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O. Sezgen and J.G. Koomey
Energy and Environment Division

December 1995

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Technology Data Characterizing Refrigeration in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0

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ABSTRACT

In the United States, energy consumption is increasing most rapidly in the commercial sector. Consequently, the commercial sector is becoming an increasingly important target for state and federal energy policies and also for utility-sponsored demand side management (DSM) programs. The rapid growth in commercial-sector energy consumption also makes it important for analysts working on energy policy and DSM issues to have access to energy end-use forecasting models that include more detailed representations of energy-using technologies in the commercial sector. These new forecasting models disaggregate energy consumption not only by fuel type, end use, and building type, but also by specific technology.

Refrigeration's share of U.S. commercial-sector electricity consumption is 8%, which corresponds to 0.7 quads of primary energy consumption annually. Electricity consumption for refrigeration, however, is much more significant in particular building types than in the commercial sector as a whole. For example, refrigeration's share of electricity consumption for groceries, restaurants, and warehouses is 49%, 20% and 35%, respectively. Although smaller in absolute size than the savings associated with other energy end uses such as lighting and space conditioning, the potential cost-effective energy savings from refrigeration for some building types are large enough in percentage terms to warrant closer attention.

The disaggregation of the refrigeration end use in terms of specific technologies, however, is complicated by several factors. First, the number of configurations of refrigeration cases and systems is quite large. Also, energy use is a complex function of the refrigeration-case properties and the refrigeration-system properties. The Electric Power Research Institute's (EPRI's) Commercial End-Use Planning System (COMMEND 4.0) and the associated data development presented in this report attempt to address the above complications and create a consistent forecasting framework.

Expanding end-use forecasting models so that they address individual technology options requires characterization of the present floorstock in terms of service requirements, energy technologies used, and cost-efficiency attributes of the energy technologies that consumers may choose for new buildings and retrofits. This report describes the process by which we collected refrigeration technology data. The data were generated for COMMEND 4.0 but are also generally applicable to other end-use forecasting frameworks for the commercial sector.

Data were obtained from various sources including the U.S. Department of Energy and publications of the Lawrence Berkeley National Laboratory, EPRI, ASHRAE, and Competitek. Several utility studies were also used.

ACKNOWLEDGMENTS

This report on commercial-sector refrigeration is one of five in a series summarizing technology data for various commercial end uses in the United States. Companion reports describe technology data for space conditioning, lighting, water heating, and office equipment in commercial buildings.

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1. INTRODUCTION

Commercial-sector conservation analyses have traditionally focused on lighting and space conditioning because of their relatively large shares of electricity consumption (33% and 40%, respectively), and the large share of space conditioning in fuel consumption (63%), in commercial buildings. In this report we focus on refrigeration, which is one of the neglected end uses in the commercial sector. The share of the refrigeration end use in U.S. commercial-sector electricity consumption is about 8%, which corresponds to 0.7 quadrillion Btus (quads) of primary energy consumption annually.

Although smaller in absolute size than the savings associated with lighting and space conditioning, the potential cost-effective energy savings from refrigeration technologies are large enough in percentage terms to warrant closer attention. In addition, electricity consumption for refrigeration is much more significant in particular building types (groceries, restaurants, and warehouses) than in the commercial sector as a whole. Refrigeration's share of electricity consumption for groceries, restaurants, and warehouses is 49%, 20%, and 35%, respectively. Furthermore, only about 8% of the warehouse floor area is refrigerated, so the refrigeration electricity in warehouses is concentrated in a small fraction of the total warehouse floor area.

Forecasting commercial-sector energy consumption is an important issue for utility capacity planning because the commercial sector is the fastest growing consumer of energy. Previously, utilities forecasted electricity and gas consumption based on time series analysis. More recently, with the growth of demand-side management (DSM) programs, there is a need to forecast by building type and end use as well as technology options within an end use. Forecasting models in which energy consumption is disaggregated by technology option are also useful to state and federal policy makers in their assessment and implementation of technology-specific standards and policies.

The disaggregation of refrigeration end uses in terms of specific technologies, however, is complicated by several factors. First, the number of configurations of refrigeration cases and systems is quite large. In addition, energy use for refrigeration is a complex function of the refrigeration-case properties and the refrigeration-system properties. The Electric Power Research Institute's (EPRI's) Commercial End-Use Planning System (COMMEND 4.0) and the associated data development presented in this report attempt to address the above complications and create a consistent forecasting framework.

In the mid-1980s, EPRI adopted COMMEND, one of the first-generation commercial-sector forecasting models. To address the need for more detailed technology representation, EPRI has developed COMMEND 4.0, an enhanced version of COMMEND that allows users to model specific refrigeration technology options as well as lighting, space conditioning, and office equipment technology options. The EPRI contractor for this effort, Regional Economic Research, Inc., worked with the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) to develop and test the technology modules contained in COMMEND 4.0. LBNL is also helping to develop and refine technology data for the model.

Expanding end-use forecasting models so that they address individual technology options requires characterization of the present floorstock in terms of service requirements, energy technologies used, and cost-efficiency attributes of the energy technologies that consumers may choose for new buildings and retrofits. This report describes the process by which we collected refrigeration technology data for COMMEND 4.0. The data are also generally applicable to other end-use forecasting frameworks for the commercial sector.

2. BASIC OVERVIEW OF THE COMMEND MODEL

The COMMEND model forecasts future commercial-sector energy consumption by fuel type, building type, and end use. First, COMMEND users enter data that characterize the commercial energy end-use market in the base year. The model then forecasts future levels of energy consumption by simulating consumer decisions regarding energy end-use technology options for each year of the forecast. Fuel prices and the growth rate for commercial floor space during the forecast period are exogenous to the model. Based on these exogenous time series data, COMMEND incorporates consumer energy and equipment choices for both new and retrofitted commercial buildings into its updated market characterization for each forecast year. Decisions regarding fuel-switching and the efficiency levels of technologies are determined using a probabilistic choice approach.

In COMMEND 3.2 and earlier versions of the model, the refrigeration end use was represented by a technology trade-off curve that related operating costs to equipment costs.[1] A trade-off curve can be viewed as a variation of the cost-efficiency function. Although cost-efficiency functions are built using market data, any information regarding which technology option a certain point on the curve actually represents disappears once the function is created. Thus, market shares cannot be attributed to specific technologies. Although it is possible to analyze several policy options such as performance standards using cost-efficiency functions, it is nearly impossible to analyze policies addressing individual technology options.

In COMMEND 4.0, modeling at the end-use level using trade-off curves is still possible. In addition, it is possible to perform a more detailed analysis based on the modeling of specific refrigeration technologies. **Figure 1** depicts the refrigeration end-use model logic. The primary features of the detailed refrigeration model are as follows:[2]

- In place of general end-use categories, the model uses an expanded set of technology definitions.
- The level of detail in the refrigeration model recognizes the complexity of commercial refrigeration systems and deals explicitly with conservation measures that affect energy use for these systems.
- The refrigeration case and the refrigeration system are modeled separately.
- The case model determines the auxiliary electricity used by the case components such as lighting, anti-sweat and defrost heaters, and fans. The case model also determines the case refrigeration loads. These loads are corrected for each case add-on measure, based on the measure saturation and effectiveness.
- The system model determines the energy use of the refrigeration system based on the refrigeration load calculated by the case model, refrigeration system type, and the saturation and effectiveness of system measures.
- Total energy use is the sum of the case and system energy uses as seen in Figure 1.

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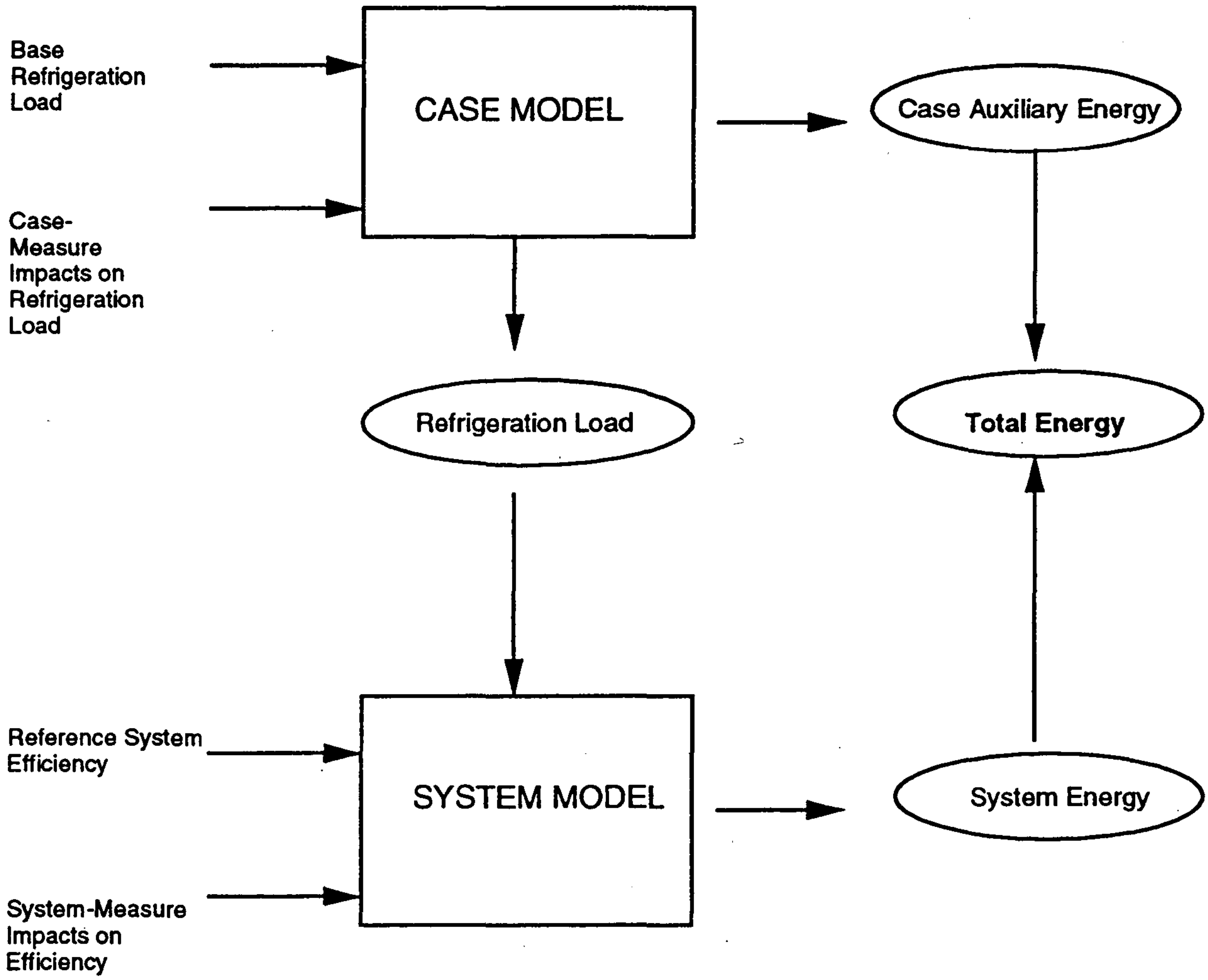
[1] For end uses that consumed more than one type of fuel, a trade-off curve was defined for each fuel type.

[2] Adapted from the *COMMEND 4.0 User's Guide* (EPRI 1993).

Figure 1. Refrigeration End-Use Model Logic



- The model deals directly with pre-defined lists of refrigeration case types (vertical, vertical with glass doors, tub-type, and walk-in units); case measures (control devices for anti-sweat heaters, high-efficiency fan motors, strip curtains, and hot-gas defrost cycles instead of electric defrost heaters); system categories (single-compressor systems and multiplex compressor systems); and system features (e.g., compressor efficiency, variable speed drives, subcooling options).

- Changes in equipment efficiency level can be modeled directly through efficiency equations or in detail through the specification of detailed design options.

3. DATA REQUIREMENTS

In order to expand an end-use forecasting model so that it addresses individual technology options, one must characterize the present floorstock in terms of service requirements, energy technologies used, and cost-efficiency attributes of the energy technologies that consumers may choose for new buildings and retrofits.

In addition, COMMEND requires data on consumer decision-making. The parameters used to forecast consumer decision-making include consumer price expectations based on past fuel prices; short-term utilization elasticities; discount rate preferences; and consumer resistance to change in retrofit situations. In our analysis, we did not create a new data set to describe consumer decision-making or how consumer choices may change in the future; instead, we rely on the COMMEND default choice parameters.

Service Demand Data

Users of COMMEND must enter service demand data into the model. Due to the complex nature of the refrigeration end use, service is demanded at different temperature levels for different uses. To characterize demand, refrigeration equipment is divided into two groups: medium-temperature equipment (coolers) and low-temperature equipment (freezers).

Refrigeration requirements vary considerably depending on application. Freezers with very low temperatures (about -12°F case temperature and -33°F evaporator temperature) are used for storing ice cream. Other frozen foods are kept at around 0°F in the case (-20°F evaporator temperature). Meat, dairy, delicatessen, and produce cases are kept at approximately 35°F (20°F evaporator temperature). For the purposes of this analysis, we aggregated the freezers into one group, assuming a case temperature of 0°F, and aggregated the coolers into a second group with a case temperature of 35°F.

Market Data for Technologies

Energy technologies related to refrigeration can be classified into four groups:

- Refrigeration case technologies;
- Refrigeration case measures;
- Refrigeration system technologies; and
- Refrigeration system measures.

For each of these four categories, COMMEND requires three types of market data: efficiency, cost, and saturation. Although efficiency/cost/saturation data for many of these technologies are explicitly entered into COMMEND, the input procedure is more complex in some cases. **Table 1** summarizes the form of the data accepted by COMMEND and indicates where the data can be found in this report. These data are prepared for groceries, restaurants, and refrigerated warehouses.

Table 1. COMMEND Input Format for Efficiency, Cost, and Saturation Data

Energy Technology	Efficiency	Cost	Saturation
Case Type	Base refrigeration load and base refrigeration case auxiliary energy use per lineal foot of case (or per ft^2 of walk-in unit) See Table 3	Cost per lineal foot of case (or per ft^3 of walk-in unit) See Table 4	Saturation of different case types is determined by the service demand See Table 2
Case Measure	Effectiveness over base refrigeration load and base refrigeration case auxiliary energy use See Table 3	Incremental cost over base case per lineal foot of case (or ft^3 of walk-in unit) See Table 4	Percent of the cases or walk-in units that are equipped with the measure See Table 5
System Type	Annual EER (energy efficiency ratio) See Table 6	Cost per compressor horse-power See Table 7	Percent of the refrigeration plants that are of a particular system type See Tables 8a and 8b
System Measure	Improvement over annual base EER See Table 6	Incremental cost over the base case per refrigeration capacity in tons or per compressor horse-power See Table 7	Percent of equipment within a particular system type that is equipped with the measure See Tables 8a and 8b

4. SERVICE DEMAND

Although most refrigeration cases utilize centralized systems (systems that serve more than one case), the number of unitary systems (cases that use a self-contained system such as a residential refrigerator) is significant. ADL (1993) estimates the 1990 electricity use to be 43.7 billion kWh for centralized systems and 13.3 billion kWh for unitary systems. This report primarily focuses on technology options for centralized systems, but we present some data on unitary systems below.

The three building types in which the refrigeration end use is important are food sales (groceries), food service (primarily restaurants), and refrigerated warehouses:

Groceries use four major types of refrigeration cases: vertical reach-in cases without doors, vertical reach-in cases with glass doors, tub-type cases, and walk-in units. Vertical cases, with and without doors, and walk-in units are used for both medium- and low-temperature refrigeration. Tub-type cases are used only for low-temperature refrigeration.

Restaurants do not typically use display cases. Instead, they use a variety of unitary systems including: reach-in refrigerators with two, three, or four doors (typically, the doors are not glass but resemble the doors on residential refrigerators); under-the-counter refrigerators; and mobile carts. Many restaurants also use walk-in units such as the ones in groceries.

Refrigerated warehouses are specially designed buildings where the indoor temperature is maintained either at the cooling or freezing level. These warehouses are essentially very large walk-in units.

Demand for the variety of services described above is presented in **Table 2**. Service demand for display cases is quantified in terms of lineal foot per 1000 ft^2 of building floor area. Service demand for walk-in cases is quantified in terms of square feet of refrigerated area per 1000 ft^2 of building floor area.

5. REFRIGERATION TECHNOLOGIES

Refrigeration Case Technologies

The most common types of refrigeration cases are:

- Vertical open, multi-deck cases with air curtain,
- Vertical cases with glass doors,
- Open tubs, and
- Walk-in units.

Efficiency measures for refrigeration cases affect one or both of case auxiliary electricity use and refrigeration load. The four types of efficiency measures considered by COMMEND for refrigeration cases are summarized below:

- *High-efficiency fan motors* reduce fan electricity use as well as the cooling requirements.
- Anti-sweat heaters are used to raise the cabinet surface temperature to prevent condensation. The use of *control devices for anti-sweat heaters* can reduce case auxiliary electricity use and also reduce the refrigeration load.
- *Hot-gas defrost systems* can be used to replace electric resistance-heater defrost systems. The primary impact of this measure is on case auxiliary electricity use. The effect on refrigeration load is not significant.
- *Strip curtains* are primarily considered for walk-in units. They are also sometimes used on vertical, open cases; recently, though, glass doors for open cases have begun to capture their market share.

Vertical open cases have merchandising advantage at the cost of fan-forced air curtains to minimize heat gain from the surrounding space. The use of *high-efficiency fan motors* is therefore very effective for this case type. Moderate energy savings can achieved by using *controls for anti-sweat heaters* in low-temperature cases. *Hot-gas defrost systems* can be utilized to replace electric defrost systems. Another possible efficiency measure is the use of *strip curtains* although, in low-temperature cases, condensation and even frost can obscure the view; the penetration of this measure for vertical open cases has been limited due to the short lifetime of this measure and also condensation problems.

Vertical cases with glass doors use much less fan energy than open cases, but a significant amount of energy is used for door anti-sweat heaters. *Controls for anti-sweat heaters* are an important efficiency measure for these types of cases. As with vertical open cases, *hot-gas defrost systems* can be utilized to replace electric defrost systems.

Open tubs, as implied by their name, are open to the air. Because they are open only at the top, convective heat gains are quite low. These types of cases are generally used for low-temperature applications. The efficiency measures covered for cases are not effective in open tubs; because the case auxiliary electricity use in open tubs is very low, the savings in auxiliary electricity that would

Table 2. Refrigeration Service Demand

Building Type	Use (Temperature) (1)	Case Type	Service Demand lineal ft/1000 ft2 of building [ft2/1000 ft2 of building] (4)
Grocery	Medium Temperature	Vertical	7.9
		Vertical w/glass doors	1.7
		Walk In	[45]
	Low Temperature	Vertical	0.8
		Vertical w/glass doors	1.9
		Tub	3.6
		Walk In	[14]
Restaurant (2)	Medium Temperature	Vertical	0.08
		Vertical w/glass doors	0.02
		Walk In	[11]
	Low Temperature	Vertical	0.01
		Vertical w/glass doors	0.03
		Tub	0.14
		Walk In	[3]
Warehouse	Medium Temperature	Walk In	[24] (3)
	Low Temperature	Walk In	[56] (3)

(1) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(2) In restaurants, many types of unitary refrigerators are used. Some of these are full-size reach-in refrigerators, under-the-counter refrigerators, and mobile carts. These units are not included in this table.

(3) It is assumed that, if a warehouse is refrigerated, the whole space is dedicated to refrigeration. About 4% of warehouse buildings and 8% of total warehouse floor area are refrigerated in the U.S. We assume 70% of the refrigerated area is for low-temperature applications, and 30% is for medium-temperature applications.

(4) Source: For groceries and restaurants, Foster-Miller 1981 and EPRI 1989 for case types other than walk in, and RER (1994) for walk-in cases.

result from the installation of efficiency measures is also very low. The impacts of the measures on refrigeration load are also negligible.

Walk-in units are used for back-up storage in groceries, and are also often used in larger restaurants. *Strip curtains* have been used successfully in walk-in units and in the entrance doors to refrigerated warehouses.

Efficiency

The efficiencies of basic case models are characterized by both the annual auxiliary electricity use of the case (including fans, anti-sweat heaters, defrost heaters, and lights) and the refrigeration load per lineal foot of case (or per ft^2 of walk-in unit) – the lower these quantities, the more efficient the cases. **Table 3** indicates the effectiveness of the case efficiency measures as a percent improvement over the base refrigeration load and case auxiliary electricity consumption; these results are presented for compatible case models, at both medium and low temperatures.

Cost

Table 4 presents the costs of both the basic case models and the case efficiency measures, at both medium and low temperatures. Display case costs are expressed per lineal foot; for walk-in units, costs are expressed per cubic foot. The costs of efficiency measures are expressed as incremental costs over and above the basic model costs, and include the cost of installation.

Saturation

Market saturations for the different types of refrigeration cases are presented in Table 2 as service demand. **Table 5** presents the market saturations of case efficiency measures. The percentages in Table 5 indicate the share of a given type of refrigeration case that is equipped with a particular efficiency measure.

Equipment Life

The useful life of refrigeration equipment is determined more by the periodic remodeling of the buildings in which the equipment is used than by the actual life of the equipment; consequently, stock accounting is dictated by the remodeling activity. Nevertheless, most refrigeration case measures have a useful life of 15 years. An exception is strip curtains, which have a useful life of five years in walk-in unit applications and three years in reach-in case applications.

Refrigeration System Technologies

Refrigeration systems can be divided into four classes:

- Single compressor systems for high-temperature applications,
- Single compressor systems for low-temperature applications,
- Multiplex compressor systems for high-temperature applications, and
- Multiplex compressor systems for low-temperature applications.

Multiplex compressor systems have several compressors (usually of different capacities) operating in parallel. Running combinations of these compressors results in operation close to full-load performance at all times, which increases the integrated-part-load efficiency of the system.

Table 3. Case Efficiency and Impacts of Case Measures on Refrigeration Load and Case Auxiliary Electricity Use (*)

Use (Temperature) (1)	Case Type	Base Refrigeration Load Btu/h-ft	Measure Impact on Refrigeration Load (% savings)			
			Control Devices for Anti-Sweat Heaters	High-Efficiency Fan Motors	Hot-Gas Defrost Cycle	Strip Curtains
Medium Temperature	Vertical	1380	-	1%	-	-
	Vertical w/glass doors	550	7%	4%	-	-
	Walk In	70 (Btu/h-ft2)	-	4%	-	25%
Low Temperature	Vertical	1425	1%	6%	0%	-
	Vertical w/glass doors	556	22%	4%	0%	-
	Tub	632	1%	0%	0%	-
	Walk In	90 (Btu/h-ft2)	~0%	3%	0%	25%
Notes		2	3	3	4	8

Use (Temperature) (1)	Case Type	Case Auxiliary Electricity Use (kWh/ft-yr)	Measure Impact on Case Auxiliary Electricity (% savings)			
			Control Devices for Anti-Sweat Heaters	High-Efficiency Fan Motors	Hot-Gas Defrost Cycle	Strip Curtain
Medium Temperature	Vertical	237	-	18%	-	-
	Vertical w/glass doors	635	16%	11%	-	-
	Walk In	17.5 (kWh/ft2-yr)	-	40%	-	0%
Low Temperature	Vertical	1135	5%	22%	19%	-
	Vertical w/glass doors	1256	27%	5%	9%	-
	Tub	67	25%	7%	27%	-
	Walk In	17.5 (kWh/ft2-yr)	3%	40%	9%	0%
Notes		2	5	6	7	9

(*) Interactions between measures: When two or more of the measures are applied simultaneously, absolute savings (in terms of kWh) in case auxiliary electricity can be added directly. Combined impact on refrigeration load can be calculated using the formula:

% savings = (1 - (1-%savings1)*(1-%savings2)*......)

(1) Medium Temperature: approx. 20°F evaporator temp. (approx. 35°F case temp.)
Low Temperature: approx. minus 20°F evaporator temp. (approx. 0°F case temp.)

(2) Data drawn from examples presented in Competitek (1990). For walk-in units, data come from RER (1994). Case intensity includes fan, electric defrost, lighting, and anti-sweat heater electricity (when applicable).

(3) Reduction in the refrigeration load (as a percentage of the base refrigeration load) due to the reduction in case auxiliary electricity use.

(4) Reduction in case auxiliary electricity does not reduce the refrigeration load significantly because hot-gas defrost replaces electric defrost.

(5) 50% of the anti-sweat heater electricity is saved.

(6) 40% of fan electricity is saved.

(7) 78% of defrost electricity is saved.

(8) Source: Usibelli (1985). Strip curtains are sometimes used on open vertical cases. Glass doors are capturing the market share now held by strip curtains.

(9) Strip curtains may indirectly affect case auxiliary electricity use. Such secondary effects for walk-in units are small and are not covered here. For applications on vertical cases, up to 75% reduction in fan energy can be achieved; because such applications are uncommon, they also are not covered here.

Table 4. Case and Case-Measure Costs

Use (Temperature) (1)	Case Type	Case Cost (1992$/ft) (8)	Measure Cost (1992 dollars/ft) (8)			
			Control Devices for Anti-sweat Heaters	High-Efficiency Fan Motors	Hot-Gas Defrost Cycle	Strip Curtains
Medium Temperature	Vertical	735	-	11 -New 72-Retrofit	-	-
	Vertical w/glass doors	1180	20	11 -New 72-Retrofit	-	-
	Walk In (*)	1.60-2.25/ft3 (7)	-	0.03/ft3	-	$9-10/ft2 of curtain
Low Temperature	Vertical	1500 (10)	20	11 -New 72-Retrofit	20 / hp - New	-
	Vertical w/glass doors	1345	20	11 -New 72-Retrofit	20 / hp - New	-
	Tub	1170	20	11 -New 72-Retrofit	20 / hp - New	-
	Walk In (*)	1.60-2.25/ft3 (7)	0.15-0.01/ft3 (9)	0.03/ft3	20 / hp - New	$9-10/ft2 of curtain
Footnotes		2	3	4	5	6

(1) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(2) Source: Competitek (1990). For low temperature vertical cases, open cases are more expensive compared to cases with glass doors because of the fans.

(3) $245 per 12' case. Source: Competitek (1990).

(4) $130 per 12' case. Source: Competitek (1990).

(5) Source: Competitek (1990). Estimated to be $30-40/ton in EPRI (1992).

(6) Source: Usibelli (1985).

(7) Source: ASHRAE (1986). These costs apply to refrigerated warehouses. (Cost of walk-ins for grocery and restaurants is significantly higher.)

(8) 1986 dollars are converted to 1992 dollars using a factor of 1.28.

(9) For the building types Restaurant and Grocery, typical volume is assumed to be 1,600 ft3 and 30,000 ft3 respectively. The costs in the table are for restaurants and groceries respectively -- cost per volume is negligible for larger volumes like in warehouses.

(10) Higher than vertical with glass doors due to fans.

(*) Typical walk-in refrigerator sizes are: grocery (50ft X 30ft X 20ft); restaurant (20ft X 10ft X 8ft); and refrigerated warehouses (250ft X 200ft X 40ft).

Table 5. Market Saturations of Case Measures (Stock and New)

Building Type	Use (Temperature) (1)	Case Type	Measure Saturation (6)			
			Control Devices for Anti-sweat Heaters	High-Efficiency Fan Motors	Hot-Gas Defrost Cycle	Strip Curtains
Grocery	Medium Temperature	Vertical	-	5%	-	-
		Vertical w/glass doors	10%	5%	-	-
		Walk In	-	5%	-	70%
	Low Temperature	Vertical	10%	5%	70%	-
		Vertical w/glass doors	10%	5%	70%	-
		Tub	10%	5%	70%	-
		Walk In	10%	5%	70%	70%
Restaurant	Medium Temperature	Vertical	-	5%	-	-
		Vertical w/glass doors	10%	5%	-	-
		Walk In	-	5%	-	70%
	Low Temperature	Vertical	10%	5%	70%	-
		Vertical w/glass doors	10%	5%	70%	-
		Tub	10%	5%	70%	-
		Walk In	10%	5%	70%	70%
Warehouse	Medium Temperature	Walk In	10%	5%	-	70%
	Low Temperature	Walk In	10%	5%	2%	70%
Notes			2	3	4	5

(1) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(2) Source: XENERGY (1992). In the Midwest and the Northeast, saturation is 10%. In the West, penetration is slightly less.

(3) Source: Competitek (1990).

(4) Source: XENERGY (1992). These saturations apply to the Pacific Coast. Here we assume that penetration is not a function of location.

(5) Source: ADM. Estimate for the BPA service area. Here we assume that saturation is not a function of location.

(6) The percentages indicate the share of a given type of refrigeration case (type and use) that is equipped with a particular efficiency measure.

The types of efficiency measures considered by COMMEND for refrigeration systems are summarized below.

Compressor Efficiency Measures: A variety of *efficient compressors and motors* are on the market; use of these efficient models improves full-load efficiency. *Variable speed drives (VSDs)* can also be used to overcome part-load efficiency penalties; using VSDs, speed follows the load and thus improves the integrated-part-load efficiency. Variable-speed drives and well-controlled multiplexed compressor systems are considered the primary load-matching measures. *Floating head pressure controls* allow the condensing pressure to float with the ambient temperature thus decreasing the compression ratio during certain times of the year/day, improving efficiency, and extending equipment life.

Condenser Efficiency Measures: For the basic system models, the condenser is air-cooled. There are several options for reducing the condensing temperature and thereby decreasing the compression ratio and improving efficiency. *Evaporative condensers* permit the condensing temperature to approach the outdoor wet-bulb temperature, which could be 20-30°F below what could be achieved with an air-cooled condenser. (An air-cooled condenser can only approach the outdoor dry-bulb temperature.) Similar condenser temperature reductions are attained using *cooling tower systems* where water is cooled in cooling towers and heat is removed from the condenser using refrigerant-to-water heat exchangers. A third method for achieving lower condensing temperatures is to precool the air flowing through the air-cooled condenser using *evaporative precoolers.*

Waste heat recovery can meet substantial heating loads for other end uses such as water heating using the otherwise rejected refrigeration heat. The impact of heat recovery on the refrigeration system efficiency depends on how the condensing temperature is affected. This secondary effect is hard to quantify and depends on how well the system is engineered.

Subcooling Efficiency Measures: There are also a number of system efficiency measures related to evaporator efficiency. Cooling the liquid refrigerant from the condenser (subcooling) prevents early flashing of condensate. This, in turn, facilitates better evaporator performance because the wet surface in the evaporator is increased and thus improves heat transfer. There are a variety of methods for achieving this further cooling. *Ambient subcooling* is the simplest of these methods. Ambient subcooling occurs either in the final passes through the condenser coil or in a separate subcooling coil where heat is rejected to the ambient air. This method takes advantage of low ambient temperatures when they occur. *Mechanical subcooling*, on the other hand, uses a separate refrigeration loop to pump the heat away. In such systems, the savings in energy consumption due to subcooling are partially lost to the energy consumption of the compressor of the new loop. Another method is to use a *liquid/suction heat exchanger*, which uses the cold refrigerant vapor from the evaporator to cool the liquid from the condenser. One method for avoiding early condensate flashing is to pressurize the liquid from the condenser using a *liquid-line pump.*

Efficiency

The basic system models are assumed to be equipped with air-cooled condensers. The efficiencies of the basic system configurations are expressed in terms of Annual EERs in **Table 6**. Annual EERs are integrated-part-load efficiencies[3] as opposed to Full-load EERs which represent efficiency only when the system is operating at full load. The impacts of efficiency measures on the Annual EERs as a percentage improvement are also presented in Table 6. It can be seen in

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[3] Integrated-part-load efficiency is the weighted average of the actual equipment performance over some period of time. Annual integrated-part-load efficiency can be used to convert annual refrigeration loads to annual energy consumption.

Table 6. System Efficiency and Impacts of System Measures on Efficiency (#)

		System Type				Notes
		Medium Temperature (*)		Low Temperature (*)		
		Single Compressor	Multiplex	Single Compressor	Multiplex	
Annual EER (Btu/Wh)		9	10.0-12.0	5	5.2-5.8	1
Compressor Measure Impacts (% improvement in Annual EER)	Efficient Compressor /Motor	10%	10%	10%	10%	2
	VSD	9%-16%	9%-16%	9%-16%	9%-16%	3
	Floating Head Pressure	10% - 15%	10% - 15%	10% - 15%	10% - 15%	4
Condenser Measure Impacts (% improvement in Annual EER)	Evaporative Condenser	5% - 10%	5% - 10%	5% - 10%	5% - 10%	4
	Cooling Tower	23%	23%	23%	23%	5
	Evaporative Precooling	9%-12%	9%-12%	9%-12%	9%-12%	6
	Waste Heat Recovery	No Direct Impact	No Direct Impact	No Direct Impact	No Direct Impact	7
Subcooling Measure Impacts (% improvement in Annual EER)	Liquid-line Pump	14% - 33%	14% - 33%	14% - 33%	14% - 33%	8
	Ambient Subcooling	1.4%-2.6%	1.4%-2.6%	1.4%-2.6%	1.4%-2.6%	9
	Liquid Suction Heat Exchanger	Not Used	Not Used	6%	6%	10
	Mechanical Subcooling	3%-28%	3%-28%	3%-28%	3%-28%	11

(#) The improvement in EER for combined measures can be calculated using:
% improvement = ((1+ % improvement1)*(1 + % improvement2)* ....*(1 + % improvement) -1) * 100, when the measures do not interact. Interactions between measures which are not mentioned in individual footnotes are as follows: (a) the first three condenser measures are mutually exclusive (cannot be applied simultaneously) and (b) when floating head pressure controls are used together with VSD, combined improvement will be less than that which is calculated with the above formula. The exact improvement is dependent on specific system characteristics.

(*) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(1) Annual EERs including electricity for compressor, fans, and pumps (if any). Source for single compressor EER is EPRI (1992). Source for Annual EER for multiplex systems is Comptetitek (1990): simulation results indicate that for high temp., pressure controls alone generate 13% savings, pressure controls together with temp. controls generate 27% savings compared to a single compressor; for low temp., pressure controls alone generate 4% savings, pressure controls together with temp. controls generate 13% savings compared to a single compressor.

(2) Source: Competitek (1990)

(3) Corresponding to condenser temperatures of 80°F and 50°F, respectively. Source: Competitek (1990). Also, improvement in seasonal COP is estimated at 10-15% in ADL (1993).

(4) Source: ADL (1993)

(5) Source: ASHRAE (1985) page 28.7

(6) More effective when the relative humidity of the ambient air is low. Source: Usibelli (1985).

(7) This measure does not affect the energy required for the refrigeration.

(8) This is average improvement. Savings are greater in cooler climates and less in warmer climates. The figures are for applications with and without floating head pressure respectively. Source: Competitek (1990).

(9) For air-cooled and evaporatively cooled condensers, respectively. Source: Competitek (1990).

(10) Improvement in Annual EER is 3% if there is mechanical subcooling also. Source: EPRI (1989) and Competitek (1990).

(11) Corresponding to condenser temperatures of 60°F and 80°F, respectively. Source: Competitek (1990). ADL (1993) estimates an improvement of 5% in seasonal COP for mechanical subcooling.

Table 6 that there are sometimes interactions among the measures and, if the interacting measures are applied concurrently, the impact on overall efficiency cannot be calculated by adding together the impacts of individual measures. For example, the impact of a liquid/suction heat exchanger is reduced by half if mechanical subcooling also exists. In its present form, the COMMEND 4.0 refrigeration model does not account for measure interactions. If the necessary saturation data are available, one way around this problem is to define a combination of measures as a separate measure.

Cost

The costs of the basic system models and the incremental costs of the efficiency measures are presented in **Table 7**. The incremental costs of the measures are generally a one-time cost accrued at the time of equipment purchase or retrofit. For evaporative condensers and cooling towers, there are also annual costs representing the increase in operation and maintenance costs. In one case, the incremental cost is negative – the initial cost of the evaporative condenser happens to be lower than the cost of a typical air-cooled condenser. However, the annual operating costs are much higher for the evaporative condenser and thus make it a less desirable option.

The COMMEND 4 .0 refrigeration model is not designed to account for a stream of future costs in the analysis. One way to include such costs is to add the present value of future expenses to the initial cost.

Saturation

Tables 8.a and 8.b present market saturations for both refrigeration system type and efficiency measures by system type. Saturations are indicated for both the stock (Table 8.a) and new installations (Table 8.b).

Equipment Life

As mentioned above, the useful life of refrigeration equipment is determined more by the periodic remodeling of the buildings in which the equipment is used than by the actual life of the equipment; consequently, stock accounting is dictated by the remodeling activity. Nevertheless, most refrigeration system measures have a useful life of 15 years. An exception is evaporative precooling coils, which have a useful life of about ten years; the lifetime, however, is highly dependent on maintenance and water quality.

Unitary Refrigerators

As mentioned above, most commercial-sector refrigeration uses centralized systems. However, commercial buildings are equipped with a variety of unitary systems such as commercial 2-, 3- or 4-door reach-in refrigerators, unitary display cases, and under-the-counter refrigerators. ADL (1993) estimated the number of unitary systems in 1990 to be about 2.1 million. Retail and restaurant buildings are estimated to house more than 0.5 million units each. Additional significant users of unitary systems are offices, grocery stores, and schools – each building type is estimated to house 0.2-0.3 million units. Hospitals and hotels are estimated to have about 0.1 million units each. Based on these distributions, as well as utilization factors, typical coefficients of performance, and typical rated capacities, ADL (1993) estimated the total electricity consumption of all unitary coolers in the U.S. commercial sector to be 13.3 billion kWh for 1990.

Table 7. System and System-Measure Costs (#)

		System Type				Notes
		Medium Temperature (*)		Low Temperature (*)		
		Single Compressor	Multiplex	Single Compressor	Multiplex	
System Cost (Installed) (1992 dollars) (**)		$790/hp	$860-$1040/hp plus $24/hp-year	$790/hp	$860-$1040/hp plus $24/hp-year	1
Compressor Measure Incremental Costs	Efficient Compressor /Motor	$26/hp-New	$26/hp-New	$26/hp-New	$26/hp-New	2
	VSD	$120-$300/hp	$120-$300/hp	$120-$300/hp	$120-$300/hp	3
	Floating Head Pressure	$1025/system (retrofit) $130/system (new)	$1025/system (retrofit) $130/system (new)	$1025/system (retrofit) $130/system (new)	$1025/system (retrofit) $130/system (new)	4
Condenser Measure Incremental Costs	Evaporative Condenser	(-) $32/hp-new plus $15/hp-year	(-) $32/hp-new plus $15/hp-year	(-) $32/hp-new plus $15/hp-year	(-) $32/hp-new plus $15/hp-year	5
	Cooling Tower	$450/ton + $75/ton-year	$450/ton + $75/ton-year	$450/ton + $75/ton-year	$450/ton + $75/ton-year	6
	Evaporative Precooling	$380-$1540/ condenser	$380-$1540/ condenser	$380-$1540/ condenser	$380-$1540/ condenser	7
	Waste Heat Recovery	$140-150/ton	$140-150/ton	$140-150/ton	$140-150/ton	8
Subcooling Measure Incremental Costs	Liquid-line Pump	$85/hp	$155/hp	$85/hp	$155/hp	9
	Ambient Subcooling	$60-$70/ton	$60-$70/ton	$60-$70/ton	$60-$70/ton	10
	Liquid Suction Heat Exchanger	-	-	$130-160/ton	$130-160/ton	11
	Mechanical Subcooling	$80-$90/ton	$80-$90/ton	$80-$90/ton	$80-$90/ton	12

(#) Some costs are given per ton of cooling capacity and some others per compressor hp. Costs can be converted from one convention to the other using the following approximate conversion factors: (a) for medium temperature systems, 1 ton = 1.78 hp; (b) for low temperature systems, 1 ton = 3.2 hp.

(*) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(**) A price deflator of 1.28 is used between the years 1992 and 1986.

(1) The costs for multiplex systems are for 3- and 5-compressor systems respectively. The maintenance cost is about $24 greater per hp for the multiplex systems. Source: Competitek (1990).

(2) Source: Competitek (1990).

(3) Costs are for 100 and 10 hp systems, respectively. Source: Nadel et al. (1991). (A price deflator of 1.07 is used between the years 1990 & 1992.)

(4) Source: Usibelli (1985). Competitek (1990) estimates the cost for floating head pressure controls at $37/hp for new systems. EPRI (1992) estimates these costs in the range $80-90/ton.

(5) Installed cost of evaporative condenser is less than the cost of air-cooled condenser, but the magnitude of the maintenance cost makes this option less attractive (Competitek 1990). EPRI (1992) estimates these costs as approx. negative $70-80/ton, plus annual maintenance cost of $30-40/ton.

(6) There is a maintenance and water supply cost associated with this measure. Source: Competitek(1992).

(7) For condenser coil face areas of 5 ft2 and 30 ft2, respectively. Source: Usibelli (1985).

(8) Source: EPRI (1992).

(9) Source: Competitek (1990).

(10) Source: EPRI (1988). Competitek (1990) estimates this to be $26/hp.

(11) Source: Competitek (1992).

(12) Source: EPRI (1988). Competitek (1990) estimates this to be $37/hp.

Table 8.a. Market Saturations of Systems and System-Measures: Stock Average (*)

				Compressor Measure Saturation			Condenser Measure Saturation				Evaporator Measure Saturation			
Building Type	Use (Temperature) (**)	System Type	System Saturation	Efficient Compressor	VSD	Floating Head Pressure	Evaporative Condenser	Cooling Tower	Evaporative Precooling	Waste-Heat Recovery	Liquid-Line Pump	Ambient Subcooling	Liquid Suction Heat Exchanger	Mechanical Subcooling
Grocery	Medium Temperature	Single Compressor	75%	19%	5%	49%	0%	25%	0%	<3%	<2%	19%	-	19%
		Multiplex	25%	19%	5%	49%	40%	0%	0%	<3%	<2%	19%	-	19%
	Low Temperature	Single Compressor	75%	19%	5%	49%	0%	25%	0%	<3%	<2%	19%	<2%	19%
		Multiplex	25%	19%	5%	49%	40%	0%	0%	<3%	<2%	19%	<2%	19%
Restaurant	Medium Temperature	Single Compressor	100%	<5%	0%	0%	0%	0%	0%	<5%	0%	0%	-	0%
		Multiplex	0%	<5%	0%	0%	0%	0%	0%	<5%	0%	0%	-	0%
	Low Temperature	Single Compressor	100%	<5%	0%	0%	0%	0%	0%	<5%	0%	0%	<2%	0%
		Multiplex	0%	<5%	0%	0%	0%	0%	0%	<5%	0%	0%	<2%	0%
Warehouse	Medium Temperature	Single Compressor	75%	5%	5%	12%	0%	0%	0%	<1%	<2%	5%	-	5%
		Multiplex	25%	5%	5%	12%	40%	0%	0%	<1%	<2%	5%	-	5%
	Low Temperature	Single Compressor	75%	5%	5%	12%	0%	0%	0%	<1%	<2%	5%	<2%	5%
		Multiplex	25%	5%	5%	12%	40%	0%	0%	<1%	<2%	5%	<2%	5%
Notes			1	2	3	4	5	6	7	8	9	10	11	12

(*) System saturation indicates the share of system types in each market segment (i.e building-type/use combination).
Measure saturations indicate the penetration of the measure in the building-type/use/system-type combination.

(**) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(1) Source: ADM (1989) for groceries.
(2) Source: WCDSR (1990). Competitek (1990) estimates an overall penetration of 5% .
(3) Source: Comptetitek (1990).
(4) Source: WCDSR (1990).
(5) Estimate. ADL (1993) estimates an overall penetration of 25%.
(6) Estimate.
(7) Estimate.
(8) Estimate.
(9) About 2000 installations in the U.S. Liquid/suction heat exchanger is the main competition. Source: Competitek (1990).
(10) Source: WCDSR (1990).
(11) Estimate.
(12) Source: WCDSR (1990). ADL (1993) estimates an overall penetration of 25%.

Table 8.b. System and System-measure Saturations: New Buildings (*)

				Compressor Measure Saturation			Condenser Measure Saturation				Evaporator Measure Saturation			
Building Type	Use (Temperature) (**)	System Type	System Saturation	Efficient Compressor	VSD	Floating Head Pressure	Evaporative Condenser	Cooling Tower	Evaporative Precooling	Waste-Heat Recovery	Liquid-Line Pump	Ambient Subcooling	Liquid Suction Heat Exchange	Mechanical Subcooling
Grocery	Medium Temperature	Single Compressor	75%	30%	5%	49%	0%	25%	0%	<3%	<2%	19%	-	19%
		Multiplex	25%	30%	5%	49%	40%	0%	0%	<3%	<2%	19%	-	19%
	Low Temperature	Single Compressor	75%	30%	5%	49%	0%	25%	0%	<3%	<2%	19%	<2%	19%
		Multiplex	25%	30%	5%	49%	40%	0%	0%	<3%	<2%	19%	<2%	19%
Restaurant	Medium Temperature	Single Compressor	100%	30%	0%	0%	0%	0%	0%	<5%	0%	0%	-	0%
		Multiplex	0%	30%	0%	0%	0%	0%	0%	<5%	0%	0%	-	0%
	Low Temperature	Single Compressor	100%	30%	0%	0%	0%	0%	0%	<5%	0%	0%	<2%	0%
		Multiplex	0%	30%	0%	0%	0%	0%	0%	<5%	0%	0%	<2%	0%
Warehouse	Medium Temperature	Single Compressor	75%	30%	5%	12%	0%	0%	0%	<1%	<2%	5%	-	5%
		Multiplex	25%	30%	5%	12%	40%	0%	0%	<1%	<2%	5%	-	5%
	Low Temperature	Single Compressor	75%	30%	5%	12%	0%	0%	0%	<1%	<2%	5%	<2%	5%
		Multiplex	25%	30%	5%	12%	40%	0%	0%	<1%	<2%	5%	<2%	5%
Notes			1	2	3	4	5	6	7	8	9	10	11	12

(*) System saturation indicates the share of system types in each market segment (i.e building-type/use combination).
Measure saturations indicate the penetration of the measure in the building-type/use/system-type combination.

(**) Medium Temperature: approx. 20°F evaporator temperature (approx. 35°F case temperature)
Low Temperature: approx. minus 20°F evaporator temperature (approx. 0°F case temperature)

(1) Assumed to be the same as for stock buildings because of lack of data.

(2) Source: Competitek (1990). WCDSR (1990) estimates penetration of efficient compressors at 19% for groceries and 5% for warehouses.

(3) Assumed to be the same as for stock buildings because of lack of data.

(4) Source: WCDSR (1990). (Competitek (1990) estimates an overall penetration of 27% for New England. These values are for New England. Penetration is a bit bigger in the Mid West and a bit lower in the South and Southwest due to warmer climates.)

(5) Assumed to be the same as for stock buildings because of lack of data.

(6) Assumed to be the same as for stock buildings because of lack of data.

(7) Assumed to be the same as for stock buildings because of lack of data.

(8) Assumed to be the same as for stock buildings because of lack of data.

(9) Assumed to be the same as for stock buildings because of lack of data.

(10) Source: WCDSR (1990).

(11) Assumed same as for stock buildings for lack of data.

(12) Source: WCDSR (1990).

O'Regan et al. (1984) estimated the amount of food-service refrigeration equipment that was in use in 1979, based on data from the National Association of Food Equipment Manufacturers. These data are shown in **Table 9** and provide a general indication of the size of the stock for different types of unitary equipment. We estimate the electricity consumption of these unitary coolers to be 10.5 billion kWh for 1992.

Although the two estimates of unitary refrigerator energy use differ by 2.8 billion kWh, the two estimates of the number of unitary refrigerators are remarkably similar. The ADL report estimates inventory by *building type* and uses utilization factors, typical rated capacities, and COPs to calculate their estimate. In the alternative estimate, inventories by *equipment type* are multiplied by typical annual energy use figures. Both methods have weaknesses. In the ADL method, equipment utilization information and equipment information (such as COPs and rated capacities) are disaggregated by building type but not by equipment type. In the O'Regan et al. estimate, the reverse is true: equipment utilization information and equipment information are disaggregated by equipment type but not by building type.

Table 9. Estimates of Total Stock of Food-Service Refrigeration Equipment

Equipment Type	**1979 Stock (in 1000s)**[1]	**1992 Stock (in 1000s)**[2]	**Energy Use per Unit (kWh/yr)**[1]	**1992 Total Energy Use (10^9 kWh/yr)**
Full-size reach-in				
refrigerator	638	797	4400	3.5
freezer	482	602	7300	4.4
Under-the-counter reach-in				
refrigerator	362	452	2900	1.3
freezer	176	220	5500	1.2
Mobile Cart				
refrigerator	50	62	1200	0.07
freezer	10	13	1200	0.02
TOTAL	**1718**	**2146**		**10.5**

(1) Based on O'Regan et al. (1984)

(2) Based on EIA (1981, 1994), commercial-sector floor area increased by 25% between 1979 and 1992. We assume here that the number of unitary refrigerators also increased by 25% and that the mix of equipment used in the commercial sector has not changed during this period.

Another significant user of commercial-sector refrigeration energy is ice machines. ADL (1993) estimated the total number of ice makers to be about 1.2 million in 1990. Half a million of these were estimated to be in hotels, 0.3 million in hospitals, and 0.16 million in restaurants; the remainder were found in smaller numbers in offices, retail establishments, supermarkets, and schools. ADL estimated the total 1990 energy consumption of ice makers to be 9.4 billion kWh.

Residential refrigerators are used in employee break rooms or lunch rooms in virtually all types of commercial buildings. Small residential refrigerators are also rapidly penetrating hotel rooms. It is difficult to estimate the number of residential refrigerators in the commercial sector; nevertheless, their energy consumption can be estimated approximately based on conditional demand studies for building types in which other forms of refrigeration are not utilized (primarily offices and retail establishments). Such estimates, however, may also include water coolers and vending machines.

ADL (1993) estimated the total number of commercial-sector vending machines and water coolers to be six million each in 1990. The total amount of electricity used by these vending machines and water coolers was estimated to be 9.7 billion kWh and 4 billion kWh, respectively.

6. REFRIGERATION DEMAND FOR THE U.S.

The floor areas for groceries, restaurants, and warehouses are presented in **Table 10**, together with the areas for the other building types. These areas can be used together with the service demand characteristics in Table 2 to arrive at the total refrigeration service demand (by service type) for the U.S.

7. CONCLUSIONS

Because energy consumption is increasing so rapidly in the commercial sector, it is important for energy analysts to have access to commercial energy end-use forecasting models that disaggregate energy consumption not only by fuel type, end use, and building type, but also by specific technology. In this report, we describe our development and refinement of a base-year data set characterizing refrigeration technologies in commercial buildings.[4]

Although this highly detailed data set was developed specifically for EPRI's COMMEND 4.0 forecasting model, it will also be useful for forecasters using other commercial-sector models, and researchers and practitioners involved in policy analysis. Using the data set that we created for COMMEND 4.0, analysts will be able to evaluate national commercial-sector, energy-related policies and programs at the technology level.

The data presented in this report will be refined and improved as more commercial-sector data become available. Although there is little information now available regarding the market shares of specific technologies, we expect future commercial-sector surveys to respond to this lack by including questions that will allow for improved characterization of the commercial sector.

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[4] We have also developed data sets characterizing lighting, space conditioning, office equipment, and water heating technologies. These characterization studies are published as LBNL reports (Sezgen et al. 1994, Sezgen et al. 1995, Koomey et al. 1995, Sezgen and Koomey 1995).

Table 10. U.S. Commercial Floor Area by Building Type

	Floor Area (billion ft2)		
Building Type	**1992**	**1993**	**2000**
Assembly	7	7.03	7.07
Education	8.36	8.45	8.38
Grocery	0.83	0.85	0.96
Restaurant	1.23	1.25	1.4
Health Care	2.28	2.37	2.79
Lodging	3.65	3.7	4.07
Office-large	7.2	7.34	8.22
Office-small	5.22	5.31	5.95
Retail	13.17	13.47	15.65
Warehouse	9.83	9.96	10.94
Other	7.32	7.29	6.91
TOTAL	66.09	67.01	72.36

Source: EIA (1995), Table 22 for 1993 and 2000, and unpublished information supporting EIA (1995) for 1992.

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