ENERGY CONSUMPTION OF REFRIGERATORS AS AFFECTED

BY SELECTED CONSUMER PRACTICES

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND PROBLEM STATEMENT

Introduction and Justification

Total energy consumption in the United States increased 4.5 percent per year during the period from 1965 to 1973 (The Ford Foundation, 1974, p. 1). Residential energy consumption, which accounts for an estimated 20 percent of the total, increased at an even greater rate of 4.8 percent per year (Stanford Research Institute, 1972, p. 5). Consumers became increasingly aware of the energy shortage caused by this rapidly rising rate of consumption during the 1974 gasoline shortage, and during the severe winter of 1976-77 when they experienced shortages of natural gas, heating oil, and electricity. In April of 1977, President Carter, in introducing his energy plan, proposed an overall goal of reducing this annual growth rate of total energy consumption in the United States to less than 2 percent by 1985 (The National Energy Plan, 1977, p. 83).

One area in which a reduction in residential energy consumption might take place is in the use of appliances. This can be achieved by either increasing the efficiency of appliances or by consumers using the appliances in a more efficient manner. Greater efficiency means that an appliance would perform the same function using less energy (Meyerson, 1973, p. 9). Manufacturers are currently trying to improve the energy efficiency of appliances in accordance with the Department of Commerce Voluntary Program for Appliance Efficiency. New major appliances should soon have energy efficiency labeling to aid consumers in comparison shopping.

Ruffin (1974, p. 25) indicated the importance of the second alternative, the consumer's use of the appliances, when she wrote:

> For the most part, a family's energy consumption needs are based on choices made in the past--for example, selection of a home furnace, appliances, automobile, and location of home. Except for reducing their level of use, families have little flexibility in the short run with respect to their energy requirements.

New major appliances may have a rather long service life, ranging from 20.4 years for a freezer to 10.8 years for a washing machine (Ruffin and Tippett, 1975, p. 169). This indicates that more immediate results in reducing energy consumption might be obtained by re-educating consumers in the use of their appliances. Behrens (1977, p. 7) states that:

> From the functional standpoint, majors [major appliances] are remarkably efficient machines. Continuing improvements in basic operating mechanisms over the years have actually pushed them to an efficiency plateau. As a result, opportunities for further efficiency improvements are quite limited. . . . Any significant energy reductions, therefore, will have to come through more efficient use of appliances.

In 1968, estimates were that the refrigerator consumed more energy than any other major appliance in the home--an estimated 6.0 percent of the total residential energy consumption. This was exceeded only by space heating, at 57.5 percent, and water heating, at 14.9 percent of the total residential energy consumption (Stanford Research Institute, 1972, p. 33). Refrigerators are present in more homes than any other major appliance, with a saturation rate of 99.9 percent ("Saturation Index for Key Products," 1978, p. 54). The service life expectancy of a new refrigerator was 15.2 years in 1974 (Ruffin and Tippett, p. 169). This long service life expectancy indicates that those who have recently purchased refrigerators probably will be using them for many years.

Since 99.9 percent of the 75,889,000 domestic and farm electrical customers ("Saturation Index for Key Products," 1978, p. 54) in the United States in 1977 had refrigerators, each of which consumed an estimated 4.7 kilowatt-hours daily (Midwest Research Institute, 1977), refrigerators are an important area in which to attempt reduction in energy consumption. A need exists for quantitative information consumers can use in operating their refrigerators in a manner which will reduce energy consumption. No recent research is available in this area. A few studies were conducted in the 1930's when refrigerators first achieved widespread use and again in the 1950's when automatic defrosting systems were introduced.

Problem Statement and Objectives

The research problem was to determine the effect of selected consumer practices on the energy consumption of refrigerators. Objectives of the study were to measure the effect on energy consumption of:

1. Variations in temperature control setting
2. Frequency of door openings
3. Duration of door openings

4. Location of the refrigerator near a heat source

5. Use of an energy saver switch

6. Thickness of frost accumulation on the evaporator coils of a manual-defrost refrigerator

7. Defrosting process of a manual-defrost refrigerator, including temperature recovery

Assumptions

Assumptions inherent in the design of this study were that:

1. The household refrigerator and household combination refrigerator-freezers used in this study were representative of those on the market today.

2. The consumer practices simulated in this study were representative of those practiced by consumers.

3. The load used in this study simulated that which would be found in a refrigerator in consumer use.

Delimitations

The following constraints were applied to this study:

1. The tests were conducted under controlled laboratory conditions and thus may not resemble the practices of consumers.

2. Objectives 1 through 5 applied only to the fresh food compartment. In the three refrigerators in which the freezer compartment had a separate control, the temperature was set at the warmest setting possible and the freezer compartment was not utilized in the test procedures.

Definition of Terms

The appliances that consumers commonly call refrigerators may be differentiated according to operating temperatures and defrost systems. In this thesis the term "refrigerator" will be used as the generic term to designate the appliances studied. However, industry definitions of different types are included below to aid the reader.

Types of Refrigerators

A household refrigerator is a cabinet or part of a cabinet intended for the storage of food at or above a temperature of 32^{o}Fahrenheit (F) or 0^{o}Celcius (C), which has a source of refrigeration, and which is designed for household use. It may or may not include a compartment for the making and storage of ice and for the short-term storage of food at or below a temperature of $32^{o}F(0^{o}C)$ (AHAM Refrigerator and Freezer Standard - No. HRF-1, 1967, p. 1).

A household combination refrigerator-freezer is a cabinet consisting of two or more compartments at least one of which is designed for the storage of food at or above a temperature of $32^{o}F(0^{o}C)$, and at least one of which is designed for the freezing and storage of foods at or below a temperature of $8^{o}F(-13^{o}C)$ average. It must have a source of refrigeration and be designed for household use.

Types of Defrost Systems

A manual-defrost household refrigerator is a household refrigerator in which defrosting of refrigerator and freezer compartments must be manually performed.

A cycle-defrost household combination refrigerator-freezer is a household combination refrigerator-freezer which has automatic defrosting of the refrigerator compartment. Defrosting of the freezer compartment must be performed manually.

A <u>no-frost</u> <u>household</u> <u>combination</u> <u>refrigerator-freezer</u> is a household combination refrigerator-freezer in which defrosting of the refrigerator and freezer sections is automatic. It is also referred to by manufacturers as "frost-free" and "frost-proof."

CHAPTER II

REVIEW OF LITERATURE

The literature review describes the refrigeration system, the development of modern refrigeration, types of refrigerators, variables which affect energy consumption, energy efficiency, and refrigeration research. Information was collected from periodicals, books, manufacturers' publications, and master's theses.

The Refrigeration System

The purpose of a refrigerator is to remove heat from food and maintain the food at a low temperature. There are several reasons for refrigerating food. Temperatures of $40^{o}F(4^{o}C)$ or below retard the growth of microorganisms in food and help prevent spoilage. Most foods will stay fresh longer when stored at temperatures below $40^{o}F(4^{o}C)$ (Peet, Pickett, Arnold, and Wolf, 1975, p. 246). However, some foods, such as beverages, are chilled simply because people prefer to consume them cold.

Refrigerators commonly used in households in the United States operate on the principle of heat absorption. A cool liquid, the refrigerant, passing through the refrigeration system, absorbs heat from food in the refrigerator, causing the refrigerant to vaporize. This vapor, which is then compressed and cooled, changes into a liquid again, giving up the heat is has absorbed (Genetron

Refrigeration Training Series, 1969).

The standard household refrigerator has four basic components: the evaporator, the compressor, the condenser, and the capillary tube. The refrigerant passes through each of these components during the process of refrigeration. In the evaporator, the refrigerant, at a low pressure and a lower temperature than the food compartment, changes from the liquid state to the gaseous state as it absorbs heat from the food compartment and its contents. The vaporized refrigerant is pumped into the compressor where its pressure is increased in preparation for the condensation process. The refrigerant, under high pressure, then passes into the condenser and, giving up the heat it has absorbed, returns to the liquid state. As the liquid refrigerant, at a high pressure, passes through the capillary tube, the pressure is reduced, causing some of the liquid to vaporize and the temperature to decrease. This process continues as long as the compressor motor is running. When the interior of the refrigerator reaches the preset temperature, the thermostat causes the compressor motor to stop and the process is interrupted until the refrigerator warms to the temperature for which it is scheduled to resume operation (Ehrenkranz and Inman, 1973, pp. 236-241). In order to prevent the constant operation of the compressor motor, heat gain must be minimized by adequate insulation in the walls and doors and by close-fitting gaskets.

Development of Modern Refrigeration

The first mechanical refrigerator was developed in the 1890's. Prior to that time, the icebox had been the chief means of cooling food. The earliest mechanical refrigerators were small, expensive, and poorly constructed. They had little insulation, leaked refrigerant gas, and the wooden cabinets tended to warp and come apart. By the 1930's, insulation was improved and a new breaker strip was developed which reduced heat gain. One-piece steel cabinet construction also reduced heat gain and resulted in a sturdier product. In 1933, Frigidaire introduced the "Meter-Miser" which was a hermetically sealed compressor, eliminating belts, gas seals, and allowing the use of a smaller motor ("An Early History. . .," 1957, p. 216).

The two-compartment refrigerator was developed around 1939 ("An Early History. . .," 1957, p. 224). It had one section which maintained a temperature suitable for storing fresh foods and another suitable for ice cubes and ice cream. The refrigerators of the 1930's maintained a temperature of about 50°F(10°C) in the fresh food section. Later models could maintain a more constant temperature of 40°F(4°C).

Types of Refrigerators

Refrigerators on the market at the present time are of two basic types--the household refrigerator and the household combination refrigerator-freezer. The household refrigerator must be manually defrosted. It has one evaporator and does not have a barrier between the fresh food and frozen food compartments. It consumes less energy than a household combination refrigerator-freezer of comparable size (1977 Directory of Certified Refrigerators and Freezers, p. 5).

A household combination refrigerator-freezer may be a cycle-defrost or a no-frost model. It has an insulated barrier between the fresh and frozen food compartments. The no-frost refrigerator-freezer has a low-wattage fan which circulates air over the evaporator to cool both the fresh and frozen food compartments. The cycle-defrost refrigerator-freezer has two evaporators, one in the fresh food compartment and one in the frozen food compartment.

Freezing Compartment Location

Refrigerator-freezers may be additionally classified according to the location of the freezing compartment as top-mount, side-by-side, and bottom-mount. The top-mount refrigerator-freezer has a freezer compartment located above the refrigerated compartment with a separate outside door. This type accounted for 82 percent of refrigerator-freezer sales in 1977 ("Major Appliance Highlights," 1978, p. 106).

The side-by-side refrigerator-freezer consists of two long narrow compartments next to each other, one for freezing and one for refrigerating. Each compartment has its own door and the freezer compartment may have an ice or beverage dispenser located in the door. The shelves in both compartments are narrow, making it difficult to store some foods. The side-by-side model has a higher purchase price than the top-mount model and occupies more space. It may, however offer a larger volume of freezer space. Side-by-side refrigerator-freezers accounted for 16 percent of refrigerator sales in 1977 ("Major Appliance Highlights," 1978, p. 106).

The bottom-mount refrigerator-freezer has the freezer compartment located below the refrigerated section. This model accounted for only 2 percent of refrigerator-freezer sales in 1977; however, sales of bottom-mount models have more than doubled in the last year ("Major Appliance Highlights," 1978, p. 106).

Size

Refrigerators range in size from compact models, with a capacity of as little as 1.5 to 3 cubic feet, to full-sized refrigerators with 11 to 28 cubic feet of food storage space for fresh and frozen food. The trend in refrigerator sales is toward the larger sized refrigerators. In 1977, 40 percent of all refrigerators sold had a capacity of 18 cubic feet or more ("Major Appliance Highlights," 1978, p. 106).

Defrosting Systems

Frost results from condensation of moisture-vapor deposits freezing on the evaporator coils. As large amounts of frost accumulate, a thick icy coating results which insulates the coils, decreasing the efficiency of the evaporator, and possibly causing the motor to run longer. This inefficient operation can be prevented by periodic defrosting.

The three basic types of defrosting systems in refrigerators and refrigerator-freezers (AHAM Refrigerator and Freezer Standard - No. HRF-1, 1967, p. 1) are the manual-defrost system, the cycle-defrost system, and the no-frost system. All frost accumulation must be manually removed in the manual-defrost system.

The cycle-defrost system is available only on combination refrigerator-freezers. The defrosting of the fresh food section is accomplished automatically each time the compressor cycles off, while the freezer section must be manually defrosted. Water resulting from the defrosting process drains into a pan where it evaporates.

The no-frost system also is available only on the combination refrigerator-freezer. The automatic defrosting of both the freezer and refrigerator compartments prevents the accumulation of frost on food in the refrigerator compartment. Defrosting is accomplished by means of a heater which is activated by a timer. The defrost cycle is terminated by a thermostat when a preset temperature is reached. Water resulting from the defrosting process is drained into a pan where it evaporates. The no-frost combination refrigerator-freezer is the most popular type, and accounted for 78 percent of all refrigerator sales in 1977 ("Major Appliance Highlights," 1978 p. 106).

Variables Which Affect Energy Consumption

The variables which affect the energy consumption of refrigerators can be separated into two broad categories--those related to the design of the refrigerator and those resulting from consumer usage of the refrigerator. The design variables include such things as storage capacity, type of defrost system, amount and type of insulation, and the presence of anti-condensation, or mullion, heaters, which are located in the walls of the refrigerator to keep the exterior surfaces warmer than the dew point thus preventing condensation (D'Aleandro, 1973, pp. 11-14).

The heat load of a refrigerator determines the required energy input. Heat load is increased by heat gain through the walls and door and around the door opening, and by heat created by heaters and motors. Heat which is conducted through the walls can be minimized by increasing the thickness of insulation or by substituting urethane foam, which has better insulating properties, for fiberglass insulation. Door gaskets can be improved to reduce heat infiltration by convection around the door. The radiant heat created by heaters and fan motors can be reduced by eliminating the heaters and relocating the fan motors (D'Aleandro, 1973, p. 12).

The remaining design variables--storage capacity and type of defrost system--cannot, with present technology, be altered to lower energy consumption. According to the literature, a large capacity refrigerator uses more electricity than a small one. It is estimated that a no-frost refrigerator-freezer uses approximately 29 percent more electricity than a manual-defrost refrigerator of the same volume (Hoskins and Hirst, 1977, p. 30). The increased energy consumption may be attributed to the lower temperature maintained in its freezer compartment, the fans used to circulate the air, and the heaters used to defrost the no-frost model.

The heat load of a refrigerator is also increased by consumer practices. Ice-making, food freezing and chilling, frequency and duration of door openings, frequency of defrosting, temperature control adjustments, and the location of the refrigerator all influence energy usage. For maximum efficiency, one manufacturer cautions against extra door openings and recommends defrosting manual-defrost models before more than one-fourth inch of frost accumulates (G.E. Consumer Inquiry Guide, 1974, p. 6). An excessive accumulation of frost can increase energy consumption by as much as 25 percent (Hoskins and Hirst, 1977, p. 9). Another manufacturer advises consumers to locate the refrigerator away from any heat source and to avoid setting the temperature controls any colder than necessary, in order to use less energy (Use and Care Manual for Your Stor-Mor Refrigerator-Freezer, p. 3). Appliance manufacturers have no control over these consumer practice variables yet the influence on energy consumption is thought to be considerable.

Energy Efficiency

The Voluntary Energy Labeling Program for Appliances was introduced by the Department of Commerce in 1973. The program's goal was to produce a label which would offer the consumer information on the energy consumption and cost of operation of appliances. The Voluntary Program for Appliance Efficiency originated in 1975 as a result of the President's request for the development of energy efficiency goals for appliances. The Department of Commerce and the Federal Energy Administration were assigned the responsibility for administering the program. The Energy Policy and Conservation Act, passed on December 22, 1975, mandated these programs and shifted the responsibility for implementation to the Federal Energy Administration, now the Department of Energy (Office of Consumer Products, 1977).

The Act requires that energy efficiency targets be set, that energy efficiency testing procedures be developed, and that manufacturers' efforts to improve appliance efficiency be monitored. The National Bureau of Standards is responsible for developing the test procedures used to determine the efficiency of appliances and for establishing energy efficiency improvement targets. The Federal Trade Commission has been given the responsibility of designing energy efficiency labels for appliances which will include an "estimated annual operating cost" and the range of costs for similar products. The labels will assist consumers in shopping for major appliances by allowing them to compare estimated operating costs in addition to the initial cost. The thirteen appliances to be included in the program are refrigerators and refrigerator-freezers, freezers, dishwashers, clothes dryers, water heaters, room air conditioners, home heating equipment not including furnaces, televisions, ranges, clothes washers, humidifiers and dehumidifiers, central air conditioners, and furnaces. The test procedure for refrigerators has been developed and the current energy efficiency goal is a 47 percent improvement (Office of Consumer Products, 1977).

Refrigerator manufacturers have been working toward the goal of energy efficiency in several ways. By increasing insulation and switching from fiberglass to urethane foam, energy consumption may be reduced by as much as 22 to 35 percent (D'Aleandro, 1973, p. 12). Research is being conducted on a new type of compressor with increased efficiency; however this is still in the development stage ("Demand defrost: Consumers do!" 1977, p. 52). Several manufacturers are installing "energy-saver" switches that turn off the mullion heaters or reduce them to half power. Based on AHAM data, an energy-saver switch may reduce energy consumption by 2.6 to 26.4 percent (1977 Directory of Certified Refrigerators and Freezers, 1977). Other manufacturers use methods other than mullion heaters to heat the exterior of the refrigerator and reduce condensation.

Although Hoskins and Hirst have estimated that the elimination of automatic defrosting systems on refrigerators could result in a 29 percent reduction in energy consumption (1977, p. 30), consumers seem to prefer the convenience of the no-frost models. Over 78 percent of all refrigerators sold in the United States in 1977 were of the no-frost type ("Major Appliance Highlights," 1978, p. 106). It is generally accepted that manual-defrost refrigerators are more efficient if defrosted before one-fourth inch of frost forms, yet one study showed that 16 percent of the homemakers surveyed did not defrost their refrigerators for a period of 8 weeks or more, which might allow a frost build-up greater than one-fourth inch (Heisler, 1975, p. 29).

Refrigeration Research

No recent research is available related to the effect of consumer practices on the energy consumption of refrigerators.

Some research was carried out in the 1930's when refrigerators first achieved widespread use, however the appliance has changed a great deal in the past 40 years. Refrigerators are now larger and most have automatic defrosting systems. Different materials are being used for both the liner and the cabinet as well as the insulation. There is a greater difference in operating temperatures between the fresh food and freezer compartments and the proper temperatures are easier to maintain.

Gray and Glasgow (1933) conducted tests on an 18 cubic foot refrigerator and a 6 cubic foot refrigerator. They discovered that reducing the interior temperature, opening the door, and adding a load were all related to an increase in energy consumption. Decreasing the interior temperature from $30^{\circ}F(-1^{\circ}C)$ to $27^{\circ}F(-3^{\circ}C)$ caused a 20 percent increase in energy consumption. Opening the door caused an increase in energy consumption of 11 to 33 percent. Adding a load increased energy consumption by 21 percent.

Sater observed the energy consumption of two 5 cubic foot refrigerators under a variety of tests including the frequency and duration of door openings. It was found that the length of time the door was open caused a greater increase in energy consumption than the frequency of opening the door. Increasing the length of time the door was open from 1 to 4 minutes caused a 6.7 percent increase in running time of the motor. Changes in the frequency of door openings resulted in a .5 percent increase in running time.

Ehrenkranz and Pickett (1955) examined the effect of automatic defrosting systems on energy consumption, temperature of the refrigerator and freezer compartments, and on the palatability of the food stored in the freezer compartment. They tested five automatic-defrosting refrigerators and found the energy consumption for a 24-hour period ranged from .94 to 3.83 kilowatt-hours. Two of the refrigerators automatically defrosted when the motor cycled off. The other three refrigerators defrosted by means of a heating coil in the evaporator. Two of these defrosted automatically every 24 hours and one defrosted when the user pushed a button which activated the heating coil. Ehrenkranz and Pickett concluded that the energy consumption of the automatic-defrosting refrigerator was small enough to be of little importance in choosing a refrigerator. Refrigerators currently on the market are larger than those used in the 1955 study and most have different defrosting mechanisms.

Midwest Research Institute (1977) has monitored appliance energy consumption patterns in 150 households located in sixteen cities across the United States. The average daily energy consumption of refrigerators was found to be 4.7 kilowatt-hours. The highest average daily energy consumption occurred in August; the lowest, in January.

Summary

According to the literature, the energy consumption of refrigerators is dependent on the type and size of refrigerator, the type of defrosting system, design features, and consumer practices. This research will deal with the effect on energy consumption of consumer practices in the use of refrigerators and refrigerator-freezers.

CHAPTER III

DATA COLLECTION

Design of Study

The procedures of data collection were designed to measure the effect on the refrigerator's energy consumption of:

1. Variations in temperature control setting
2. Frequency of door openings
3. Duration of door openings
4. Location of the refrigerator near a heat source
5. Use of an energy-saver switch
6. Thickness of frost accumulation on the evaporator coils of a manual defrost refrigerator
7. Defrosting process of a manual-defrost refrigerator, including temperature recovery

Data were collected in a household equipment laboratory at the Virginia Polytechnic Institute and State University College of Home Economics during the fall and winter of 1977-78. Temperature in the laboratory ranged from $67^{\circ}F(19^{\circ}C)$ to $77^{\circ}F(25^{\circ}C)$ throughout the study, but was usually between $70^{\circ}F(21^{\circ}C)$ and $75^{\circ}F(24^{\circ}C)$. The ralative humidity was normally near 45 percent; however, it ranged from 25 to 60 percent.

Seven separate tests designed to simulate consumer practices were performed during the course of the study. Tests 1 through 7, listed on the previous page, were performed on the refrigerators as indicated below.

	Refrigerator 1 Manual-defrost	Refrigerator 2 Cycle-defrost	Refrigerator 3 No-frost	Refrigerator 4 No-frost with energy-saver
Test 1	X	X	X	
Test 2	X	X	X	
Test 3	X	X	X	
Test 4	X	X	X	
Test 5				X
Test 6	X			
Test 7	X			

Equipment

Refrigerators

The refrigerators used in this study were chosen to represent the three types of defrosting systems available to consumers. In addition, a no-frost refrigerator with an energy-saver switch was used in Test 5.

Since the fresh food storage compartment was of primary concern in this study, it was necessary for the appliances to have a similar net refrigerator volume. For the refrigerators chosen these volumes ranged from 11.03 cu. ft. to 12.6 cu. ft. as certified according to AHAM standards. For ease of discussion, the refrigerators have been numbered 1 through 4 and are described on the following page.

Refrigerator 1 - Whirlpool Manual-Defrost Refrigerator
(Model EEL 131CT, 4 amps)
Net refrigerator volume 11.12 cu. ft.
Net freezer volume 1.76 cu. ft.
Net refrigerated volume 12.9 cu. ft.

Refrigerator 2 - Whirlpool Cycle-Defrost Combination Refrigerator-Freezer (Model EET 141DT, 4 amps)
Net refrigerator volume 11.03 cu. ft.
Net freezer volume 3.11 cu. ft.
Net refrigerated volume 14.1 cu. ft.

Refrigerator 3 - Frigidaire No-Frost Combination Refrigerator-Freezer (Model FPCI-170T, 5.8 amps)
Net refrigerator volume 12.26 cu. ft.
Net freezer volume 4.75 cu. ft.
Net refrigerated volume 17.0 cu. ft.

Refrigerator 4 - Amana Free-O-Frost Combination Refrigerator-Freezer (Model TR-16N, 6 amps)
Net refrigerator volume 12.6 cu. ft.
Net freezer volume 3.4 cu. ft.
Net refrigerated volume 16.0 cu. ft.

Measuring Instruments

Energy consumption was measured by the use of three 120-volt Duncan watt-hour meters. Tests of 24 hours duration were timed by the use of a General Electric electric clock. A Meylan stop watch (Model no. 204 BD) was used to time door openings in Tests 2, 3, and 4, range usage in Test 4, and the defrosting process in Test 7. The interior refrigerator cabinet temperature was measured and recorded with a Leeds and Northrup Multipoint Temperature Recorder, Model W on chart paper marked with five-degree intervals. Each temperature was recorded every thirty seconds. Room temperature and humidity were measured by an Arthur H. Thomas Co. wet and dry bulb thermometer, and an Arthur H. Thomas Co. barometer was used to record atmospheric pressure.

Load

A load was devised and used in the refrigerator compartment during all tests. The load consisted of one-quart (950 ml.) plastic freezer containers filled with tap water tempered to 77°F(25°C) prior to being placed in the refrigerator. The number of freezer cartons was varied to occupy 8 percent of the refrigerator volume. The exact arrangement and number of containers used are shown in Figures 2, 3, and 4 (Appendix A).

Miscellaneous Equipment

A Litton Range, Model 610, was used for the heat source in Test 4. A Wearever Centennial aluminum two-quart (1.89 liter) saucepan and cover (No. 39902) were used in Test 4 to boil water. A Wearever 9x13x2-inch (23x33x5-cm.) aluminum pan was used to hold water during the defrosting process in Test 7.

General Procedure

Room temperature, humidity, and atmospheric pressure were recorded at the beginning and end of each test. The refrigerator temperature control was set on the middle setting for all tests except Test 1. In all tests, if a separate freezer control was present, it was set at the warmest setting possible. The freezer compartment door remained closed throughout the study, and with the exception of Tests 2, 3, and 4, the refrigerator door also remained closed during each test. Interior refrigerator cabinet temperature was automatically recorded.

Prior to beginning each test, the following procedures were followed:

1. The refrigerator was connected to a watt-hour meter.

2. Three thermocouples were attached to the interior of the refrigerator at three different points indicated in Figure 5 (Appendix B). For Tests 4 and 5, two additional thermocouples were attached to the exterior of the refrigerator at different points as indicated in Figures 6 and 7 (Appendix B).

3. The temperature control was adjusted to the desired setting and the refrigerator was allowed to operate for a sufficient length of time prior to the beginning of the test period to assure a steady state. The length of time allowed between each test period was sufficient for the refrigerator to return to a steady state--that is, for the temperature to return to what it had been immediately prior to the test period.

Specific Test Procedures

Test 1 - Variations in Temperature Control Setting

To determine the effect of variations in the temperature control setting on the energy consumption of Refrigerators 1, 2, and 3, energy consumption was recorded for each refrigerator for a period of 24 hours at the lowest, middle, and highest temperature settings. A period of at least four hours was allowed between test periods when changing from one temperature setting to another to assure a steady state.

Test 2 - Frequency of Door Openings

In order to determine the effect of frequency of door openings on the energy consumption of Refrigerators 1, 2, and 3, energy consumption was recorded for the following three-hour test periods:

Test number	Three-hour test period	Number of door openings
2.1		0
2.2		6
2.3		12
2.4		24
2.5		48

In each case, the door was held open to a 90-degree angle for 30 seconds and then closed. A yardstick was taped to the side of the refrigerator and the door opened until it touched the yardstick to assure a 90-degree angle. A length of three hours was arbitrarily chosen after pretesting periods of various lengths. At least 25 minutes was allowed between three-hour test periods for the refrigerator to return to a steady state.

<u>Test 3 - Duration of Door Openings</u>

To determine the effect of duration of door openings on the energy consumption of Refrigerators 1, 2, and 3, energy consumption was recorded for the following three-hour test periods:

Test number	Three-hour test period	Length of door openings* (seconds)
3.1		0
3.2		15
3.3		30
3.4		60
3.5		120

*Marks used to designate length of door opening are as follows:

- 15 seconds
- 30 seconds
- 60 seconds
- 120 seconds

The door was opened twelve times during each test period to a 90-degree angle for the specified length of time. At least 25 minutes was allowed between three-hour test periods for the refrigerator to return to a steady state.

Test 4 - Location of Refrigerator Near a Heat Source

In order to determine the effect on energy consumption of locating the refrigerator near a heat source, the following tests were conducted on Refrigerators 1, 2, and 3. During all test periods the refrigerator was located one inch away from the range, with the range adjacent to the door opening.

Test 4.1 - closed door--range inoperative

A two-hour test was conducted, during which time the range remained inoperative and the refrigerator door was not opened.

Test 4.2 - open door--range inoperative

Forty-five minutes after the beginning of the two-hour test period the refrigerator door was opened to a 90-degree angle for 15 seconds and then closed. The door opening was repeated every ten minutes thereafter for a total of four openings. The range remained inoperative during the test period.

Test 4.3 - open door--range operative

A two-hour test period was conducted, opening the refrigerator door as specified in Test 4.2, and operating the range as follows:

1. At the beginning of the test period, the exterior temperature of the side of the range next to the refrigerator was $89^{\circ}F$

(32°C) ± 1°.

2. One minute after the start of the test period, the oven temperature control was set at "BAKE"-400°F (204°C).

3. After 40 minutes, the rear surface unit closest to the refrigerator, with a saucepan containing one quart (950 ml.) of water at 77°F (25°C), was turned to the "HIGH" setting.

4. After 44.25 minutes, the oven door was opened completely for 15 seconds and closed.

5. After 44.75 minutes, the refrigerator door was opened and closed as in Test 4.2.

6. After 45 minutes, the surface unit was turned down to the "MEDIUM-HIGH" setting.

7. After 55 minutes, the refrigerator door was opened and closed. This was repeated again at 65 minutes and 75 minutes.

8. After 75 minutes, the surface unit was turned off and the pan of water removed.

9. After 90 minutes, the oven was turned off.

Test 5 - Use of Energy-Saver Switch

To determine the effect on energy consumption of using the energy-saver switch on a no-frost refrigerator-freezer, energy consumption of Refrigerator 4 was recorded for a 24-hour test period with the energy-saver switch set at the low humidity setting. The test was repeated with the energy-saver switch set at the medium humidity setting and again at the high humidity setting. A minimum of five minutes was allowed between test periods to assure a steady state. A longer time period was not necessary for the interior temperature to return to normal, since the temperature control was not adjusted. A thermocouple was attached to the outside of the refrigerator as indicated in Figure 7 (Appendix B) in addition to those inside the refrigerator.

Test 6 - Thickness of Frost Accumulation

In order to determine the effect of frost accumulation on the energy consumption of the manual-defrost refrigerator (Refrigerator 1), energy consumption was recorded for 24-hour test periods with no frost on the evaporator coils, with one-fourth inch of frost, and with one-half inch of frost. At least 48 hours was allowed between test periods to assure a steady state, since the refrigerator door had been propped open between tests to facilitate frost accumulation.

Test 7 - Defrosting Process and Temperature Recovery

To determine the effect of the defrosting process and temperature recovery on the energy consumption of a manual-defrost refrigerator, one-fourth inch of frost was allowed to form on the evaporator coils of Refrigerator 1. The freezer compartment was then defrosted according to the manufacturer's directions. The refrigerator door was opened, and the temperature control turned to "OFF." The load remained in the refrigerator during the defrosting process. The freezer door was opened, and a 9x13x2-inch (23x33x5-cm.) aluminum pan filled with two quarts (1.89 liters) of water at 113°F (45°C) was placed in the center of the bottom shelf of the freezer compartment. The water in the pan was poured out and replaced approximately every fifteen minutes, three times. Fifty-seven minutes after the initiation of the defrosting process, the pan of water was removed, water was poured out of the tray beneath the freezer compartment, and the freezer compartment and tray were wiped out to remove excess water. One hour after the beginning of the defrosting process, the refrigerator was turned to the medium setting and the freezer and refrigerator doors closed. Energy consumption was recorded for the next 24 hours starting at the end of the defrosting process.

Data Analysis

In order to determine the effect of the selected consumer practices on the energy consumption of the refrigerators tested, the following calculations were performed:

1. The range and mean energy consumption were computed for each refrigerator for each test.
2. The mean interior cabinet temperature was determined for each refrigerator for each test.
3. The percentage difference in energy consumption between the various operating conditions of each test was calculated.

Because of differences in volume and other design characteristics, it was not possible to compare one appliance with another.

CHAPTER IV

FINDINGS AND DISCUSSION

The effect of selected consumer practices on the energy consumption of refrigerators was investigated in this laboratory study. Seven different tests designed to simulate consumer practices were performed on four refrigerators. Each test was replicated three times. Four tests involving variations in temperature control setting, frequency and duration of door openings, and placement of the refrigerator near a heat source were each performed on a manual-defrost refrigerator (Refrigerator 1), a cycle-defrost refrigerator-freezer (Refrigerator 2), and a no-frost refrigerator-freezer (Refrigerator 3). A test involving the use of an energy-saver switch was performed on a no-frost refrigerator-freezer (Refrigerator 4), and two tests related to the effect of frost accumulation on energy consumption were performed on a manual-defrost refrigerator (Refrigerator 1). Watt-hour consumption and interior cabinet temperature were recorded for all tests. The findings of these tests are examined in this chapter.

Findings

Test 1 - Variations in Temperature Control Setting

To determine the effect of variations in the temperature control setting on the energy consumption of Refrigerators 1, 2, and 3, energy consumption was recorded for a period of 24 hours for each refrigerator under closed-door conditions with a load in the fresh food compartment.

The mean watt-hour (wh) consumption for Refrigerator 1 ranged from 878 wh at the warmest temperature setting to 1434 wh at the coldest (Table 1). Energy consumption at the coldest setting was 63 percent higher than at the warmest. Mean watt-hour consumption of Refrigerator 2 at the coldest setting was 4508 wh, 64 percent higher than at the warmest setting. At the coldest setting, mean watt-hour consumption of Refrigerator 3 was 3619, a 15 percent increase over energy consumption at the warmest setting.

The maximum mean temperature inside the refrigerator was $40^{o}F(4^{o}C)$, reached by Refrigerator 1 at the warmest temperature setting. The minimum mean temperature inside any of the refrigerator cabinets was $17^{o}F(-8^{o}C)$ in Refrigerator 2 at the coldest setting. The mean temperature in Refrigerator 1 ranged from $25^{o}F(-4^{o}C)$ at the coldest setting to $40^{o}F(4^{o}C)$ at the warmest. The range for Refrigerator 2 was $17^{o}F(-8^{o}C)$ to $36^{o}F(2^{o}C)$ and for Refrigerator 3 was $30^{o}F(-1^{o}C)$ to $35^{o}F(2^{o}C)$.

Variations in the temperature control setting were found to have a marked effect on energy consumption. The colder the temperature setting, the greater the energy consumption, since the motor must run longer to maintain the cooler temperature. At all temperature settings tested, the temperature inside the refrigerator remained at or below the maximum recommended temperature of $40^{o}F(4^{o}C)$.

TABLE 1

ENERGY CONSUMPTION, PERCENTAGE INCREASE IN ENERGY CONSUMPTION, AND INTERIOR CABINET TEMPERATURE FOR REFRIGERATORS 1, 2, AND 3 (TEST 1 - VARIATIONS IN TEMPERATURE CONTROL SETTING)

Temperature Control Setting	Refrigerator 1				Refrigerator 2				Refrigerator 3			
	Watt-hours Consumed			Mean Temp. in °F	Watt-hours Consumed			Mean Temp. in °F	Watt-hours Consumed			Mean Temp. in °F
	Range	Mean	% Incr.		Range	Mean	% Incr.		Range	Mean	% Incr.	
Warmest	857- 911	879	. . .	40	2602-2958	2756	. . .	36	3109-3231	3154	. . .	35
Middle	1020-1085	1047	19	35	4409-4434	4420	60	20	3410-3702	3562	13	32
Coldest	1404-1484	1434	63	25	4505-4512	4508	64	17	3581-3650	3619	15	30

Based on a cost of 3¢ per kilowatt-hour, the annual cost of operating the refrigerators at the warmest temperature setting ranged from $9.62 for Refrigerator 1 to $34.53 for Refrigerator 3. The projected annual cost of operation at the coldest setting ranged from $15.70 for Refrigerator 1 to $49.36 for Refrigerator 2. The energy consumption recorded during this test conforms with the AHAM estimated monthly kilowatt-hour consumption for these models (1976 Directory of Certified Refrigerators and Freezers, 1976). Over the 15.2 year life expectancy of the refrigerator (Ruffin and Tippett, 1975, p. 169) these findings indicate that one could save from $28 to $291 by setting the temperature control at the warmest recommended temperature possible. However, situations may vary, and food safety is the most important factor in determining maximum refrigerator temperature.

Test 2 - Frequency of Door Openings

To determine the effect of frequency of door openings on the energy consumption of Refrigerators 1, 2, and 3, energy consumption was recorded under load conditions for three-hour test periods when the refrigerator door was not opened. The door was then opened to a 90-degree angle for 30 seconds 6 times, 12 times, 24 times, or 48 times during each of the three-hour test periods.

The frequency of door openings had a noticeable effect on the energy consumption of all three refrigerators. For a three-hour test period, opening the door for 30 seconds every 25.3 minutes (total-6 openings, 3 minutes) resulted in an increase in energy consumption over the control test period ranging from 9 percent for

Refrigerator 1 to 27 percent for Refrigerator 3 (Table 2). Opening the door for 30 seconds twelve times (total- 6 minutes) during the test period resulted in a 30 to 37 percent increase in energy consumption. When the door was opened 24 times during the three-hour period (total-12 minutes), energy consumption was increased by 37 to 74 percent. Opening the refrigerator door 48 times (total-24 minutes) resulted in an increase in energy consumption ranging from 66 to 87 percent.

As shown in Table 2, energy consumption and interior cabinet temperature increased with the frequency of door openings. As the refrigerator door was opened more often, heat gain was increased and the motor ran longer to maintain the preset temperature.

Test 3 - Duration of Door Openings

Energy consumption was recorded under load conditions for a three-hour test period, during which time the refrigerator door was not opened, to determine the effect of duration of door openings on the energy consumption of Refrigerators 1, 2, and 3. The door was then opened twelve times during each test period for 15 seconds per opening, for 30 seconds, for 1 minute, or for 2 minutes during each of the three-hour periods.

The duration of door openings affected the energy consumption of all three refrigerators. For a three-hour test period, opening the door for 15 seconds every 13.6 minutes (total-12 openings for all test periods) for a total open time of 3 minutes, resulted in a 14 to 19 percent increase in energy consumption over the control

TABLE 2

ENERGY CONSUMPTION, PERCENTAGE INCREASE IN ENERGY CONSUMPTION, AND INTERIOR CABINET TEMPERATURE FOR REFRIGERATORS 1, 2, AND 3 (TEST 2 - FREQUENCY OF DOOR OPENINGS)

Number of 30-sec. door openings	Refrigerator 1					Refrigerator 2					Refrigerator 3				
	Watt-hours Consumed			Temp. in °F		Watt-hours Consumed			Temp. in °F		Watt-hours Consumed			Temp. in °F	
	Range	Mean	% Incr.	Mean	Max.	Range	Mean	% Incr.	Mean	Max.	Range	Mean	% Incr.	Mean	Max.
0	143-146	144	. . .	36	36	562-573	569	. . .	20	20	413-425	420	. . .	33	33
6	133-172	157	9	34	53	574-584	578	16	20	51	472-582	532	27	33	49
12	178-197	187	30	35	53	584-595	588	33	26	53	572-588	578	37	34	50
24	182-229	202	40	33	52	564-607	590	37	19	53	712-763	730	74	36	50
48	227-267	248	72	33	55	601-618	607	66	25	54	765-812	788	87	33	52

test (Table 3). Opening the door for 30 seconds (total-6 minutes) resulted in a 30 to 37 percent increase in energy consumption. When the door was opened for 1 minute (total-12 minutes) energy consumption was increased by 23 to 72 percent over the control test. Opening the refrigerator door every 12 minutes for 2 minutes (total-24 minutes) resulted in a 51 to 85 percent increase in energy consumption.

The longer the duration of the door opening, the higher the temperature reached within the refrigerator for all test periods (Table 3). As the refrigerator door was opened for a longer period of time, heat gain was increased and the motor ran longer to restore the preset temperature.

Comparison of Findings for Tests 2 and 3

A comparison of Tests 2 and 3 indicates that there was no meaningful difference in energy consumption between test periods with door openings of short duration and test periods with door openings of longer duration (Figure 1). It was the total length of time the door was open which affected the energy consumption. Doubling the total amount of time the door was open resulted in an average increase in energy consumption of 14 percent for Refrigerator 1, 2 percent for Refrigerator 2, and 17 percent for Refrigerator 3.

TABLE 3

ENERGY CONSUMPTION, PERCENTAGE INCREASE IN ENERGY CONSUMPTION, AND INTERIOR CABINET TEMPERATURE FOR REFRIGERATORS 1, 2, AND 3 (TEST 3 - DURATION OF DOOR OPENINGS)

Length of door openings in seconds	Refrigerator 1					Refrigerator 2					Refrigerator 3				
	Watt-hours Consumed			Temp. in °F		Watt-hours Consumed			Temp. in °F		Watt-hours Consumed			Temp. in °F	
	Range	Mean	% Incr.	Mean	Max.	Range	Mean	% Incr.	Mean	Max.	Range	Mean	% Incr.	Mean	Max.
0	143-146	144	. . .	36	36	562-573	569	. . .	20	20	413-425	420	. . .	33	33
15	162-167	164	14	32	47	538-575	561	-14	22	41	475-538	499	19	35	45
30	178-197	187	30	35	53	584-595	588	33	26	53	572-588	578	37	34	50
60	188-210	198	37	33	58	576-586	582	23	21	57	689-755	724	72	36	55
120	226-248	234	62	33	60	593-601	598	51	19	59	760-803	777	85	37	58

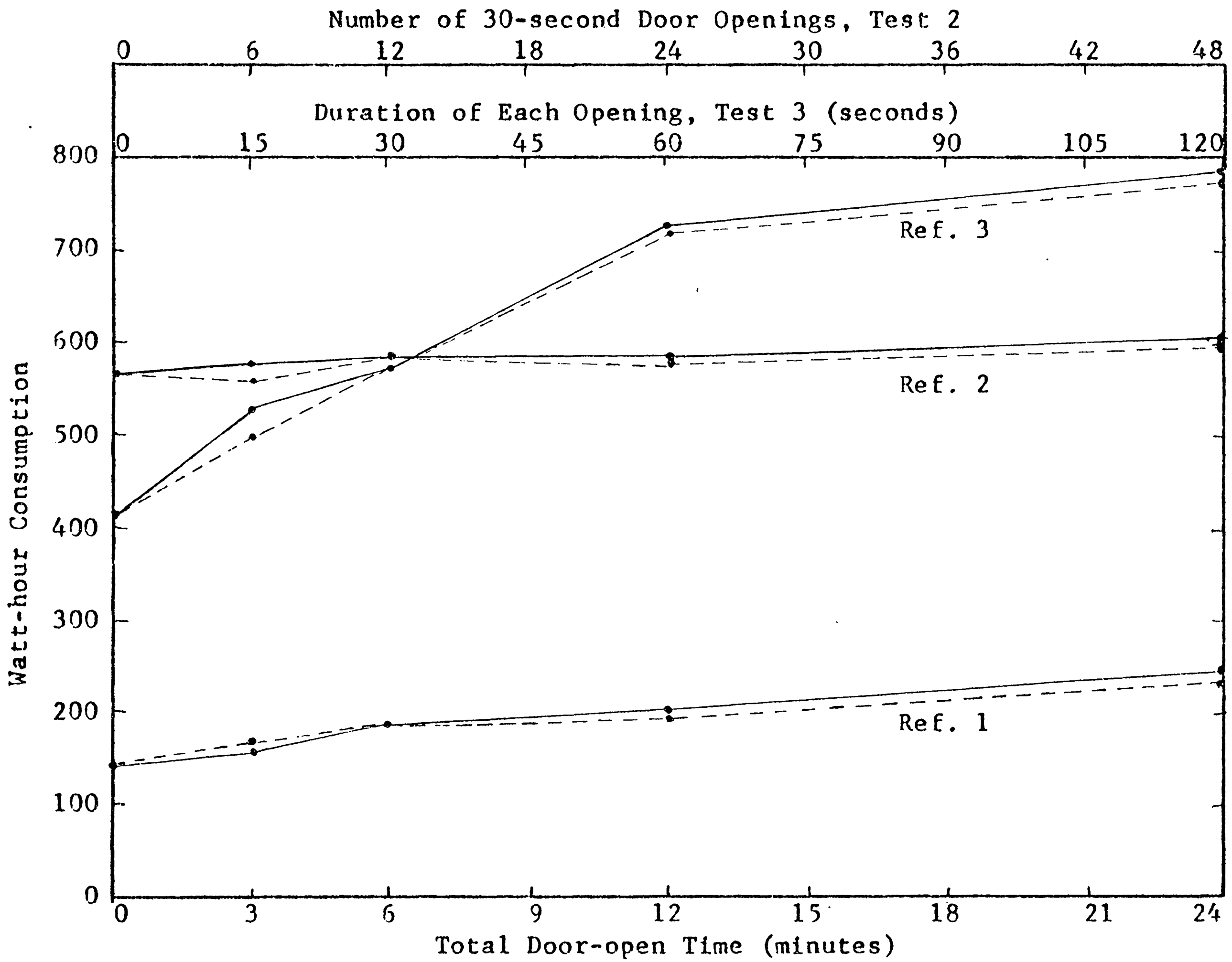

Figure 1. Graph of energy consumption versus total door-open time.
Top axes show number of openings in Test 2 and duration of each opening in Test 3.
Lines are drawn from point to point to aid visualization.
"——" designates Test 2. "– – –" designates Test 3.

Test 4 - Location of Refrigerator Near a Heat Source

Energy consumption was recorded under load conditions for two-hour test periods with the refrigerator located next to a range to determine the effect on the energy consumption of Refrigerators 1, 2, and 3. A length of two hours was arbitrarily chosen after pretesting time periods of various lengths. Tests were conducted as follows: Test 4.1 - closed door--range inoperative; Test 4.2 - open door (four 15-second openings)--range inoperative; and Test 4.3 - open door (four 15-second openings)--range operative.

Locating the refrigerator near a heat source did not appear to have much effect on energy consumption (Table 4). Mean energy use of Refrigerators 1 and 2 was less when the range was in operation than when it was not, however this difference was slight and could have happened by chance. Refrigerator 3 consumed a mean of 19 watt-hours more when the range was in operation. However, that difference may not be meaningful due to the large variation in watt-hour consumption for the three replications of the test.

The exterior of the refrigerators reached temperatures ranging from 103°F(39°C) to 112°F(44°C) while the range was in operation, however this did not appear to affect the interior cabinet temperature (Table 4). Operating the refrigerator near a heat source (in this case, a range) did not have a noticeable effect on energy consumption or interior cabinet temperature for any of the refrigerators tested. This may be due to the amount of insulation in both the range and the refrigerators or the large size and open

TABLE 4

ENERGY CONSUMPTION AND MEAN INTERIOR AND MAXIMUM EXTERIOR CABINET TEMPERATURES FOR REFRIGERATORS 1, 2, AND 3
(TEST 4 - LOCATION OF REFRIGERATOR NEAR A HEAT SOURCE)

Operating Conditions	Refrigerator 1				Refrigerator 2				Refrigerator 3			
	Watt-hours Consumed		Temp. in °F		Watt-hours Consumed		Temp. in °F		Watt-hours Consumed		Temp. in °F	
	Range	Mean	Mean Int.	Max. Ext.	Range	Mean	Mean Int.	Max. Ext.	Range	Mean	Mean Int.	Max. Ext.
4.1 closed door-- range inoperative	84- 89	87	36	68	373-383	379	20	70	258-267	263	33	65
4.2 open door-- range inoperative	95-101	99	35	68	367-372	370	25	70	277-349	302	32	65
4.3 open door-- range operative	89- 98	95	31	112	367-372	369	15	104	310-328	321	32	103

arrangement of the laboratory which facilitates air circulation.

Test 5 - Use of Energy-Saver Switch

The objective of Test 5 was to determine the effect on energy consumption of using the energy-saver switch of a no-frost refrigerator-freezer. Energy consumption was recorded under closed-door conditions with a load for three 24-hour test periods, first with the energy-saver switch set at high humidity, then at medium humidity, and then at low humidity for each of the 24-hour test periods.

The use of the energy-saver switch resulted in a considerable difference in energy consumption. When the switch was set at the low humidity setting, the refrigerator consumed a mean of 2310 wh (Table 5). At the medium humidity setting, it consumed a mean of 2604 wh, an increase of 13 percent. At the high humidity setting, the refrigerator's mean energy consumption was 3224 wh, an increase of 40 percent over the low humidity setting. Based on a cost of 3¢ per kilowatt-hour, the cost of operating the refrigerator at the low humidity setting for one year is \$25.29. The projected annual cost of operation at the high humidity setting is \$35.30.

The exterior temperature of the refrigerator was $63^{o}F(17^{o}C)$ at the low and medium humidity settings and increased to $70^{o}F(21^{o}C)$ at the high humidity setting. The interior temperature rose from $37^{o}F(3^{o}C)$ at the low and medium humidity settings to $40^{o}F(4^{o}C)$ at the high humidity setting.

The difference in the energy consumption at the different humidity settings can be attributed to both increased energy

TABLE 5

ENERGY CONSUMPTION, PERCENTAGE INCREASE IN ENERGY CONSUMPTION, AND MEAN INTERIOR AND EXTERIOR CABINET TEMPERATURES FOR REFRIGERATOR 4 (TEST 5 - USE OF ENERGY-SAVER SWITCH)

Energy-saver Switch Setting	Watt-hours Consumed			Temperature in °F	
	Range	Mean	Percentage Increase	Interior	Exterior
Low	2249-2341	2310	. . .	37	63
Medium	2414-2821	2604	13	37	63
High	3044-3407	3224	40	40	70

consumption by the anti-condensation heaters and increased heat gain when those heaters are in operation, causing the motor to run longer to maintain a given temperature.

Test 6 - Thickness of Frost Accumulation

The effect on energy consumption of frost accumulation on the evaporator coils of the manual-defrost refrigerator was examined in Test 6. Energy consumption was recorded under closed-door, load conditions for 24-hour test periods with no frost on the evaporator coils, with one-fourth inch of frost, and with one-half inch of frost.

The thickness of frost accumulation in the manual-defrost refrigerator resulted in a slight (2 percent) increase in energy consumption when the frost was one-fourth inch thick (Table 6). When the frost reached a thickness of one-half inch, the mean energy consumption decreased by 23 percent over the test without frost.

The mean cabinet temperature during the test without frost was 35°F(2°C) and dropped to 34°F(1°C) during the test with one-fourth inch of frost. When one-half inch of frost had accumulated on the evaporator coils, the mean temperature dropped to 31°F(-1°C). The interior temperature of the refrigerator declined as the thickness of frost increased.

TABLE 6

ENERGY CONSUMPTION, PERCENTAGE CHANGE IN ENERGY CONSUMPTION, AND INTERIOR CABINET TEMPERATURE FOR REFRIGERATOR 1 (TEST 6 - THICKNESS OF FROST ACCUMULATION)

Thickness of Frost in Inches	Watt-hours Consumed			Mean Temperature in ^{o}F
	Range	Mean	Percentage Change	
0	1020-1085	1047	. . .	35
1/4	1029-1136	1067	+2	34
1/2	764- 851	806	-23	31

Test 7 - Defrosting Process Including Temperature Recovery

The purpose of Test 7 was to determine the effect on energy consumption of defrosting a manual-defrost refrigerator and then cooling it to the original temperature. For the control test, energy consumption was recorded under closed-door, no-frost, load conditions for a 24-hour period. After one-fourth inch of frost had accumulated on the evaporator coils, the refrigerator was defrosted according to the manufacturer's directions. Energy consumption was recorded under load conditions for a 24-hour test period starting at the end of the defrosting process, one hour after the process was initiated.

Cooling the refrigerator to normal operating temperature after the defrosting process produced a 22 percent increase in energy consumption over the control test for the 24-hour period immediately following the defrosting process. The mean cabinet temperature at the end of the defrosting process was $67^{o}F(19^{o}C)$. The mean cabinet temperature during the control test was $35^{o}F(2^{o}C)$ and during the period after defrosting, $36^{o}F(2^{o}C)$. If defrosted once or twice per week as recommended by the manufacturer, the cost of the energy consumed by the recovery period would be about 35¢ to 70¢ per year.

TABLE 7

ENERGY CONSUMPTION AND INTERIOR CABINET TEMPERATURE FOR REFRIGERATOR 1
(TEST 7 - DEFROSTING PROCESS AND TEMPERATURE RECOVERY)

Operating Conditions	Watt-hours Consumed		Mean Temperature in ^{o}F
	Range	Mean	
Control	1020-1085	1047	35
Recovery Period	1181-1335	1273	36

Discussion

The findings presented may be more meaningful when viewed in relation to the findings of other researchers. It is necessary however, to first examine the limitations of this study. Limitations which influence the generalizability of this study can be separated into two categories--laboratory conditions and test procedures.

Laboratory Conditions

Laboratory setting and activities, although controlled to the extent possible, may not have been representative of the home environment. Variations in room temperature and humidity could not be controlled, and although they did not vary a great deal, energy consumption may have been affected.

Test Procedures

Ideally, all tests should have been performed in a random order, a standard period of time allowed between tests (at least 12 hours), and each test performed on Refrigerators 1, 2, and 3 at the same time. Because of time and equipment constraints, this was not possible. However, minimum length of time between tests was consistent for each test period. Time constraints also prevented more than three replications and longer test periods, both of which may have given more reliable data.

A limited number of brands, models, and sizes of refrigerators and refrigerator-freezers were tested. Other brands, models, and sizes may produce different results.

The load used in this study, although representative of the amount of food in home refrigerators, may not have been representative of the size, shape, and specific heat of actual food items.

Findings of Other Researchers

The findings of this study generally support those of the Midwest Research Institute and AHAM. The kilowatt-hour consumption of Refrigerators 1, 3, and 4 was 17 to 25 percent lower than that published in the AHAM Directory of Certified Refrigerators and Freezers (1976). However, AHAM test conditions were somewhat different. For example, in this study the freezer control in the refrigerator-freezers were set at the warmest setting, and in AHAM test procedures the control is set at various settings. AHAM testing procedures also require an ambient temperature of 90°F(32°C), and room temperature during this study was usually 70°F(21°C) to 75°F(24°C). The kilowatt-hour consumption of Refrigerator 2 was higher than the AHAM figure, possibly resulting from the unusually low cabinet temperature which ranged from 15°F(-9°C) to 26°F(-3°C) during most tests and which may need adjustment.

The data collected in this study are also somewhat lower than the 4.7 average daily kilowatt-hour consumption of refrigerators in the United States as reported by the Midwest Research Institute (1977). Energy consumption for the 24-hour test periods reported in Test 1 ranged from .879 to 4.508 kilowatt-hours. This difference, again, is probably due to the warmer freezer temperature control setting and the difference between the test procedures and home use.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Since the increasing costs of electricity are causing consumers to attempt to reduce their energy consumption, it is important for researchers to determine methods in which this reduction may be achieved. Because the refrigerator may consume more electricity than any other major appliance in the home, it is an important area in which to reduce energy consumption. The purpose of this study was to determine the effect on the energy consumption of a refrigerator related to:

1. Variations in temperature control setting
2. Frequency of door openings
3. Duration of door openings
4. Location of the refrigerator near a heat source
5. Use of an energy-saver switch
6. Thickness of frost accumulation on the evaporator coils of a manual defrost refrigerator.
7. Defrosting process of a manual-defrost refrigerator, including temperature recovery

Data were collected in the Virginia Polytechnic Institute and State University College of Home Economics household equipment laboratory during the fall and winter of 1977-78. All tests were designed to simulate consumer practices and were performed with a load in the fresh food compartment. Energy consumption was recorded during seven tests on a total of four refrigerators. Each test was replicated three times. The first four tests were performed on a manual-defrost refrigerator, a cycle-defrost refrigerator-freezer, and a no-frost refrigerator-freezer. Test 5 utilized a no-frost refrigerator with an energy-saver switch. Tests 6 and 7 were performed on a manual-defrost refrigerator.

Conclusions

The primary conclusion derived from findings was that temperature control setting, frequency of door openings, duration of door openings, use of an energy-saver switch, and the defrosting process all had an effect on the energy consumption of refrigerators. Operating the refrigerator near a heat source affected energy consumption, but not to the extent of the other tests. Due to inconsistent results, the effect of frost accumulation on energy consumption needs further investigation.

Implications for Consumers

The results of this study indicate several ways in which consumers may reduce operating costs of their refrigerators. By setting the temperature control at the warmest setting, energy consumption may be reduced up to 64 percent, however, food safety is an important consideration. Foods specialists and appliance manufacturers recommend a maximum temperature of $40^{\circ}F (4^{\circ}C)$. A thermometer placed inside the refrigerator can assure that the temperature is appropriate. Manufacturers sometimes suggest that if milk is the cold temperature desired for drinking, the temperature control setting is correct.

Reducing the total length of time the refrigerator door is open by one-half may reduce energy consumption up to 27 percent. It appears to make no difference in energy consumption whether the refrigerator door is opened for a few long openings or many short openings.

By keeping the energy-saver switch set on the low humidity setting whenever possible, energy consumption can be reduced up to 40 percent. Even using the medium humidity setting instead of the high humidity setting could result in a savings of 27 percent.

Although locating the refrigerator near a heat source and the allowing of frost to accumulate on the evaporator coils did not result in a noticeable increase in energy consumption, it cannot be assumed that the manufacturers' recommendations regarding these conditions should be ignored. Further testing is needed before any conclusions can be made.

Recommendations for Further Research

A limited number of brands, models, and sizes of refrigerators and refrigerator-freezers were tested in this study. The models tested all had top-mount freezer compartments and ranged in size from 12.9 cubic feet to 17.0 cubic feet. Refrigerators currently on the market range in size from 1.5 cubic foot compact models to 28 cubic foot side-by-side models (1977 AHAM Directory of Certified Refrigerators and Freezers, 1977).

Recommendation: Further research is needed to determine if these findings hold true for other brands, models, and sizes.

A limited number of measuring instruments were used in this study.

Recommendation: Further research, for example, recording the flow of current with a recording ammeter would provide additional information concerning the running time of the refrigerator. It would then be possible to relate the running time to actual test conditions.

The load used in this study may not have been representative of the load in the home refrigerator. A refrigerator in home use contains objects of varying sizes, shapes, and degrees of fullness, and foods of varying density.

Recommendation: Further research is needed to develop a reference food load for refrigeration research.

Two tests (Test 4 and Test 7) resulted in findings which contradict manufacturer's recommendations.

Recommendation: Further research is necessary to again examine the effect on energy consumption of frost accumulation and of locating the refrigerator near a heat source.

The consumer practices tested may not have adequately represented those in the home environment.

Recommendation: Further research is needed to determine actual consumer practices related to refrigerator usage.

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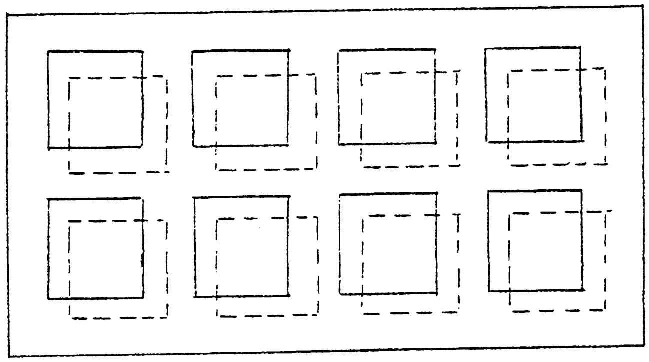
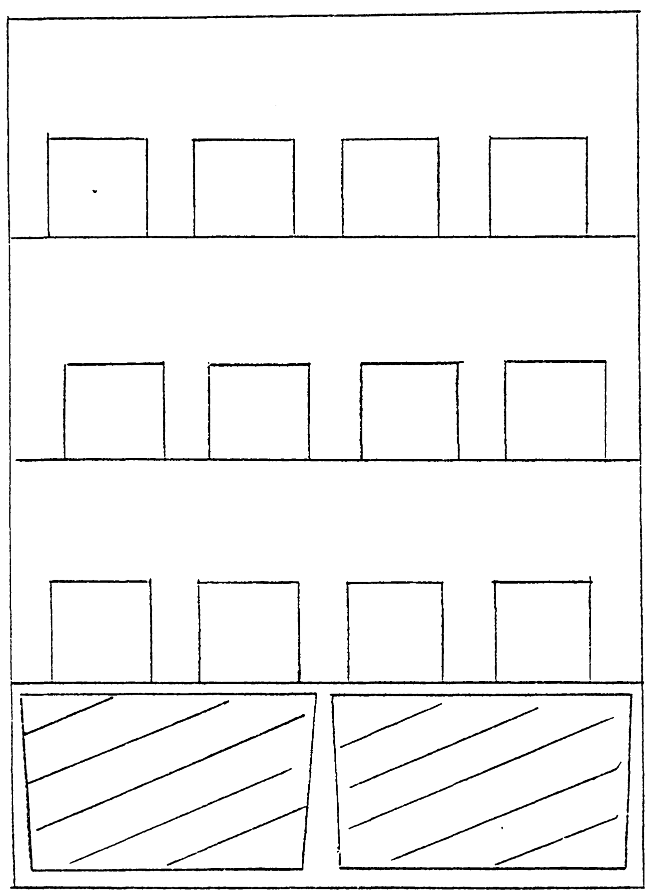
APPENDIX A

LOAD ARRANGEMENT

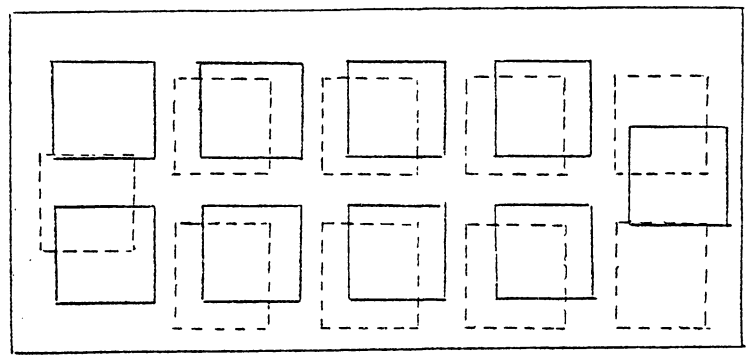


a) Plan view

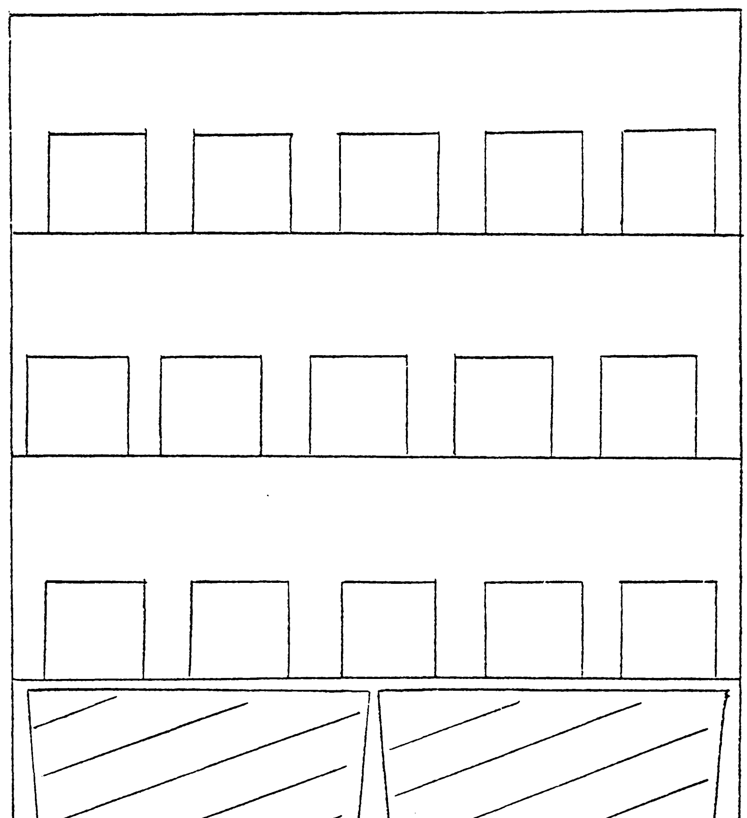


b) Elevation

Figure 2. Load arrangement of fresh food compartment of Refrigerators 1 and 2. Load consists of 24 one-quart plastic freezer containers filled with water. Those on top and bottom shelves are indicated by ———. Those on middle shelf are indicated by — — — —.

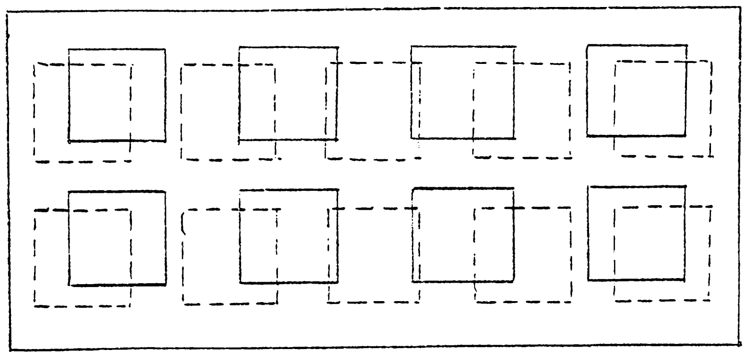


a) Plan view

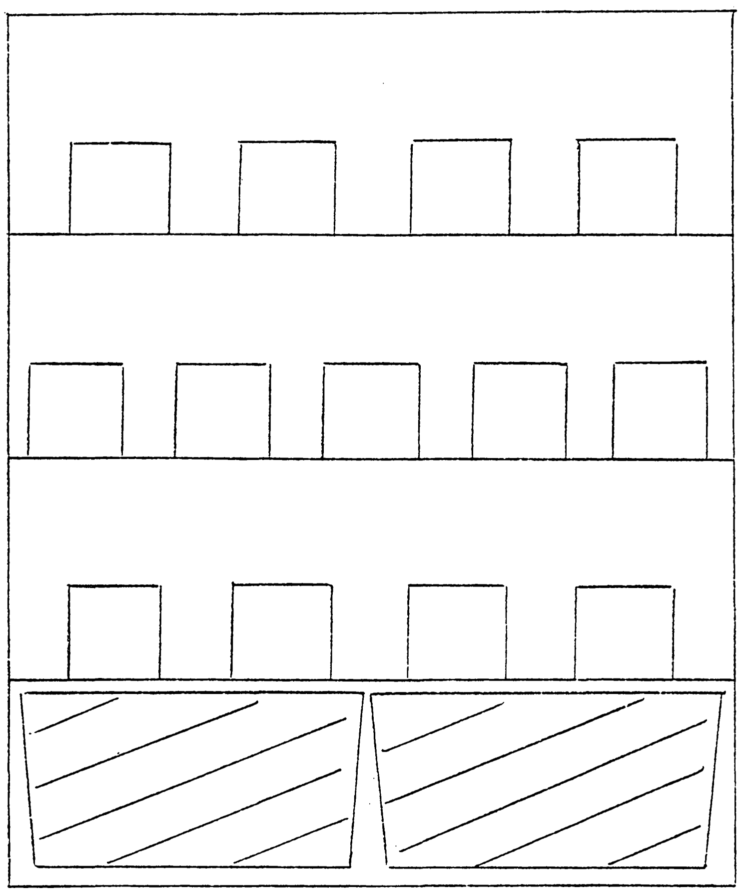


b) Elevation

Figure 3. Load arrangement of fresh food compartment of Refrigerator 3. Load consists of 27 one-quart plastic freezer containers filled with water. Those on top and bottom shelves are indicated by ———. Those on middle shelf are indicated by — — — —.



a) Plan view



b) Elevation

Figure 4. Load arrangement of fresh food compartment of Refrigerator 4. Load consists of 26 one-quart plastic freezer containers filled with water. Those on top and bottom shelves are indicated by ______. Those on middle shelf are indicated by — — — —.

APPENDIX B

THERMOCOUPLE PLACEMENT

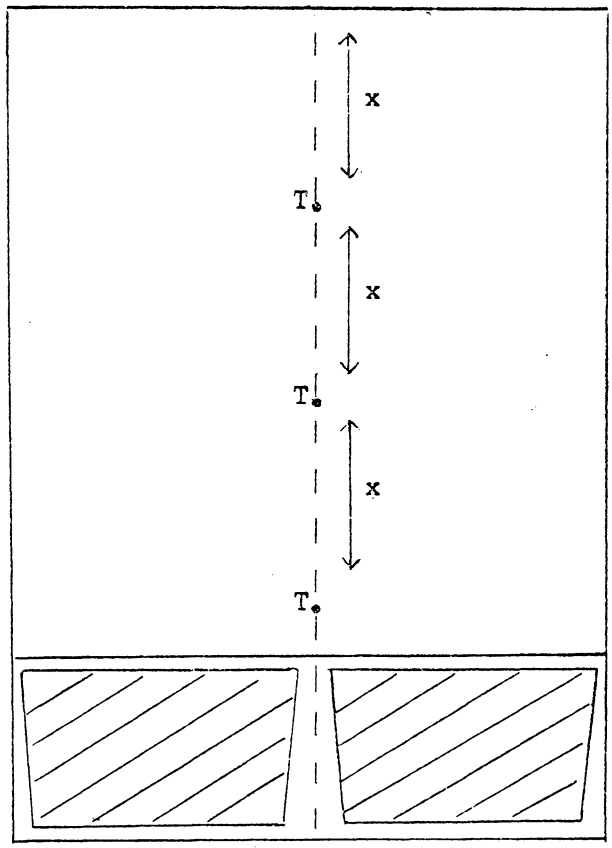


Figure 5. Interior thermocouple placement for Refrigerators 1, 2, 3, and 4.

"x" designates an equal distance.
"T" is a point, an equal distance from door and back of cabinet, designating thermocouple placement.

Adapted from AHAM Refrigerator and Freezer Standard - No. HRF-1 (1967)

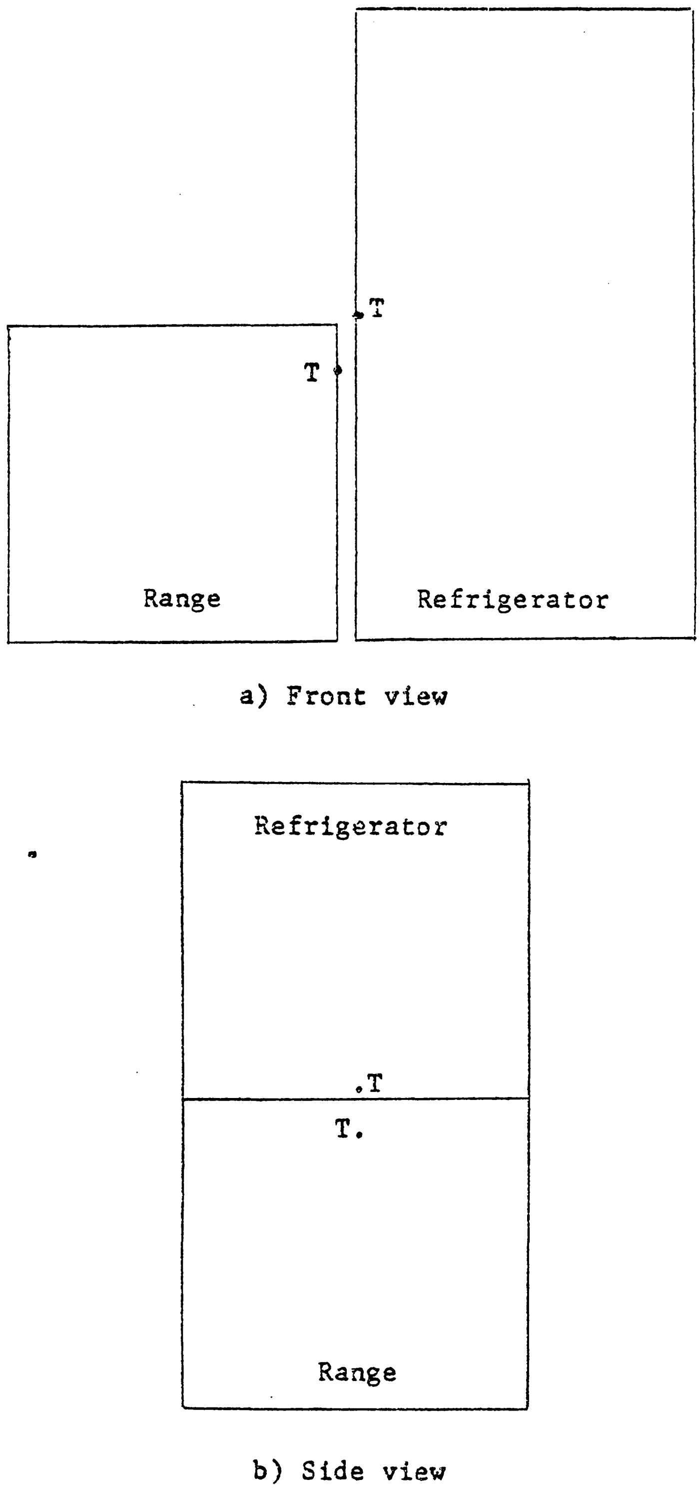


Figure 6. Exterior thermocouple placement for Refrigerators 1, 2, and 3, Test 4.
"T" designates thermocouple placement.

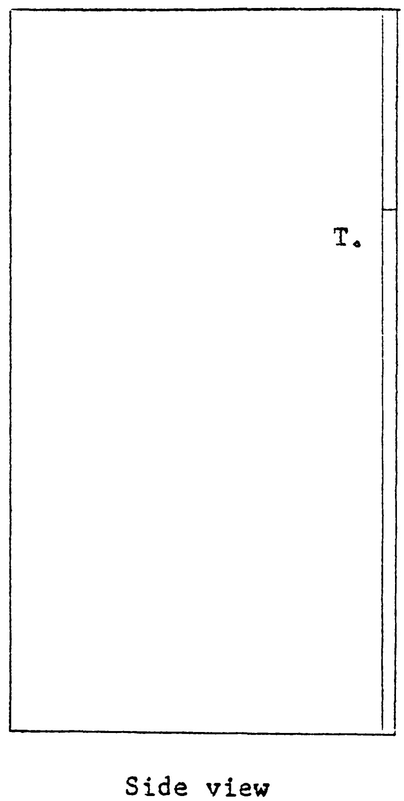


Figure 7. Exterior thermocouple placement for Refrigerator 4, Test 5. "T" designates thermocouple placement.

APPENDIX C

DATA COLLECTION SHEETS

DATA COLLECTION SHEET

TEST 1 - VARIATIONS IN TEMPERATURE CONTROL SETTING

REFRIGERATOR #____

Temp. Control Setting	Warmest						Middle					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Temp. Control Setting	Coldest					
Trial #	1		2		3	
Start/End	S	E	S	E	S	E
Date						
Time						
Temp.						
Atm. Press.						
Humidity						
Meter: After						
Before						
Wh Consumed						

DATA COLLECTION SHEET

TEST 2 - FREQUENCY OF DOOR OPENINGS

REFRIGERATOR #____

Door Openings	Open door every 25.3 min., total - 6 times						Open door every 13.4 min., total - 12 times					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Door Openings	Open door every 6.7 min., total - 24 times						Open door every 3.2 min., total - 48 times					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

DATA COLLECTION SHEET

TEST 3 - DURATION OF DOOR OPENINGS

REFRIGERATOR #___

Door Openings	Open door every 13.6 min. for 15 seconds						Open door every 13.4 min. for 30 seconds					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Door Openings	Open door every 12.9 min. for 1 minute						Open door every 12 min. for 2 minutes					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

DATA COLLECTION SHEET

TEST 4 - LOCATION OF REFRIGERATOR NEAR A HEAT SOURCE

REFRIGERATOR #____

Test	Test 4.1 Closed door--range inoperative						Test 4.2 Open door--range inoperative					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Test	Test 4.3 Open door--range operative					
Trial #	1		2		3	
Start/End	S	E	S	E	S	E
Date						
Time						
Temp.						
Atm. Press.						
Humidity						
Meter: After						
Before						
Wh Consumed						

DATA COLLECTION SHEET

TEST 5 - USE OF ENERGY-SAVER SWITCH

REFRIGERATOR #4

Humidity Setting	Low						Medium					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Humidity Setting	High					
Trial #	1		2		3	
Start/End	S	E	S	E	S	E
Date						
Time						
Temp.						
Atm. Press.						
Humidity						
Meter: After						
Before						
Wh Consumed						

DATA COLLECTION SHEETS

TEST 6 - THICKNESS OF FROST ACCUMULATION

REFRIGERATOR #1

Inches of Frost	No frost						1/4 Inch					
Trial #	1		2		3		1		2		3	
Start/End	S	E	S	E	S	E	S	E	S	E	S	E
Date												
Time												
Temp.												
Atm. Press.												
Humidity												
Meter: After												
Before												
Wh Consumed												

Inches of Frost	1/2 Inch					
Trial #	1		2		3	
Start/End	S	E	S	E	S	E
Date						
Time						
Temp.						
Atm. Press.						
Humidity						
Meter: After						
Before						
Wh Consumed						

DATA COLLECTION SHEET

TEST 7 - DEFROSTING PROCESS AND TEMPERATURE RECOVERY

REFRIGERATOR #1

Temperature Recovery						
Trial #	1		2		3	
Start/End	S	E	S	E	S	E
Date						
Time						
Temp.						
Atm. Press.						
Humidity						
Meter: After						
Before						
Wh Consumed						

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ENERGY CONSUMPTION OF REFRIGERATORS AS AFFECTED BY SELECTED CONSUMER PRACTICES

by

Sandra Lane Fischgrund

(ABSTRACT)

This study was designed to measure the effect of selected consumer practices on energy consumption of refrigerators. Seven tests designed to simulate consumer practices were performed three times each on four refrigerators. Four tests involving variations in temperature control setting, frequency and duration of door openings, and placement of the refrigerator near a heat source were each performed on a manual-defrost refrigerator, a cycle-defrost refrigerator-freezer, and a no-frost refrigerator-freezer. A test involving the use of an energy-saver switch was performed on a no-frost refrigerator-freezer, and two tests related to the effect of frost accumulation on energy consumption were performed on a manual-defrost refrigerator. Watt-hour consumption and interior cabinet temperature were recorded for all tests.

Increasing the temperature control setting, frequency of door openings, and duration of door openings; the use of an energy-saver switch; and the defrosting process all increased the energy consumption of the refrigerators. Operating the refrigerator near a heat

source did not affect energy consumption to the extent of the other tests. Due to inconsistent results, the effect of frost accumulation on energy consumption needs further investigation.