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ENERGY EFFICIENCY IN COMMERCIAL FOOD SERVICE REFRIGERATION: AN ASSESSMENT OF TECHNICAL POTENTIAL AND DATA NEEDS

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ABSTRACT

Food-service refrigeration equipment consumes about 11 x 10^9 kWh/yr in the United States. Over the long run, probably 40% of the consumption of this end-use can be economically conserved, equivalent to almost a 1% reduction in the electricity consumed by the commercial sector. This paper discuses the typical equipment used in this end-use, the sources of reduced energy use, and outlines the research needed to further quantify and accomplish this potential.

KEYWORDS: energy conservation, refrigeration, food service equipment, energy consumption, commercial sector

INTRODUCTION

This paper explores a specific end-use in a specific building type of the commercial sector, food-service refrigeration, both because of its intrinsic interest, and as a model for data compilation and analysis in other parts of the commercial sector. We chose restaurants because of their small size (relative to other commercial buildings), and because they contain a wide variety of equipment and end-uses. We chose to look first at refrigeration because it is common to all restaurants, uses somewhat standardized equipment, is relatively easy to submeter, and because the end-use energy consumption was underestimated in several references which have served as a basis for many other studies.[1,2] Also, remarkably, ASHRAE lacks a committee, standards, and testing procedures for food-service refrigeration.

In this paper we first describe the equipment involved in this end-use and the way it is used. Second, we review the small amount of measured data now available and estimate the aggregate energy use and potential savings. Last, we outline a program to gather some of the data needed for an intelligent discussion of conservation measures and their potential.

I. End Use Description

Food service refrigeration equipment, although it works by the same principles as residential equipment, is very different from residential equipment in size range, variety of construction and usage, and typical operating environments. This section will give a brief overview of the type and use of food service refrigeration equipment.

The largest items of equipment used in food service refrigeration are "walk-in" units, i.e those with high enough ceilings and large enough interiors that a person can comfortably walk into the unit to fill or unload it. These units are often as large as 10' x 20' (7' or 8' ceiling) and can be ordered larger. A 10x20' walk-in freezer (0 or -10 ^{o}F) will have at least a 2.5 KW motor to run the compressor. (A residential refrigerator will have typically about a 350 watt motor.) At the small end of the size range are many use-specific units such as water coolers, beer-on-tap coolers, and display cases. The smallest of these might have 4 cubic feet of refrigerated volume and a 180 watt motor. The most common sizes are the one and two door "reach-in" models, which have about 25 and 50 cubic feet of refrigerated volume respectively. The term "reach-in" describes a unit with the same shape and access as a residential refrigerator. A typical two door reach-in refrigerator might have an 800 watt motor and consume about 4000 KWh per year (vs. a residential refrigerator consumption of about 1000 KWh/yr). More on consumption later.

As well as a large size range, food service refrigeration equipment comes in a wide variety of designs and purposes. Units vary with respect to what is being cooled, how it is stored, and what material is between the cooled volume and the ambient environment. Glass display cases, pizza preparation tables, ice makers, roll-ins, open face coolers, and ice-cream machines are a few models where some special purpose has caused the design to differ from the stereotypical "insulated box around a cold volume of food and air".

Pizza preparation tables, for example, have a typical rectangular refrigerated space, underneath a counter-height table. In addition, however, pizza tables have a fan that blows air from that space across the bottom of a row of trays which hold and keep cool the materials used on the pizzas. These trays are open to the kitchen air, thus in this design some of the cooled material is actually outside the cooled volume of air. In some places only a single layer of metal separates the cold volume from the ambient environment. Because the trays are only loosely set in the top of the passage holding the cold air there is some leakage of air around them in the best of conditions. If the trays are bent or not properly placed the cold air leakage could be very large.

Ice makers, on the other hand, are different in that they do not directly refrigerate a volume at all. Most ice makers freeze water on a refrigerated plate, cut the slab of ice into cubes and drop the cubes into a storage box. The storage box is typically insulated but not refrigerated except by melting ice. The energy consumed by ice makers is thus mainly determined by how much ice is used.

The typical usage patterns of food service refrigerators--in otherwords how often the doors are opened, how much food is put in the unit and at what temperature--vary more than those of residential refrigerators. In some food service refrigerators, used almost entirely for long-term storage, food is brought in, already cold, from a refrigerated truck, and the doors are opened infrequently (perhaps 10 times per day). In such a unit the heat gain through the walls is the major determinant of electricity consumption. In other equipment, such as a reach-in unit used to cool baked goods, the main determinant of energy use is the heat gain from warm food placed in the refrigerated space to be cooled. (This does not imply that heat gain through the walls becomes unimportant.) In still other units (beer coolers, for instance) the doors are opened so frequently that the heat gained in the air introduced by each door opening becomes a major factor. A small fraction of food service refrigeration equipment is used for display or short-term cooling only and is unloaded (and hopefully turned off) when not in use.

On the average, process loads, such as door openings and warm food, are responsible for a much larger fraction of the electrical consumption in food-service refrigeration equipment than in residential equipment. Many units in food-service applications have more than one complete turnover of their contents per day. In residential equipment standby electrical consumption is above 80% of total electrical consumption.[3]

The variation in designs and usage patterns of food-service refrigerators, and the corresponding differences in the main determinant of their energy use, will determine what measurements will be necessary to establish average consumption, and what design changes will be most cost effective.

II. Stock of Units and Aggregate Energy Consumption

Below, we estimate the total electricity consumption of food service refrigeration. We include these stock and consumption numbers only to establish the order of magnitude of each. The surveys are of unknown size and quality and some of the unit consumption figures are guesses. In Appendix A we review the data sources we have uncovered to date.

The National Association of Food Equipment Manufacturers (NAFEM) has estimates of the total stock of food service refrigeration equipment based on a survey done in 1979 (Table 1).[4] We have combined the stock data from NAFEM and our own estimates of the average consumption of each type of equipment to estimate total nationwide consumption (Table 2).

Table 1. Estimates of the total stock of food service refrigeration equipment from the National Association of Food Equipment Manufacturers (NAFEM) and from a report by Thermo Electron Corp.

NAFEM (1979)		Thermo Electron (1975)	
Equipment Type	Stock (in 1000s)	Equipment Type	Stock (in 1000s)
Full size reach-in			
refrigerator	638	Reach-in	914
freezer	482		
Under counter reach-in			
refrigerator	362	Storage	330
freezer	176		
Walk-in			
refrigerator	263	Walk-in	271
freezer	113		
Mobile cart			
refrigerator	50	Ice cream	470
freezer	10		
TOTAL	2094	TOTAL	1985

Equipment Type	Stock (1000s)	Unit Energy Use kWh/yr	Total Energy Use 10^9 kWh/yr	Basis for unit energy use
Full-size reach-in:				
refrigerator	638	4400	2.8	LBL data (see text), this type and its consumption will be referred to as #1 below
freezer	482	7300	3.5	1.67 x #1: Twice delta T, lower COP, but more insulation? fewer door openings, smaller.
Under-counter reach-in:				
refrigerator	362	2900	1.0	0.67 x #1: Less than ½ size, but less insulation, special purpose units.
freezer	176	5500	1.0	0.75 x #2: same as above but probably includes ice makers.
Walk-in:				
refrigerator	263	5500	1.4	LBL data and run time estimates combined with common compressor sizes.
freezer	113	9100	1.0	1.67 x walk-in refrigerator.
Mobile cart	60	1200	0.1	complete guess, 10kWh/day when in use, in use one third of the time.
TOTAL	2094		11×10^9 kWh/yr	

Table 2. Calculation of aggregate energy use based on NAFEM stock and LBL unit energy use estimates.

Our estimate is 11×10^9 KWh/yr, or about 2% of the electricity use in the commercial sector. This figure covers a population of about 400,000 food service establishments. Thus the "average establishment" has about 6 pieces of equipment, which together consume about 3×10^4 KWh/yr and require an expenditure of ~ $2,000/yr for electricity. This is about 10% of a typical restaurant bill for energy.

Thermo Electron Corp., under contract to Oak Ridge National Laboratory, studied the potential for conservation in commercial appliances.[5] The section on refrigeration contained estimates of the stock based on a survey by Frost and Sullivan Inc. (Table 1.). To estimate the total consumption for this stock, Thermo Electron got estimates of average compressor on-times from manufacturers, and estimated average compressor sizes for each of the sub-stocks. The product of these two, multiplied by the number of units in the substock, produced a calculated total consumption of 13 x 10^9 KWh/yr.

III. Magnitude of Potential Savings

Although the data are lacking for any firm calculations, we estimate the long-term potential for cost-effective conservation to be at least 40% of present use. About half this potential resides in the range of energy efficiency in the models presently on the market. We believe it likely that a difference of greater than 20% exists between the average efficiency of all of the units now on the market and that of the most efficient 25% of those units. Because there are no energy consumption values available from the manufacturers, and no standard procedure for measuring energy consumption, this estimate is by necessity based on the models we have seen in the field and on the situation prevalent in residential refrigeration before the application of standards and energy labels (see Figure 1).[6]

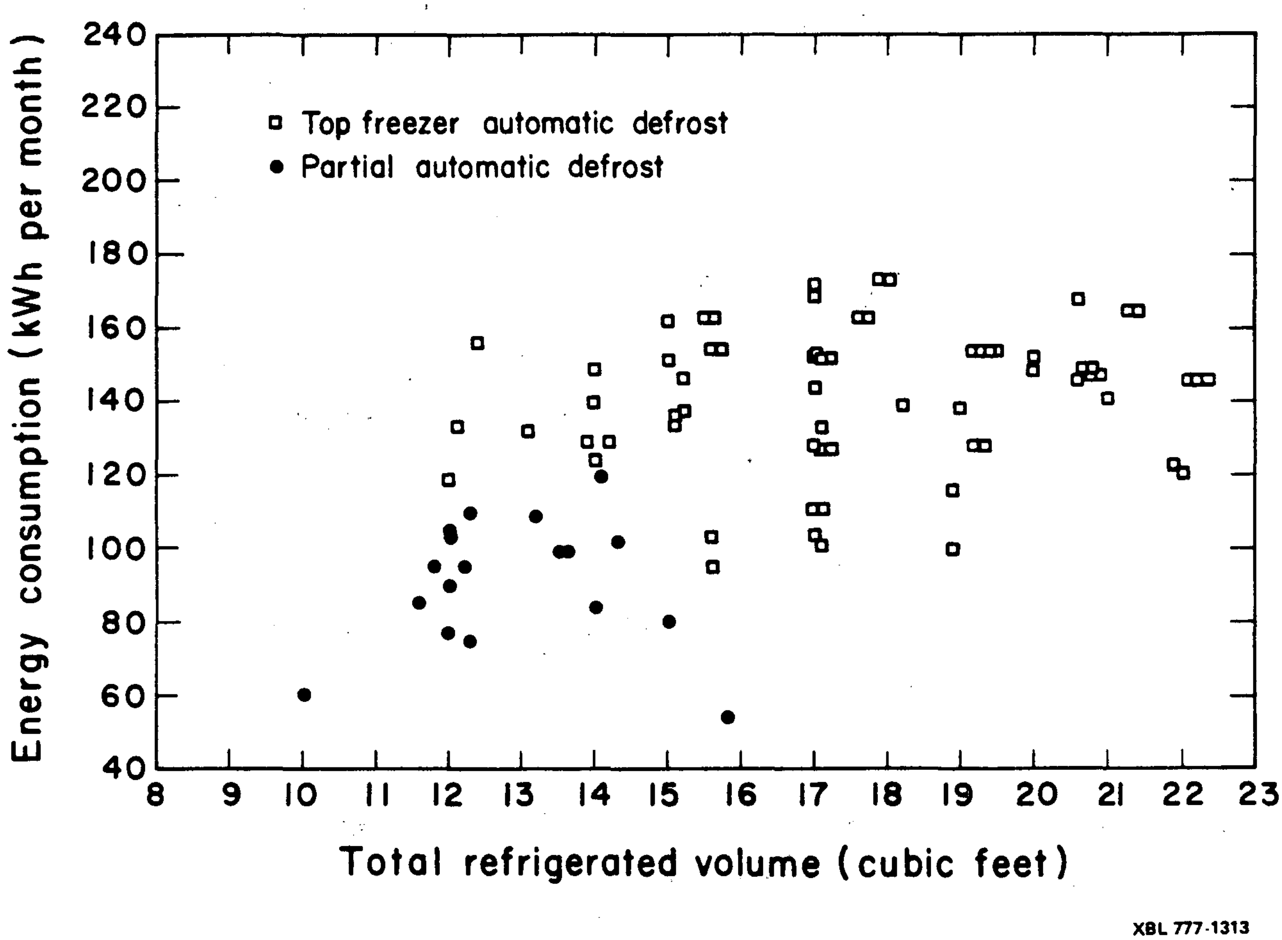

Fig. 1. Scatter plot of energy consumption vs size for all 1976 partial automatic defrost and top freezer automatic defrost residential refrigerators. (From Ref. 5)

The other half of the estimated conservation potential is available from cost-effective design changes in even the more efficient models presently on the market. Once again this is supported by analogy to residential refrigerators (see Figure 2)[7,8] but it is also based on a number of common, easily observable, design features.

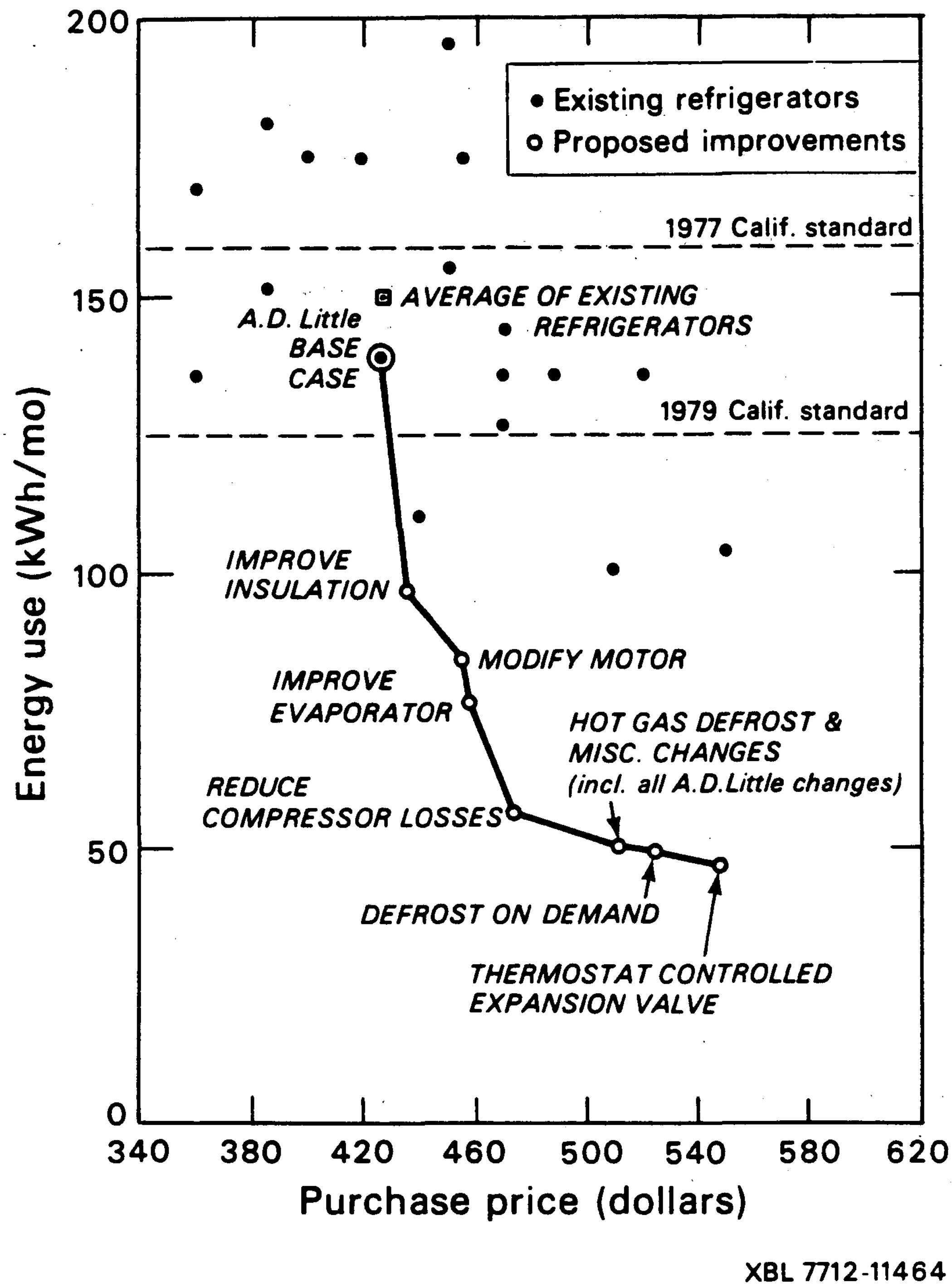

Fig. 2. Scatter plot of energy use vs purchase price for 1976 residential automatic defrost refrigerators between 16 and 17.5 ft^3 (From Ref. 7) and a plot of energy use vs purchase price for a hypothetical refrigerator as a progression of efficiency improvements are added. (Based on Ref. 6)

These include small condensers, which are necessarily coupled with large power-consuming fans, poorly placed condenser air intakes and outlets (with respect to the likelihood of being blocked by other equipment or the coil surfaces being soiled by debris from the floor), and the sacrifice of insulation thickness or other energy-efficient characteristics in models designed for cramped spaces or specialized uses (e.g., pizza preparation tables, pie displays, undercounter units). See Table 3 for a list of possible conservation measures.

Table 3. The following list of measures is applicable to commercial refrigeration. We have not yet gathered sufficient information to be able to calculate potential savings by measure.

Measures for New Refrigerators

- Improved evaporator efficiency
  - optimized air flow
  - higher fan and motor efficiency and motor outside of cooled space
  - staged or variable speed fan
- Improved refrigerant cycle controls
- Different refrigerants
- Higher motor and/or compressor efficiency
- Improved condenser
  - larger condenser, smaller fan and motor
  - better located (thus cleaner, better air flow)
  - water cooled
  - outside condenser, or outside air to condenser
- Better shell
  - special glass for glass doors
  - more insulation, especially on small, and display units
  - better design for special purpose (e.g. pizza table) units
  - hot gas mullion heaters

Measures for Retrofitting Existing Units

- Replace evaporator fan motor with one of higher efficiency
- High-efficiency replacement motor/compressor when it fails
- Replacement doors, curtains, etc. for units where that feature is poorly designed
- Insulated floors for walk-ins
- Refrigerant cycle changes, controls
- Timers on walk-in lights
- Improved door seals
- Outside air to condensers
- Central compressor/condenser
- Effect of heat reclaim

IV. Data Needed

A relatively small amount of research would allow a much better analysis of both components of the conservation potential. To quantify the potential savings from purchasing the best models on the market one needs the average in-situ energy consumption and market share of all current models. Without large scale in-situ metering, establishing actual energy consumption will require an accurate measurement procedure. To quantify the savings from design changes and retrofits (without constructing prototypes for each proposal) will require a computer simulation for food-service refrigerators with sufficient accuracy to predict their energy consumption in-situ. To establish a standard measurement procedure and to develop and test a simulation will require data on a range of in-situ conditions and usage patterns, along with the resultant in-situ energy consumption for several refrigerators. We outline below a project that will allow a reasonable first approximation of the conservation potential from changing purchase habits and will also collect the necessary data for simulating design changes.

A likely procedure for measuring energy consumption will use a "hot box" test chamber like that used for residential refrigerators, with some provision for adding heat directly to the interior of the refrigerator and perhaps for subjecting the refrigerator to high radiant temperature as well as air temperature. In order to calibrate such a procedure we suggest testing 3 to 6 reach-in* models and simultaneously instrumenting identical units in "typical" restaurants. The in-situ measurements should include: energy use, compressor on-time, door openings, food load, and temperatures. The temperatures should include: air temperatures in the kitchen, in the refrigerator, and near the condensing coils (if different from the kitchen), and the radiant temperature near the refrigerator. The conditions in the test chamber should be modified until it can cause a refrigerator to mimic its in-situ energy use. If significant variation is suspected between units of the same make and model, an exchange could be arranged so that the same units instrumented in-situ could also be tested in the chamber. This process will prove some correspondence between test chamber results and real usage. As the restaurants chosen for the in-situ measurements are unlikely to be completely average, a survey of typical kitchen temperatures and refrigerator usage patterns will be needed before a standard measurement procedure can be established.

In order to make the comparison of test chamber and in-situ consumption as valuable as possible we suggest that the models used span the range of energy efficiency available on the market. If the manufacturers can't supply approximate energy consumption figures; "better" and "worse" models can be found by looking at insulation levels and compressor sizes.

In parallel to the above project, using the data gathered on the units in-situ and in the test chamber, one of the computer simulations developed for residential refrigerators could be modified

*Reach-ins are simple, small enough to move, and common.

to predict energy use in food-service refrigerators. Work with this simulation could begin to quantify the conserved energy available from more efficient designs.

This research program should give a reasonable estimate of the amount of conserved energy available from this building type/end-use combination. If the program results in a decent understanding of the determinants of consumption for the reach-in equipment, proven by the ability to match in-situ consumption in a test chamber and with a simulation, then a similar program could be applied to less standardized units (e.g. pizza tables, display cases). These will be more difficult to simulate, because of the unusual designs, but the potential for conserved energy appears to be high.

CONCLUSIONS

We have described the poor quality of energy information available on food-service refrigeration. The absence of such data prevents simple comparison of different refrigeration schemes and between different models of a particular type. It is, at present, impossible to identify successful energy efficient-designs and technologies.

Our research suggests that a substantial potential for conservation exists in this end-use, about 4,000 GWh/yr. This is sufficient to justify a research program to better quantify, and eventually improve, food-service refrigeration efficiency.

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APPENDIX. SOURCES OF UNIT CONSUMPTION

LBL has metered the in-situ consumption of 10 food-service refrigerators, including 6 self-contained two-door reach-in units, average size ~ 50 ft^3. The consumption of the two-doors averaged 12 kWh/day, range 7-16 kWh/day. We plan to continue sub-metering such equipment as time permits.

Frigidaire Inc. lists consumption of their ice makers given the rate of ice production and ambient and water temperature. (A typical size uses 20-25 kWh/day.) Similar ratings may be available from other manufacturers.

There are quite a few studies which presumably involved sub-metering of individual units but where the published information is aggregated or the sub-metered units are not described well. These include:

- DOE funded Jolly Tiger project. One restaurant was extensively sub-metered, no disaggregated data given.
- Kentucky Fried Chicken and Pacific Gas and Electric project. One restaurant was sub-metered. Two walk-ins consumed 35 and 40 kWh/day respectively, but no size or manufacturer given.
- Hotel and Motel Association Study. At least 1 kitchen was sub-metered, no disaggregated data given.
- California Energy Commission. Equipment in one restaurant was sub-metered, no disaggregated data available.

DOE and National Restaurant Association have funded Pacific Northwest Labs to extensively sub-meter approximately 8 restaurants. This project is underway and data should be available by the end of 1983.

Although we have done a literature search, we have not thoroughly checked the utilities for projects which involved sub-metering of food-service refrigerators but which did not published the results. We have checked, fairly exhaustively, with ASHRAE, Air Conditioning and Refrigeration Institute (ARI), manufacturers and manufacturer associations, without results.