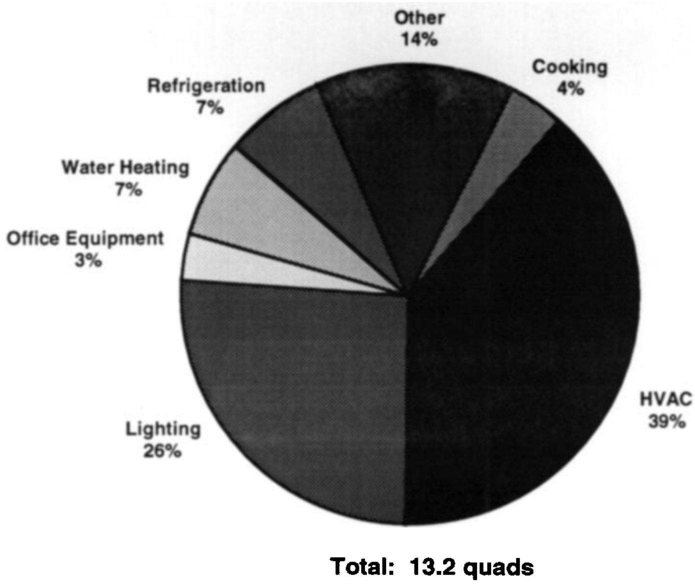

Figure 1. Commercial Sector Primary Energy Use - 1993
Sources: DOE EIA "Annual Energy Outlook 1995"; Patel et al. 1993 and Westphlan et al. 1996

Success of energy conservation programs in the commercial sector depends largely on financial incentives, which are closely tied to the market structure associated with equipment sales, equipment ownership, and equipment use. These structures are somewhat varied for commercial refrigeration. For instance, beverage merchandisers and vending machines are typically owned by bottling companies, while the energy they consume is paid for by the establishment in which they are located. For other commercial refrigeration equipment types, owners generally pay the energy bills.

Required simple payback periods for energy improvements are fairly low in this sector, generally 1 to 3 years, as reported by end users, vendors, and engineers in the many interviews conducted during the study described in Westphalen et al. 1996. Energy expenditures are generally less of a concern than equipment reliability and the sales productivity of display cases. Equipment production volumes are relatively low as compared to white goods or HVAC. Hence, limited resources are available for R&D to improve efficiency. Furthermore, there are no energy standards in the U.S. for commercial refrigeration equipment. The efficiency of components such as compressors is usually much lower than with components for domestic refrigerators, where DOE energy standards have resulted in significant gains. The possible exception to this rule is supermarket refrigeration, which has achieved a higher level of efficiency. However, equipment manufacturers generally do not make improvements unless their customers request them.

A refrigeration system failure in a supermarket can result in thousands of dollars of merchandise losses. Much more money is spent on display cases than the other refrigeration system components because of the importance of generating sales. This is seen in the continued popularity of open display cases and bright lighting, which use more energy, but increase sales. Energy costs represent about 1% of a supermarket's revenue, about the same percentage as typical profit margins. Although any energy savings can significantly increase profits, a small reduction in sales productivity can be much more significant.

Methodology, Approach and Framework

The study is a "bottom-up" analysis, involving estimates of equipment energy use and estimates of equipment inventories (see Westphalen et al. 1996 for a more detailed summary of the study). The major focus was on the equipment types representing most of the sector's energy use: supermarket refrigeration systems, walk-in coolers and freezers, reach-in refrigerators and freezers, ice machines, refrigerated vending machines, and beverage merchandisers. The procedure for estimating baseline energy usage is illustrated in Figure 2 below.

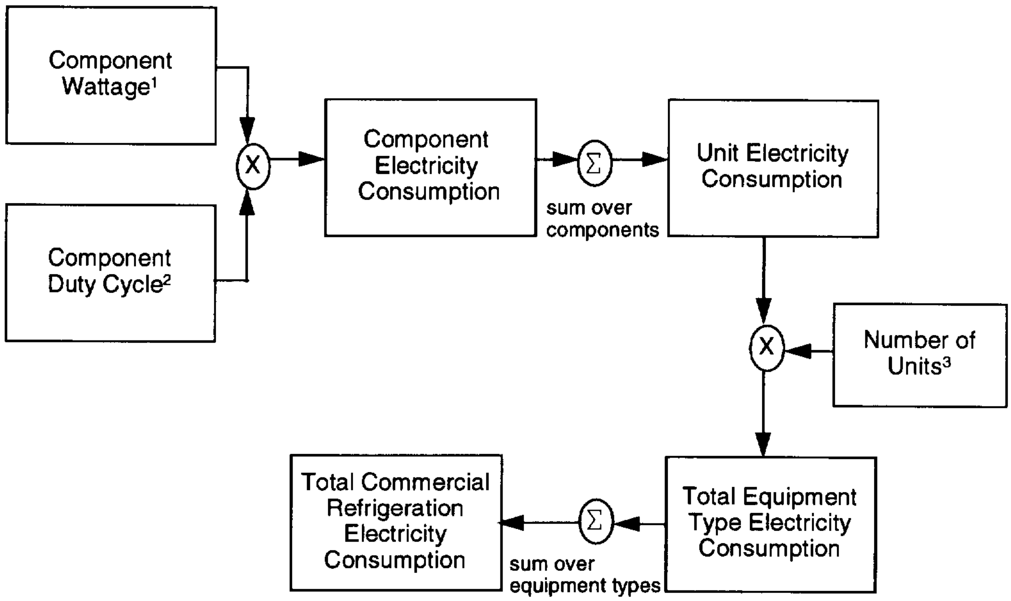

Figure 2. Baseline Energy Use Calculation
Sources: [1]Product Literature and Vendor Inquiries; [2]Vendor Inquiries and Engineering Estimates; [3]Vendor Inquiries and Trade Literature

Prototypical descriptions characterizing energy use were developed for each of these equipment types by examination of product literature and discussion with manufacturer representatives. These descriptions were developed with sufficient technical detail to allow rational estimation of energy savings in subsequent analysis. For instance, the compressor energy use calculation was based on typical compressor Coefficient of Performance (COP), so that estimation of savings resulting from COP improvement could easily be calculated. For example, Table 1 below shows the energy use breakdown for a prototypical beverage merchandiser. The estimates are intended to represent average conditions for variables such as ambient temperature, door opening frequency, etc.

Table 1. Energy Use Breakdown for a Prototypical One-Door Beverage Merchandiser (27 cuft)

Component	Power Consumption, W[1]	Duty Cycle, %	Energy Consumption, kWh/yr	Energy Consumption %
Compressor	425[2]	45[3]	1,675	43
Evaporator Fans (2)	106 (53x2)	100	928	24
Condenser Fan	57	45[3,4]	225	6
Lighting	125	100	1,095	27
Total	—	—	**3,923**	**100**

Source: Westphalen et al. 1996

In addition, the numbers of each of the systems in use in the U.S. in the baseline year (1993) were estimated. The estimate for U.S. energy use in beverage merchandisers is summarized in Table 2 below.

Table 2. U.S. Energy Use in Beverage Merchandisers

Unit Type	Estimated Inventory	Unit Energy Consumption, kWh/yr	Total Energy Consumption, TWh/yr	Total Energy Consumption, %
One-Door	400,000	3,900	1.56	33
Two-Door	360,000	7,600	2.74	58
Three-Door (or more)	40,000	11,200	0.45	9
Total	**800,000**	–	**4.74**	**100**

Source: Westphalen et al. 1996

Equipment inventory information was obtained in part through discussions with industry experts such as refrigeration engineers and manufacturer representatives. Final estimates were also reviewed by these people to ensure accuracy.

A number of energy savings options were examined for each equipment type. Many of these options were applicable to multiple equipment types. The energy savings options were classified according to technical and market status as follows:

- Current: technologies which are commercially available
- New: technologies which are available but have not generated significant market acceptance
- Advanced: technologies which are not yet commercially available and require further research and development

Energy Use of the Major Equipment

Total energy use for commercial refrigeration equipment is about 1 Quad (see Figure 3 below). The top four energy users are supermarkets, walk-ins, refrigerated vending machines, and ice machines. The "Other" category includes roll-ins, under-counter, non-beverage self-contained display cases, and display cases in smaller food sales establishments which are served by remote condensing units. The businesses represented by this energy use are primarily food sales and food service.

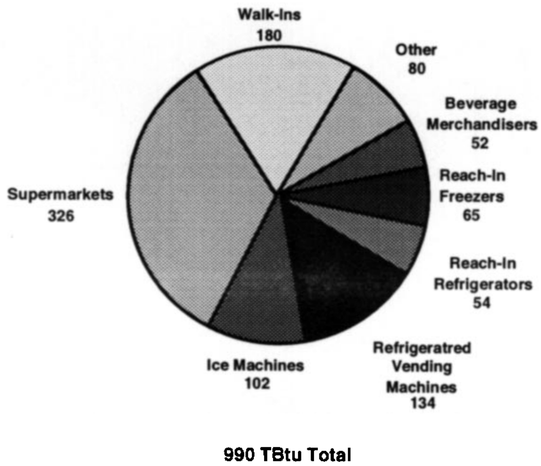

Figure 3. Total National Energy Use by Commercial Refrigeration Equipment (Trillion Btu Primary Energy)
Source: Westphalen et al. 1996

Table 3 below illustrates the electricity use breakdown for a typical supermarket. The largest amount of electricity is used for general lighting. The refrigeration system accounts for about half of the electricity use, and it is dominated by the compressors.

Table 3. Supermarket Electricity Use Estimate Summary (45,000 sqft)

	Electricity Use 1000kWh per year	Percent of Refrigeration Energy	Percent of Total Energy
Medium-Temp Compressors	**485.7**	31%	
Low-Temp Compressors	**375.3**	24%	
Condenser(s)	**99.3**	7%	
Medium-Temp Display Cases	**129.6**	8%	
Evaporator Fans	*56.9*		
Antisweat Heaters	*10.5*		
Defrost	*7.9*		
Lights	*54.3*		
Low-Temp Display Cases	**348.2**	22%	
Evaporator Fans	*56.3*		
Antisweat Heaters	*186.7*		
Defrost	*28.1*		
Lights	*77.1*		

	Electricity Use 1000kWh per year	Percent of Refrigeration Energy	Percent of Total Energy
Medium-Temp Walk-Ins	**83.8**	5%	
Evaporator Fans	*67.7*		
Defrost	*2.9*		
Lights	*13.2*		
Low-Temp Walk-Ins	**50.0**	3%	
Evaporator Fans	*35.0*		
Defrost	*10.6*		
Lights	*4.4*		
Lighting	**1,220**		38%
Space Conditioning	**160**		5%
Miscellaneous	**224**		7%
TOTAL REFRIGERATION	**1,600**		
GRAND TOTAL	**3,200**		

Source: Westphalen et al. 1996; Walker et al. 1990.

Table 4 shows electricity use breakdowns for beverage merchandisers, reach-in freezers and refrigerators, refrigerated vending machines, and walk-ins. For each of these equipment types, the

Table 4. Component Energy Use Estimates (kWh) for Major Commercial Refrigeration Equipment

	Refrigerant Compressor	Evaporator Fan(s)	Condenser Fan(s)	Lights	Antisweat Heaters	Defrost Heater	TOTAL
Beverage Merchandiser (1-dr, 27 cuft)	1,675 43%	928 24%	225 6%	1,095 27%	-	-	**3,923** **100%**
Reach-In Refrigerator (2-dr, 45 cuft)	2,506 58%	420 10%	512 12%	14 -	869 20%	-	**4,321** **100%**
Reach-In Freezer (1-dr, 22 cuft)	3,482 67%	175 3%	460 9%	7 -	745 14%	329 6%	**5,198** **100%**
Vending Machine (400-can)	1,303 44%	324 11%	113 4%	1,223 41%	-	-	**2,964** **100%**
Walk-In Cooler (240 sqft)	22,259 53%	7,008 17%	8,718 20%	1,693 4%	2,628 6%	-	**42,306** **100%**
Walk-In Freezer (80 sqft)	8,861 57%	1,577 10%	2,017 13%	350 2%	2,015 13%	735[1] 4%	**15,555** **100%**

Source: Westphalen et al. 1996; Note: Percentages may not add to 100% due to roundoff error.
Estimates are for prototypical equipment--see Westphalen et al. 1996 for more detailed descriptions

[1] Defrost Heater usage includes 183 kWh for drip pan heater.

compressor is the largest energy user. However, there are slight differences among these equipment types, depending on the need for lighting, defrost, and anti-sweat heating. Lighting represents a large load in the vending machines and in the beverage merchandiser because illumination is needed to generate sales. Evaporator fans represent a large load in beverage merchandisers because of the tendency to use inefficient shaded pole motors.

Figure 4 below shows typical energy use breakdown for an ice machine. Nearly 90% of the electricity is used by the compressor. The condenser fan and water pump make up the balance of the electricity use. Ice machines generally do not have lighting, and their evaporators cool ice directly, requiring no evaporator fan for air circulation.

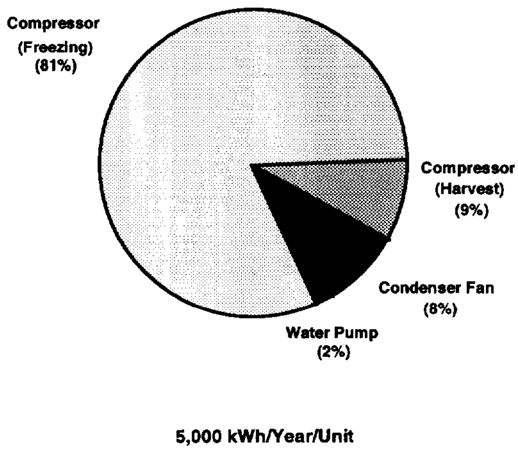

Figure 4. Typical Ice Machine Electricity Use Breakdown
Source: Westphalen et al. 1996

National Energy Savings Potential

Energy savings potential for different energy saving options are shown for the major equipment types in Table 5 and Table 6. The savings numbers represent totals for the U.S. in trillion Btu of primary energy, assuming a conversion efficiency of 10,867 Btu/kWh and complete penetration of the technologies into the existing product base. The charts show classification of the options as current, new, or advanced. The most effective options are ECM motors and high-efficiency compressors.

The energy savings potential is presented by equipment type in Figure 5 and by technology option in Figure 6.

Use of ECM fan motors has a very large savings potential because all equipment types have at least one fan. Evaporator fan motor savings have a double impact because of the reduction in cabinet load, which reduces compressor power.

High-efficiency compressors, either using conventional single-speed technology, or using variable-speed technology, can make a large impact because (1) current designs for self-contained equipment have relatively low efficiency, and (2) such a large percentage of the overall energy use for the sector is associated with compressors.

Table 5. Energy Savings Potential for Beverage Merchandisers, Reach-Ins, and Refrigerated Vending Machines (Trillion Btu Primary Energy)

	Beverage Merchandiser	Reach-In Refrigerator	Reach-In Freezer	Refrigerated Vending Machine
NEW TECHNOLOGIES				
ECM Evaporator Fan Motor	15	4	1.5	19
ECM Condenser Fan Motor	2	2	2	4
High-Efficiency Compressors	5	6	10	12
Electronic Ballasts	5			12
Improved Insulation	2	1	2.5	7
Hot Gas Defrost			4	
Liquid-Suction Heat Exchanger			2	
ADVANCED TECHNOLOGIES				
Variable-Speed Compressors	7		12	20
Hot Gas Antisweat Heating		11	9	

Table 6. Energy Savings Potential for Supermarkets, Ice Machines, and Walk-Ins (Trillion Btu Primary Energy)

Supermarket Display Cases	Supermarket Machine Room	Ice Machines	Walk-Ins
CURRENT TECHNOLOGIES			
			Hot Gas Defrost 3 Improved Insulation 3
NEW TECHNOLOGIES			
ECM Evap Fan Motor 26 Hot Gas Defrost 3 Liquid-Suction HX 4 Antisweat Heat Control 5	Evaporative Condenser 6 Floating Head Pressure 5 Heat Reclaim 4 Mechanical Subcooling 3	ECM Cond Fan Motor 6 Improved Insulation 3 High-Effic. Compressor 6 Reduced Harvest Meltage 5 Reduced Thermal Cycling 4	ECM Evap Fan Motor 19 High-Effic. Fan Blades 10 Ambient Subcooling 11 Floating Head Pressure 21
ADVANCED TECHNOLOGIES			
			Non-Electric Antisweat 16

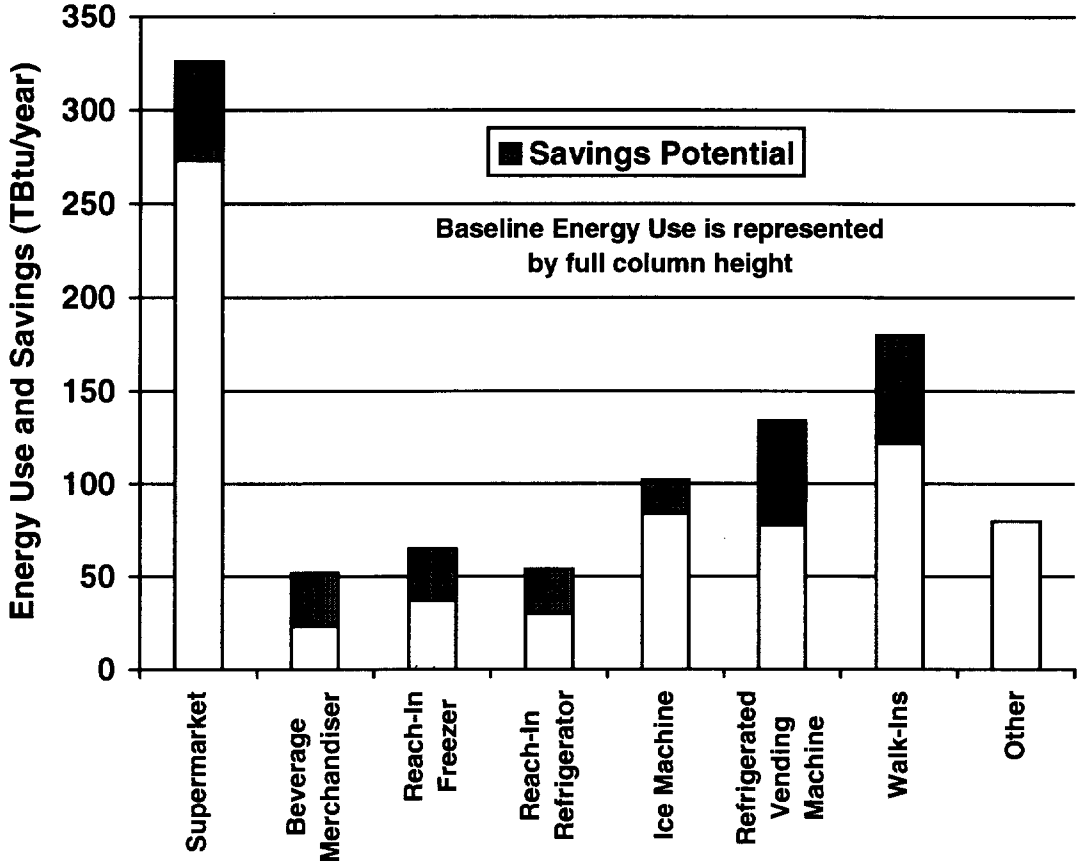

Figure 5. Energy Savings Potential by Equipment Type

The use of high-efficiency fan blades has the potential for significant energy savings because of their ubiquitous use in all of the equipment types. Implementation of this technology requires significant engineering time, however, because achieving high-efficiency designs will require more careful optimization of the fan blade for individual applications.

Insulation improvements, which can involve increasing insulation thickness or the use of better insulation, has great potential for the equipment for which conduction through the cabinet is the major cooling load (this is not the case for ice machines, open display cases, and storage or display units in which product cooldown or frequent door openings dominates the load).

Floating head pressure has significant potential in supermarkets and for walk-ins, applications for which this technology is not being used to its full potential.

Lighting improvements, specifically electronic ballasts, would result in energy savings in all of the display equipment. The lamps and ballasts are frequently in the cooled space, which means that any power input reduction also reduces the load on the compressor.

Many of the other investigated savings technologies apply mostly to one or another segment of the commercial refrigeration sector, which limits their national potential for energy savings.

Energy Savings Potential (all equipment types)

Technology	Savings Potential (TBtu/year)	Payback Range (Years)	Equipment
Evaporator Fan ECM Motor	85	0.5-3	1,2,3,4,6,7
ECM/Variable Speed Compressor	48	2-5	2,3,4,6
High-Efficiency Compressors	39	0.5-2	2,3,4,5,6
High-Efficiency Fan Blades	30	0.1-1	1,5,7
Condenser Fan ECM Motor	25	0.5-8	2,3,4,5,6,7
Floating Head Pressure	25	0.3-3	1,7
Electronic Ballasts	24	1-2.5	1,2,4,6,7
Non-Electric Antisweat	20	1-1.5	3,4,7
Thicker Insulation	20	1-1.5	1,2,3,4,6,7
Ambient Subcooling	12	2-11	1,7
Hot Gas Defrost	10	1.5-3	1,3,7
Liquid-Suction Heat Exchanger	10	4-14	1,3
Evaporative Condensers	10	None	1
Antisweat Heater Controls	10	2-6	1,7
Other Ice Machine Improvements	9	1-6	5
Evaporator Fan Shutdown	7	1-2	7
External Heat Rejection	6	7	7
Economizer Cooling	6	20	7
Heat Reclaim	3	2-5	1
Defrost Control	3	3	1,7
Mechanical Subcooling	2	5	1

Equipment Key

1 **Supermarket Refrigeration Systems**
2 **Beverage Merchandisers**
3 **Reach-In Freezers**
4 **Reach-In Refrigerators**
5 **Ice Machines**
6 **Refrigerated Vending Machines**
7 **Walk-In Coolers and Freezers**

Note:
Energy savings potential by typical stores and individual equipment type can be found in the DOE study.

Figure 6. Energy Savings Potential by Technology Option

Barriers

The barriers to implementation of the investigated energy saving technologies are both technical and financial in nature. Some of the new and advanced technologies have not yet been demonstrated for commercial refrigeration applications, and technical challenges remain before they will be commercialized and accepted. Awareness of energy-saving options is a barrier for most end-users of the self-contained equipment and walk-ins. However, the more significant barriers are financial in nature. First, the required payback for the commercial refrigeration sector is quite low, in the 1 to 3 year range. For beverage merchandisers and refrigerated vending machines, there is little incentive for equipment owners to insist on higher efficiency since they don't pay the energy bills (the equipment is located in restaurants, stores, and other establishments, while it is owned by the bottling companies who supply the beverages). For most commercial refrigeration equipment, revenues associated with the unit are much larger than energy costs. Display cases are purchased by marketers, who are looking for marketing appeal, rather than by engineers. Equipment manufacturers are in a fairly competitive business with relatively small numbers of units being sold (as compared to HVAC or white goods). Hence, the resources available for system design improvements are limited, and the emphasis is more on food sales effectiveness, reduced manufacturing cost, and reliability than energy improvement.

Energy-reducing technologies can most effectively be introduced in the commercial refrigeration sector if (1) the cost premiums to the end-user are low in comparison to the potential cost savings *and* compared to the equipment cost, (2) the development costs for the manufacturer are small or non-existent, (3) the impact on product reliability is demonstrated to be negligible or an improvement.

Conclusions

Primary energy usage in the commercial refrigeration sector is estimated as 990 trillion Btu (1993 base year). Analyses done as part of a recent ADL study for DOE's Office of Building Equipment indicate that there are large opportunities for savings in the commercial refrigeration sector. Primary energy savings of about 266 trillion Btu (29% for the seven major equipment types examined) were identified based on improvements in current technology assuming implementation of the most economically attractive energy-saving options for all equipment in the installed base. Much of this savings potential is associated with high-efficiency fan motors and high efficiency compressors, technologies with paybacks of less than 2 years when used for new equipment. High efficiency fan motors can also be implemented on a retrofit basis (with longer payback). Additional savings are associated with hot gas defrost, use of hot gas or liquid for anti-sweat heating, and defrost control. Implementation of these technologies is estimated to have payback periods typically within 5 years.

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