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FIELD TEST OF A HIGH-EFFICIENCY, AUTOMATIC-DEFROST REFRIGERATOR-FREEZER*

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ABSTRACT

Following the successful design, development, and demonstration of a high efficiency refrigerator-freezer prototype, the U.S. Department of Energy and Oak Ridge National Laboratory contracted with Arthur D. Little, Inc., and its subcontractor, Amana Refrigeration, Inc., to design and manufacture pre-production units for home usage tests. The purpose of the field test and the associated market evaluation is to confirm the energy saving potential of the high-efficiency design, identify possible design deficiencies or service difficulties, and assess the consumer appeal of the new unit. To date, the results have been promising. The first five months of field test data have shown an average 57% decrease in energy consumption when compared to a baseline unit of convention design. This energy savings is larger than predicted by the standard DOE test procedure. No serious design or service problems have been encountered. Consumers have not been adversely affected by the larger cabinet and thicker doors, and responded favorably in an actual retail sales test to initially spending more for an energy-saving refrigerator that will reduce electric usage.

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INTRODUCTION

This paper describes the market evaluation and field test portion of a program sponsored by Oak Ridge National Laboratory and the U.S. Department of Energy to design, develop, and demonstrate a high efficiency, automatic defrost refrigerator-freezer for the domestic, residential market. With the successful completion of Phase I of the program which concentrated on the design, construction, and laboratory testing of a 453 l (16 ft^3) high efficiency refrigerator-freezer prototype (1), Phase II was begun in February 1979 to evaluate the sales potential and performance of the high efficiency refrigerator concept in an actual home usage test, as a necessary step in creating a product that was both manufacturable and marketable. As in Phase I, Arthur D. Little, Inc., continued as principal contractor with Amana Refrigeration, Inc., as subcontractor.

In Phase I, a survey of food consumption and storage trends, family size, and consumer buying habits led to a 1985 sales-weighted average capacity forecast of approximately 453 l (16 ft^3) and identification of the top mount, automatic defrost refrigerator-freezer as the projected sales leader. To meet this market demand, a 453 l (16 ft^3) top mount was selected as the baseline for the Phase I design and development (2). In Phase II, a 509 l (18 ft^3) unit using Phase I technology was chosen for the field test since the slightly larger model better fit Amana's new product development efforts and market.

DESCRIPTION OF TEST UNIT

The energy saving refrigerator-freezer produced for the field test incorporates the following features:

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- Optimized insulation design;
- Static back-mounted condenser;
- Forced convection freezer evaporator;
- Natural convection fresh food evaporator in series with the freezer evaporator;
- New fan/air flow path design;
- Reduced defrost frequency.

The two-evaporator concept is the key to significantly reducing the energy needed to defrost the unit and therefore to lowering the overall energy consumption. As in conventional automatic defrost refrigerator-freezers, the test unit has a standard frost-free evaporator, defrost heater, and fan system; but it also has a natural convection evaporator, or "cold plate" in the fresh food compartment. The cold plate offers the advantage of self-defrosting after every refrigeration cycle, when the plate returns to the fresh food compartment temperature which is above freezing. The frost therefore melts off the plate without the need of an electric heater. Since the primary source of moisture is the fresh food compartment, the freezer evaporator accumulates much less frost and the electric energy required to defrost the prototype is reduced substantially.

The cabinet specifications of the field test unit, named the ESTR-18D, are shown in Table 1. A significant departure from conventional cabinet designs is the 62 mm (2.44 in) door insulation resulting in quite thick doors. This feature, combined with the large amount of polyurethane foam insulation in the cabinet, results in overall dimensions significantly larger than conventional 509 l (18 ft^3) top-mounts. One goal established for the market test was to attempt to evaluate the impact of the larger cabinet on potential sales.

The internal dimensions and features of the field test unit were chosen to be similar to the Amana TC-18D which was selected as the baseline model for comparison. Performance specifications for the two units are shown in Table 2.

FIELD TEST

The field test was envisioned and planned to accomplish the following objectives:

(a) Confirm the energy savings of the high efficiency unit when compared to a conventional automatic defrost top mount in actual home usage conditions.

(b) Assess the reliability of the high efficiency design,

and reveal any design deficiencies before possible full-scale production.

(c) Evaluate the consumer appeal of high efficiency automatic defrost refrigerator-freezers, and clarify buying patterns which may influence and be influenced by this and future commercialization programs.

It was decided that a one-year comparison field test of approximately 25 high efficiency ESTR-18D and 25 baseline TC-18D top mount refrigerator-freezers would meet objectives (a) and (b) above; a consumer preference survey and retail sales test would be used to gather information to meet objective (c). Because of the hot humid summer weather conditions that would tend to uncover any design deficiencies or service difficulties, and because of the enthusiastic commitment of the local Amana distributor, Norfolk, Virginia was chosen as the site for the field test.

Amana conducted a pilot run of 36 ESTR-18D high-efficiency units of which 25 units were chosen for the field test (3). 25 standard TC-18D units were selected as baselines for comparison and equipped with instrumentation to record power consumption. The ESTR-18D units were equipped with energy consumption measuring equipment as well as additional instrumentation that could be activated in the field to monitor cabinet temperature, refrigeration system performance, and door openings if the need arose. All units were shipped to Norfolk in preparation for the field test.

At the same time, the market evaluation portion of the program was being planned. Questionnaires and a survey methodology were developed by Arthur D. Little, Inc.; and a market research firm, Mid-Atlantic Research, Inc., was contacted to conduct consumer interviews.

Consumer Preference Survey

In-depth, in-store interviews were conducted in retail outlets in Norfolk where prospective retail refrigerator purchasers were asked detailed questions pertaining to their overall refrigerator selection and buying process. A factor analysis of the raw data was then completed. Unfortunately, because of the slow, late summer sales period during which the survey was conducted, only 62 interviews were completed out of a planned 200; therefore the results were not as conclusive as had been desired. However, some of the more interesting facts revealed were:

- Consumers still tend to replace their old refrigerator with a larger capacity unit. Apparently, rising energy prices and increased consumer energy consciousness have not affected this historical trend.

- Most purchases are to satisfy immediate needs; fast delivery is imperative.

- More than half the respondents would pay a premium of $100 if they could save this amount on their electric bills over a period of time.

- Although a large segment thinks that an energy saving refrigerator should be priced higher, there is a sizeable group who thinks that prices should be comparable or even less.

- Frost-free operation is the most important feature in terms of consumer needs and wants.

Retail Sales Test

A sales test was conducted at selected retail outlets to assess the consumer appeal of the ESTR-18D prototype. A rather elaborate plan was necessary to allow "sale" of the test units, yet retention of them for the field test, while keeping the sales test accurate and uncompromised. It was concluded that the best approach would be to offer all of the high efficiency and baseline units for sale in a conventional manner. The retail salesmen and customers would know nothing of the upcoming field test or the experimental nature of ESTR-18D. At the end of the sales test period, purchasers would be contacted, asked to participate in the field test, and given their purchase price back; thus allowing Amana to regain title to the test units. To encourage participation, a financial incentive would be offered. Units not placed in this manner would be placed into appropriate homes directly by the Amana local distributor.

Prior to the sales test, the ESTR-18D was introduced to the retail salesforce as a new, limited production Amana unit for which Norfolk had been chosen as the first test market. A special display was set up using three 509 l (18 ft^3) Amana units: the TM-18D, a basic, few-feature model; the TC-18D, a full- feature unit; and the ESTR-18D, the high efficiency prototype which offers a feature level between the TM and TC. The customer was offered the choice of the TC-18D feature-packed unit for an $80 cost increase, or the high efficiency ESTR-18D with fewer extra features for $110 over the cost of the basic TM-18D.

5 ESTR-18D and 2 TC-18D units were sold. During a weekend promotion, the price of the ESTR-18D was lowered $60.00 and 4 additional units were sold. Total sales of ESTR-18D's accounted for 28% of all sales of 482 l (17 ft^3) through 538 l (19 ft^3) units for the participating retail stores during the six- week sales test. Sales personnel

reported that the reaction towards the high-efficiency unit was quite favorable, and that factors such as the large cabinet and thick doors were not met with negative customer sentiments.

Test Sites

At the completion of the retail sales test, purchasers were contacted and asked to participate in the field test. All agreed. The remainder of the high efficiency ESTR-18D and baseline TC-18D test units were placed into homes by the local Amana distributor. A total of 24 ESTR-18D and 23 TC-18D units comprise the test sample. Household size ranges from 2 to 6 persons and most have at least 1 person at home during the day. Most homes are air conditioned, although many use room air conditioners and regulate local cooling as needed. About one-half the test refrigerators are equipped with icemakers.

Every month, participants are asked to list any abnormalities experienced in their refrigerator usage such as absence from home, visitors, etc., as well as operational difficulties experienced with their unit. These comments are collected every month when each site is visited and the meter indicating the month's energy consumption is read. The data collector also observes the controls settings, amount of food stored, and any obvious malfunctions. The data is analyzed to provide the monthly mean energy consumption for the high efficiency sample and the baseline sample, identify possible service difficulties or design defects, and point to usage patterns that may possibly affect energy consumption.

Test Results

The results of the first five months of the field test are shown in Table 3 compared with the energy consumption measured using the standard 32°C (90°F), closed door DOE test procedure. The average daily energy consumption for both refrigerator models was initially much higher than predicted by the DOE test, but showed a steady monthly decrease from August to December. This data tends to indicate that the relatively high temperature and humidity experienced in Norfolk in the late summer, coupled with ordinary household usage patterns, imposed a more stringent operating environment than simulated in the DOE test. The ESTR-18D when compared to the TC-18D, performed better than predicted, demonstrating an average 57% decrease in energy consumption over the baseline unit.

Attempts to derive correlations of energy consumption versus usage parameters such as number of persons in the household, food load, kitchen temperature, etc., have proved unsuccessful to date because of data scatter and the relatively small sample size. It is apparent, however, that refrigerator energy consumption can vary widely from month to month and unit to unit in actual home usage.

A full year of test data will be gathered in this program. Work will continue to attempt to determine if factors inherent in the design of the high-efficiency unit will affect its relative performance with

respect to conventional designs to an extent not accurately predicted by the standard rating test. Work will also continue on an attempt to identify the synergistic effects of usage patterns and climate on energy usage by simulating the field test environment in the laboratory.

To date the operational experience with the ESTR-18D has been quite satisfactory. Moisture build-up has been experienced in the refrigerator compartment of some units during periods of high humidity, but this condition is not considered serious by Amana. A fix for production units would be to add an electric ceiling heater wired to the energy saver switch. This switch could be activated during extremely humid conditions to eliminate sweating (resulting in a small increase in energy consumption), but shut-off normally to minimize electric usage. The few other problems reported were traced to defective components and not design defects.

Conclusions

The field test of the 509 l (18 ft^3) ESTR-18D is confirming the energy saving potential of a high efficiency, automatic defrost refrigerator-freezer utilizing advanced design features such as optimized thick wall foam insulation and a two-evaporator refrigeration system. Results to date show an average energy savings of 57% compared to a baseline unit of conventional design. Field test results also indicate that the standard DOE test procedure for refrigerator-freezers may not adequately simulate the large variety of factors experienced in actual home usage. It is recommended that the test procedure be further investigated to confirm its validity.

A market evaluation performed as part of this program confirmed that refrigerators incorporating high efficiency features at added cost are saleable and that large refrigerator-freezers (over 453 l (16 ft^3)) will continue to capture a large portion of the market in the years ahead.

No deficiencies inherent in the design of the high efficiency ESTR-18D have appeared. The unit promises to provide energy efficient operation over the normal useful life of a typical refrigerator-freezer. Some customer education will be necessary, however, to deal with the added moisture that can be present in the refrigerator compartment due to the design and operation of the cold-plate evaporator.

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Table 1. Cabinet Specifications

I. Insulation Thickness

Freezer Compartment				Fresh Food Compartment		
Side	Front	Back	Top	Side	Front	Back
73 (2.88)	62 (2.44)	74 (2.91)	73 (2.88)	.54 (2.13)	62 (2.44)	51mm (2.00in)

II. Heat Flow

Freezer	Mullion	Fresh Food	Gasket	Wedge	Total
14.47 (49.37)	3.07 (10.47)	25.00 (85.33)	11.48 (39.17)	5.60 (19.10)	59.61W (203.44 Btu/h)

III. Adjusted Volumes

Freezer	Fresh Food	Total	Freezer/Fresh Food Volume Ratio
124 (4.39)	391 (13.80)	515 1 (18.19 ft^3)	.32

IV. Exterior Dimensions

Height	Width	Depth
1676 (66)	813 (32)	838mm (33in)

Table 2. Energy Consumption Comparison

Model	FTC Label Number ($/Year)	EF (Ft^3/kWh/day)	Energy Usage (kWh/Yr)
ESTR-18D	37	10.14	744
TC-18D	71	5.37	1421

Table 3. Test Results

	DOE RATING	AUG	SEPT	OCT	NOV	DEC
ESTR-18D						
Avg. Energy Consumption (kWh/day)	2.04	3.00	2.45	2.00	1.86	1.70
Std. Dev.	-	1.22	.72	.28	.37	.32
TC-18D						
Avg. Energy Consumption (kWh/day)	3.89	6.31	5.45	4.97	4.58	4.28
Std. Dev.	-	.96	1.30	1.17	1.03	.91
Average Outdoor Temperature						
°C	32.2	23.9	21.5	15.3	10.4	5.0
(°F)	(90.0)	(75.1)	(70.7)	(59.6)	(50.7)	(41.0)
	(closed door)					