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Life Cycle Optimization of Household Refrigerator-Freezer Replacement

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by

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ABSTRACT

Average energy consumption of new refrigerators sold in the U.S. decreased by approximately 60 percent between 1980 and 2002. Despite the dramatic energy efficiency improvements driven by energy standards, the average replacement intervals of refrigerator remain nearly unchanged being around 14 years. Although replacing old refrigerators with new, more efficient units is an important strategy, it also leads to environmental impacts in producing new refrigerators and disposing old units.

Using a Life Cycle Assessment perspective, this research examines optimal refrigerator lifetimes that minimize cumulative energy consumption and cost over the time horizon between 1985 and 2020. Dynamic life cycle energy inventories for mid-sized top/bottom refrigerators were developed for model years between 1985 and 2020 based on available data. Parameters such as energy efficiency improvement and energy performance deterioration were also modeled. Additionally, life cycle costs for purchasing, operating, and disposing a refrigerator were estimated.

The Life Cycle Optimization (LCO) model for refrigerator replacement was developed based on a dynamic programming tool. According to the simulation results based on refrigerator energy consumption data from *Consumer Reports*, the optimal lifetime for the energy objective ranges between 2 to 12 years, while that determined by cost objective is 18 years over the time horizon between 1985 and 2020. The results show that energy optimization scenarios would save 17 to 21% of primary energy use compared with cost optimization scenarios, but require 22 to 33% higher cost than cost optimization scenarios.

The results can help manufacturers, consumers, and policymakers understand the economic and environmental implications of retiring old refrigerators and purchasing new units. The results also demonstrate that scrappage programs encouraging retirement of old, inefficient refrigerators can serve to reduce household energy consumption.

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CHAPTER I

Introduction

Energy efficiency of household refrigerator-freezers has been dramatically improved since1990's mainly because of new federal energy efficiency standards. Average energy consumption of new refrigerators sold in the U.S. decreased by approximately 60 percent from 1980 to 2002 (AHAM 2002). According to a report in 2001 by the Association of Home Appliance Manufacturers (AHAM), the average length of ownership of currently owned full-size refrigerators is 8.8 years for new units and 8.2 years for used units. These numbers suggest that many consumers still use units from model years prior to 1993, although about 5 percent of refrigerator-freezers are replaced each year (Parker and Stedman 1993). Using an old product for a long time with maintenance might be considered more environmentally friendly and less costly than replacing it with new unit many times. On the other hand, substituting newer technology for products that are energy intensive can be expected to lead environmental benefits. Consequently, the timing of product replacement to maximize environmental benefits and minimize user costs is a key question to be resolved.

1.1 Consumer Behavior

Refrigerator-freezers have become bigger, more access-friendly, more multifunctional and more fashionable over the years. The trend is toward spacious, full-featured models with flexible, and efficiently used storage space (Consumer Reports 2000). According to an Energy Information Administration (EIA) survey (EIA 1997), small (less than 14 cubic feet), medium (15-18 cf) and large (more than 19 cf) models accounted for 25%, 41% and 34% of U.S. housing units in 1990 respectively. Medium models dominated more than half of U.S. housing units in 1993, but in 1997 large refrigerators accounted for 46% of U.S. housing units while medium refrigerators accounted for 45% of U.S. housing units.

The popularity of side-by-side models has grown rapidly because of their access-friendly, multifunctional and fashionable design. A recent study by AHAM shows that side-by-side models account for 18% in 1990, 20% in 1996 and 25.2% in 2001 of U.S. housing units, while top-mounted refrigerators account for 56% in 1996 and 51.2% of U.S. housing units in 2001. Despite their growing popularity, side-by-side models have been shown to consume more energy than other designs (Consumer Reports 1995). In step with the trend toward bigger refrigerators and side-by-side models, total energy consumption of refrigerator-freezers in households has been increasing

1.2 History of Federal Regulations

The movement for federal appliance efficiency standards started in the 1970s. At that time, several states, including California, were adopting state appliance efficiency standards. The Energy Policy and Conservation Act of 1975 (EPCA) established a federal energy conservation program for major household appliances by requiring appliance efficiency targets. However, little progress was made to establish standards until the 1980s. By 1986, appliance manufacturers realized that uniform federal standards were preferable to a variety of state standards. The National Appliance Energy Conservation Act of 1987 (NAECA) established minimum efficiency standards for many household appliances including refrigerators, refrigerator-freezers, freezers, room air conditioners, clothes dryers, clothes washers, dishwashers, kitchen ranges, ovens and water heaters. NAECA set the maximum federal energy consumption for 18 different product classes of refrigerators (DOE 2004). The original NAECA level was applied to models manufactured after January 1, 1990. The standards were amended to be approximately 30% more efficient for models manufactured after January 1, 1993 and again in July 1, 2001 another approximately 30% efficiency improvement was implemented (Karney 2001). The existence of a federal standard for energy or water conservation products preempts state standards, unless the state standard is identical to the federal standard. States may petition DOE for an exemption from federal standards under certain circumstances (DOE 2004).

1.3 Problem Statement

While the federal government has tightened energy efficiency standards for refrigerator-freezers, the rate at which new, efficient refrigerator-freezers replace old, inefficient refrigerator-freezers in households is uncertain. Refrigerator-freezers have considerably long expected lifetime of approximately 20 years and average observed lifetime of 14 years[1](AHAM 1990; NFO 1996; ARIC 2004). Moreover, little attention has been paid to the environmental impact and economic cost associated with producing new refrigerator-freezers and retiring and disposing of old refrigerator-freezers.

This thesis explores whether replacements of old refrigerator-freezers with new ones would save money for consumers and reduce environmental burdens for society. Energy consumption and cost of refrigerator-freezers during the life stages change with model year and age. Thus, a dynamic analysis was conducted to evaluate impact of energy consumption and total cost to provide recommendations and educate consumers.

A recent model called life cycle optimization (LCO), which was developed for the optimization of generic vehicle replacement, provides a useful method for determining optimal lifetimes of products (Kim, Keoleian et al. 2003). This research uses the LCO model to analyze optimal lifetimes of household refrigerator-freezers from the life cycle energy and cost perspective over a 36-year time horizon.

1.4 Thesis Outline

In order to determine optimal lifetimes of household refrigerator-freezers, energy consumption during the entire product life cycle must be determined. Besides, the initial purchase price, electricity and disposal costs are estimated for cost optimization. These user costs are of primary interest for consumers.

Chapter 2 describes the method and basic concepts of life cycle assessment (LCA) and life cycle optimization (LCO). First, the life cycle inventory (LCI), which is a collection of inputs and outputs of materials, energy and waste within a system boundary of a product, is explained. Then, a dynamic life cycle inventory is developed based on a

[1] The average lifetime of an appliance may be different than the average observed life. Consumers may choose to "retire" an appliance early because repairs are no longer cost effective. For example, while the average lifespan of a refrigerator may be 20 years, the average observed lifetime is around 14 years (NFO 1996).

real-world situation where new, more efficient models are introduced every year and the efficiency of old models deteriorates. Factors and parameters that determine energy consumption throughout the life stages are also described. Based on the resulting LCIs, the life cycle optimization model (LCO) is introduced in order to estimate the optimal lifetime of refrigerator-freezers.

In Chapter 3, the life cycle inventory for a household refrigerator-freezer model is presented. The life cycle energy consumption is estimated for the entire life cycle of refrigerator-freezers that encompasses material production, manufacturing and assembly, use, and end-of-life phases. An LCA software tool called SimaPro 5.1 is used for life cycle modeling and as a secondary data source.

Chapter 4 models dynamic life cycle inventory parameters including material contents, energy intensities, refrigerator efficiency, deterioration of energy performance, and improvement of energy efficiency. These parameters affect the optimal lifetime of refrigerator-freezers. Cost minimization, energy cost and purchase cost are also estimated both for past and future models.

Chapter 5 presents the results of simulations for both energy optimization and cost minimization scenarios in using household refrigerator-freezers and discusses determinants of optimal lifetimes that affect the results.

Chapter 6 concludes with overall results and key findings, presents policy implications and suggests potential topics.

CHAPTER II

Methodology

2.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is a useful tool to evaluate the environmental aspects and potential impacts associated with a product and a service throughout its life span. Life Cycle Assessment considers products or services from a "cradle to grave" perspective. The International Organization for Standardization (ISO) describes that the basic aim of LCA is to evaluate the environmental burdens associated with a product, process, or activity by (1) identifying and quantifying energy and materials used and wastes released to the environment, (2) assessing the impact of the energy and materials used and released to the environment, and (3) identifying and evaluating opportunities for environmental improvements (ISO 2002). ISO also specifies the general framework, principles and requirements for conducting and reporting life cycle assessment studies. The complete LCA framework includes four phases shown in Figure 2.1: goal and scope definition; inventory analysis; impact assessment, and interpretation. The goal and scope defines the purpose, intended audience, and system boundaries. The inventory analysis involves data collection and calculations to quantify material and energy inputs and outputs of a product system, and the impact assessment evaluates the significance of potential environmental impacts based on the inventory analysis. Finally, in the interpretation phase the analyst evaluates findings, reaches conclusions and makes recommendations (ISO 1997).

In defining the scope of an LCA study, a clear statement of the specification of the functions (performance characteristics) of the product needs to be made. The functional unit defines the quantification of these identified functions. The functional unit must be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore, the functional unit must be clearly defined and measurable (ISO 1998).

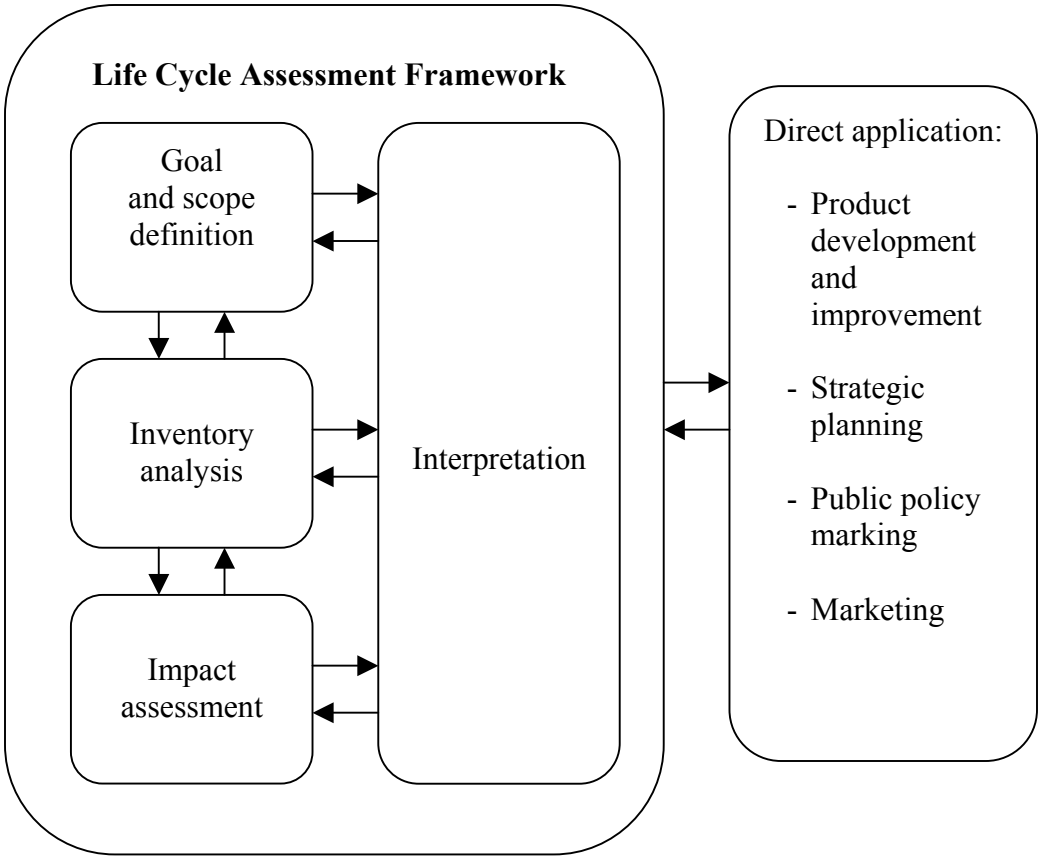

Figure 2.1: Phases of an LCA (ISO 1997)

Life Cycle Assessment can assist in (1) identifying opportunities to improve the environmental aspects of products at various points across the life cycle; (2) decision-making in industry, governmental, or non-governmental organizations (e.g., strategic planning, product or process design or redesign); (3) selection of relevant indicators of environmental performance, including measurement techniques; and (4) marketing (e.g., an environmental claim, ecolabelling scheme or environmental product declaration) (ISO 1997).

Recently, many companies across the world have started to adopt the LCA method to evaluate the environmental performance of their industrial products. More recently, LCA has begun to be utilized in evaluating large-scale systems including energy systems and waste treatment systems. For instance, Procter and Gamble (P&G), which operates globally in over 140 countries, uses Life Cycle Inventory (LCI) to measure

environmental impacts of its products. The company states that an LCI can be used directly for finding improvements in resource use and waste management. Moreover, the company, in cooperation with others, worked on a database of LCIs. P&G applied LCA to its laundry detergent to reduce environmental impacts of wastewater from the product. Although there are problems still existing in gathering reliable data from its own suppliers and manufactures, P&G has used the data as much as possible to examine the environmental effects of its products and processes (Verschoor and Reijnders 1999; Procter and Gamble 2003).

Japanese industries including automotive, electronic, and heavy manufacturing, have also applied LCA to their environmental management policies. For instance, Matsushita Electronic Industries Co., Ltd., also known as Panasonic, measures and reports key environmental impacts of a product's life cycle from the material acquisition phase to the end-of-life phase, in order to assess the effects that their manufacturing activities have on society. Their life cycle model tracks electricity, oil, gas, water and resources as inputs and CO2, NOx, SOx, chemical substances, effluent, and other wastes as outputs (Panasonic 2003). Some corporations such as Matsushita utilize LCA with the goal of reducing global warming and abiding by the Kyoto protocol.

2.2 Life Cycle Inventory Analysis

A product system is a collection of unit processes connected by the flows of intermediate products that perform one or more defined functions. Figure 2.2 shows an example of a product system. The description of a product system includes unit processes, elementary flows, and product flows across the system boundaries (either into the system or out of the system), and intermediate product flows within the system (ISO 1998).

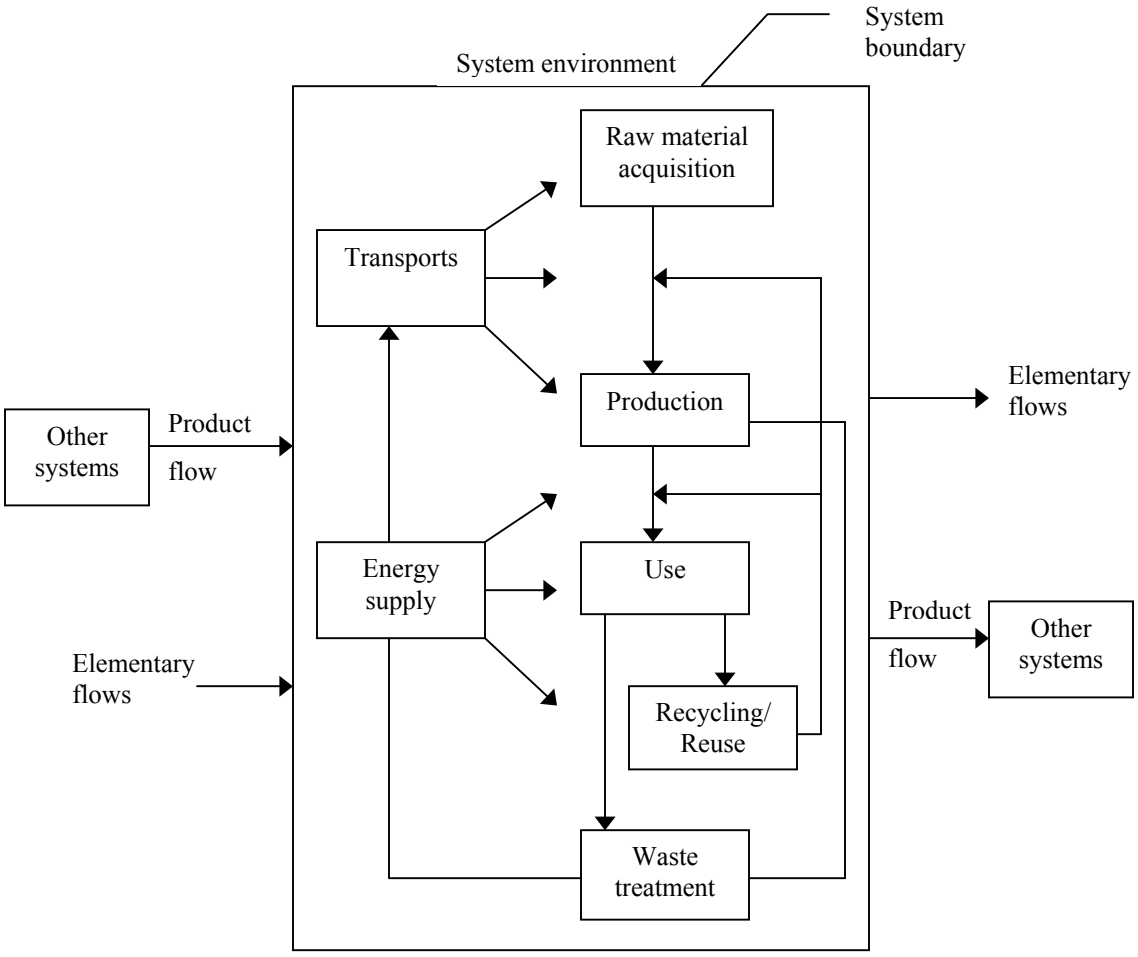

Figure 2.2: Example of a product system for life cycle inventory analysis (ISO 1998)

The system boundary defines the unit processes to be included in the system that is being modeled. Ideally, the product system should be modeled in such a manner that inputs and outputs at its boundary are elementary flows. However, in many cases there is not sufficient time, data, or resources to conduct such a comprehensive study. As shown in Figure 2.2 above, elementary flows, such as crude oil in the ground, land areas and solar radiation as heat, enter each unit process and leave as emissions to air, water and land. All inputs and outputs should be taken into consideration through the life cycle stages from the raw material acquisition stage to the waste treatment stage. Between these

life cycle stages, there are distribution or transportation processes and related environmental burdens associated with the delivery of materials. Recovery of used products including reuse, recycling and energy recovery also need to be considered (ISO 1998).

2.3 Dynamic Life Cycle Inventory

Life Cycle Assessment studies typically measure the environmental performance of a product based on a functional unit that defines the quantification of performance characteristics of the product. However, the typical LCA method using a functional unit ignores changes in environmental burden over time. In the real-world condition, new models with improved efficiencies are introduced every year. Moreover, based on recent studies, the energy efficiency of products such as refrigerator-freezers significantly deteriorates. Thus, a new LCI method that takes into account these changes over time period is necessary in order to determine optimal lifetimes while considering technology improvement and deterioration of energy performances.

The dynamics of environmental performance based on a particular product model year are described in Figure 2.3. Three main LCI dynamic factors change with each model year and these factors affect environmental parameters and life cycle stages. The *regulatory/socioeconomic factors* include demographic, regulatory, and macro-economic changes. The *technology improvements* affect energy efficiency of compressors, insulation, blowing agents, materials composition, and recycled materials. Durability of the product and maintenance requirements influence on *deterioration behaviors* (Kim 2003). For most model years, changes in industrial factors affect other factors. For example, if a regulation is enacted, industries need to comply with it and improve energy efficiency.

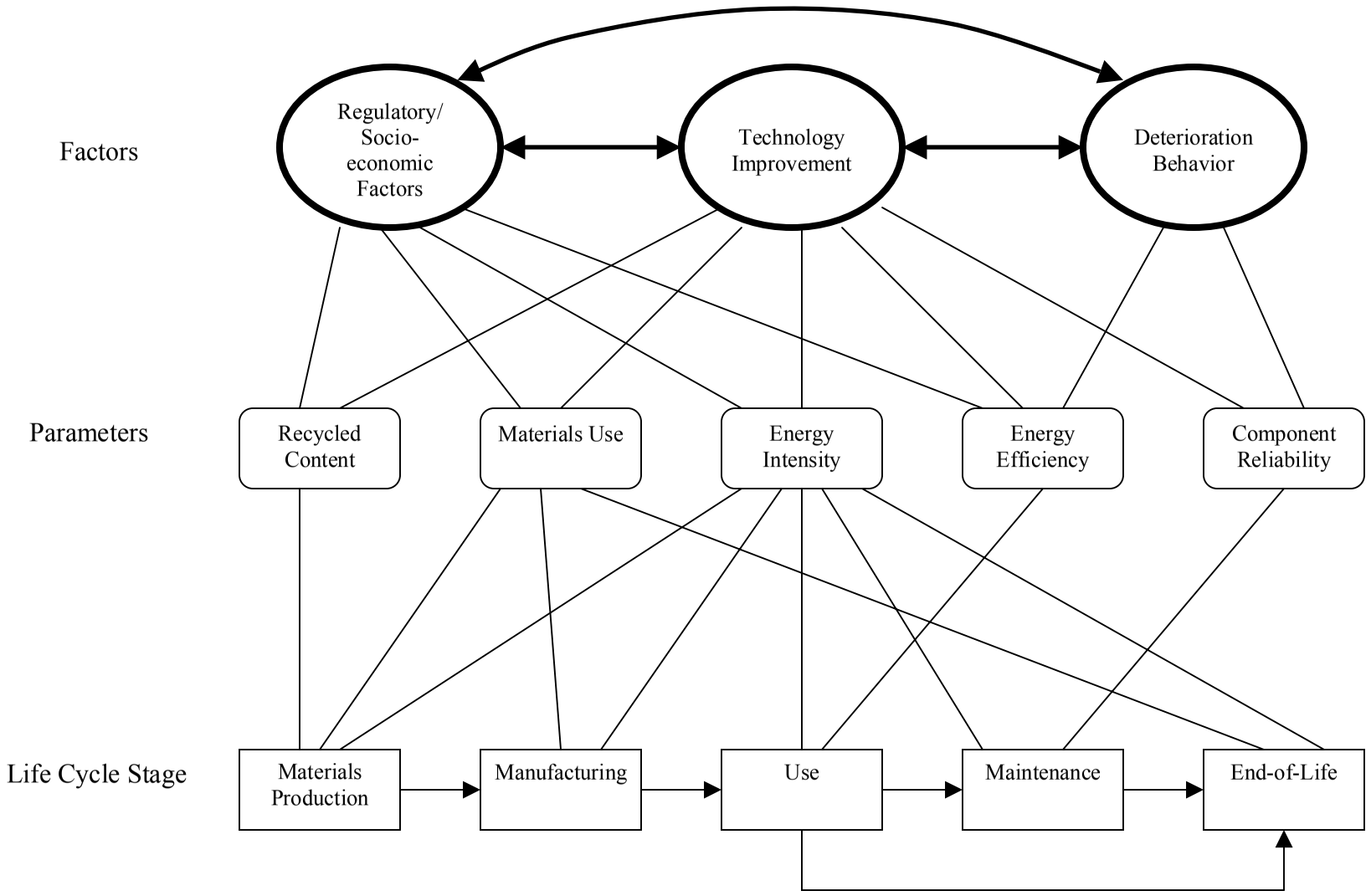

Figure2.3: Factors, parameters, and life cycle stages illustrating the dynamic LCI for a refrigerator-freezer

2.4 Life Cycle Optimization Model

Extension of a product lifetime avoids environmental impacts associated with production of new products. On the other hand, replacement of an older, inefficient product with a newer, more-efficient product may reduce energy consumption and emissions during the use phase of the product life cycle.

The concept of Life Cycle Optimization (LCO) is based on a dynamic programming method, and the input data for this model are the dynamic LCIs of a product (Kim, Keoleian et al. 2003). The factors and parameters for the dynamic LCI are discussed in detail in Chapter 3. This research applies the LCO of a generic vehicle model to a household refrigerator-freezer model.

Figure 2.4 is a schematic example of the LCO model. The *y*-axis depicts the cumulative environmental burden of the product lifetime (e.g., CO_2, NO_x, SO_x, particulate matter, or energy consumption), while the *x*-axis represents time. The initial refrigerator is introduced at the start, T_0. A new model refrigerator with a different environmental profile is introduced at time intervals marked T_a and T_b. Decisions to keep or replace the product are made at the points marked by black dots. Environmental burdens associated with material production and manufacturing occur at the time when the product is replaced. The slope of each line segment represents an energy efficiency or emission factor of a product depending on the criterion to be minimized. The slopes tend to increase with time, illustrating deteriorations of energy efficiencies or other environmental performance.

It is assumed that a decision maker (e.g., policy maker, employer, or household owner) tries to minimize the environmental burden of a criterion within the time horizon, N, based on information the decision maker has regarding the environmental performance of the product. As an example, environmental burdens for a few different policies are considered in Figure 2.4 based on decisions at T_a and T_b. A more detailed version of the model is available elsewhere (Kim 2003).

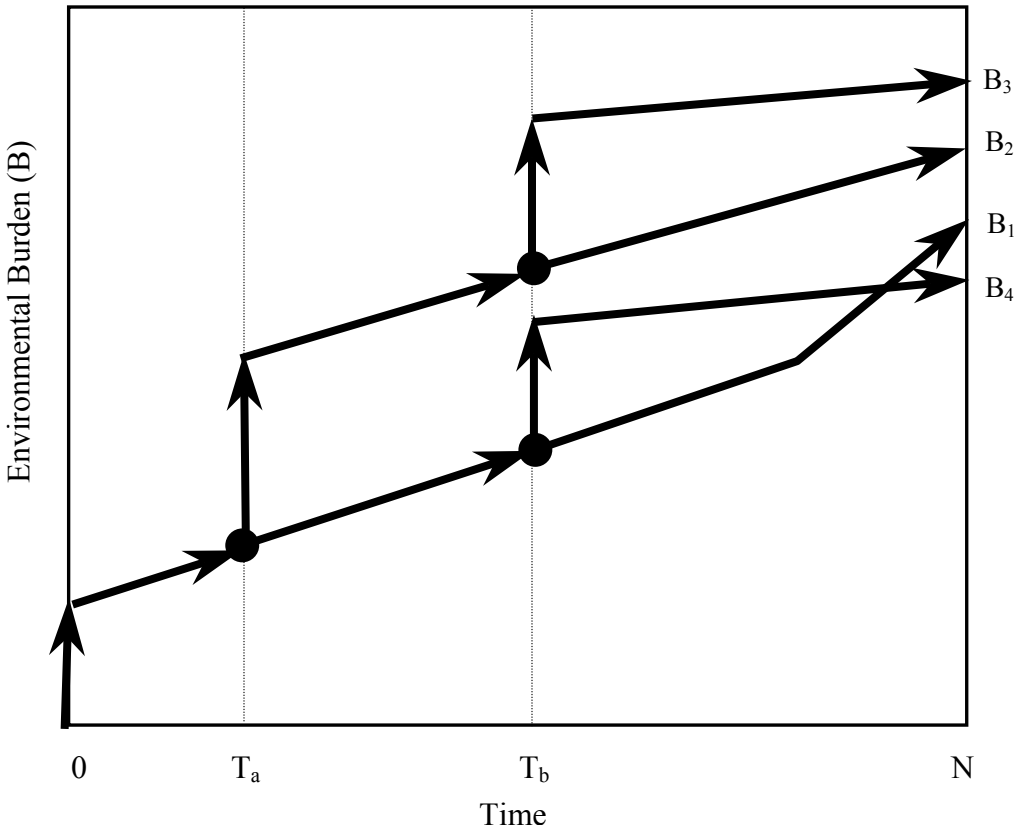

Figure 2.4: A schematic example of the life cycle optimization (LCO) model based on four policies. B_1, B_2, B_3, and B_4 represent the final environmental burdens of the four policies (Kim 2003).

With this hypothetical example, the optimal policy is as follows:

- If the product owner replaces the initial product at time T_b with a new refrigerator and keeps the new product until N, the cumulative environmental burden (B) will result in B_4, which is the minimum possible outcome.

Also, the optimal policy and the optimal product lifetimes are T_b and $N-T_b$. However, the real-world situation is more complicated and the number of possible outcomes is often unpredictable. In order to determine the optimal lifetime of the top-mounted refrigerator-freezer and conduct this optimization model, the timeframe between 1985 and 2020 was set. This optimization seeks the best sequence of decisions to minimize energy consumption during this time horizon.

CHAPTER III

Refrigerator Life Cycle Inventories

3.1 Life Cycle Phases

3.1.1 Material Production

Life cycle inventories of the material production phase were determined based on the available materials composition data and an LCA software tool, SimaPro 5.1, which provides environmental burdens of specific materials. There are two different materials composition datasets available; (1) average 1997 U.S. top/bottom refrigerator, (2) typical Japanese 4 door-400L (14 cu. ft.) top-mounted refrigerator-freezer from model year 1994. According to the two sources above, ferrous materials account for 62% and 47% respectively. The second- largest group of materials used is plastics, although each refrigerator-freezer has slightly different materials composition of plastics. Non-ferrous metals include aluminum and copper. Other key materials are glass, refrigerant, and refrigerant oil. Culture, food characterization and lifestyle can affect material compositions of refrigerators used in different countries. For instance, Japanese refrigerators have more thermoplastic and thermosetting resins used for separate compartments for fish, meat and vegetables. Hence, these differences can affect the LCI of each refrigerator type.

3.1.2 Manufacturing and Assembling

The second phase of the refrigerator-freezer life cycle is the manufacturing and assembly phase. This phase consists of four major manufacturing processes: (1) assembly of the cabinet, (2) assembly of the door, (3) process line of inner liner, inner door and resin and plastic parts, and (4) assembly of refrigeration components. A process flow diagram from the Japanese Environmental Management Association for Industry (JEMAI) is shown in Figure 3.1.

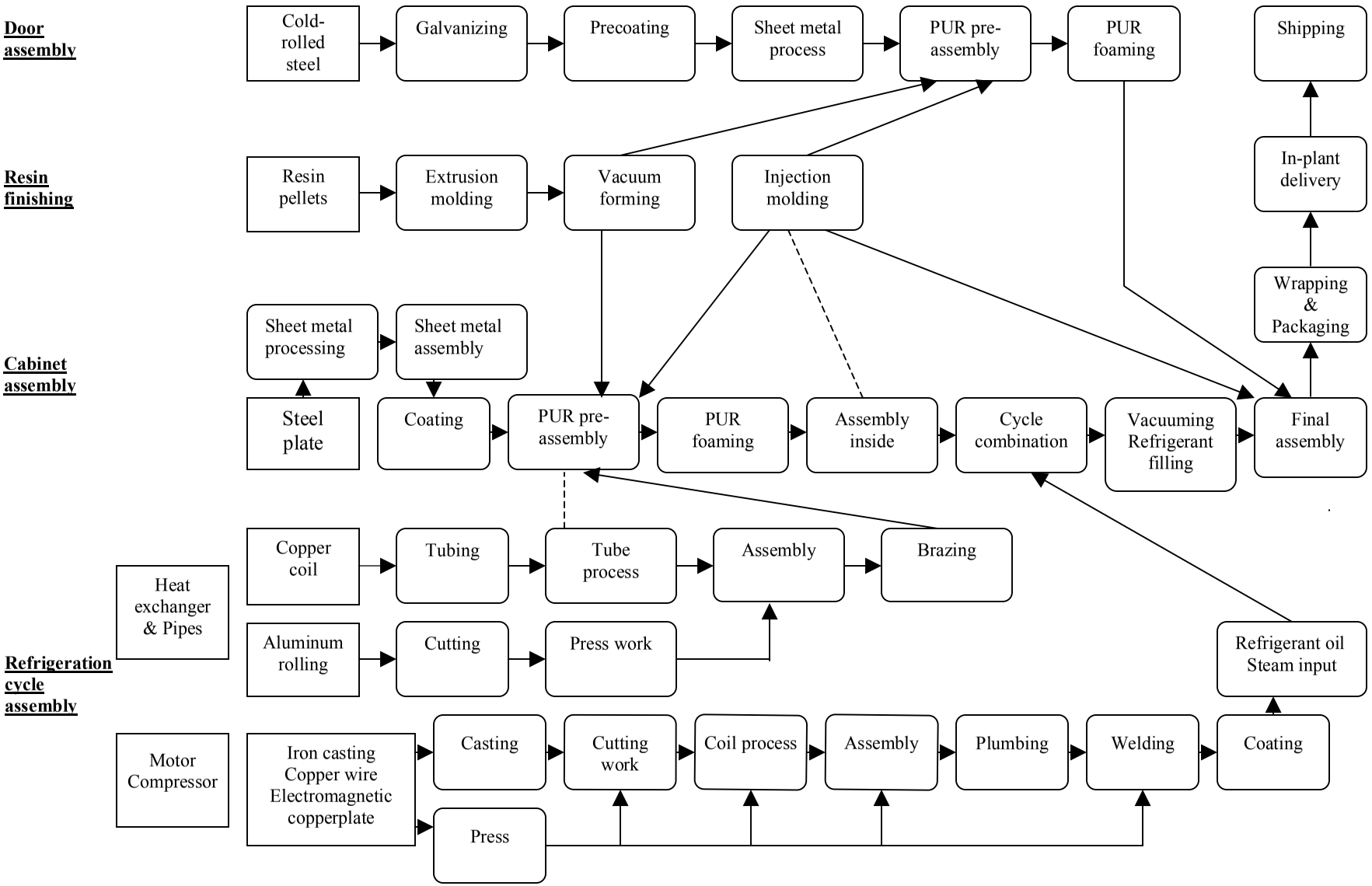

Figure 3.1: Flow diagram of manufacturing and assembly for household refrigerator-freezers (JEMAI 1995)

The first process, cabinet assembly is the fundamental process for manufacturing and assembly. This assembly is comprised of the following procedures:, sheet metal processing including roll forming and spot welding, bonderizing and coating, polyurethane forming, installation of refrigerant components, refrigerant and refrigerant oil filling, performance testing for cooling capacity, attaching interior components, and packaging. As shown in Figure 3.1, components and parts from three other manufacturing processes are installed with the cabinet assembly.

In the second assembly line process, cold-rolled steel for the door is galvanized and coated. Then after processing of the plate metal through pressing, bending, and other metal forming processes, sashes, inner reinforcing boards and hinge pins are attached. Finally, the door is injected with foaming polyurethane foam.

The third process is a line of inner liner, inner door and resin and plastic parts. Mainly this process begins with manufacturing plastic sheet from resin pallets with extrusion molding. From this sheet, some inner parts and the door are manufactured with vacuum forming. Also, injection molding is used to produce vegetable compartments, and ice trays. These resin and plastic parts are supplied to the door and cabinet assembly lines.

The fourth process for the refrigeration components consists of two assembly lines: (1) heat exchanger and pipes, and (2) motor compressors. Heat exchangers consist of pipes and fins. Fins are made of aluminum and pipes are made of either copper or aluminum. Copper coils are processed to create pipes that are used for the cooling system. After those pipes and aluminum rolling are cut, and attached with pressed aluminum fins, heat exchangers are completed with brazing. Those are supplied to the cabinet assembly process after testing for leakage. For motor compressors, at first metal casting is cut and polished, and then crankshafts, rotors, and stators are machined. Manufacturing of motor compressors is completed after plumbing, welding, and coating. Motor compressors also are tested for leakage and pressure, filled with nitrogen and refrigerator oils and then sent to the cabinet assembly process. The LCIs associated with these processes are determined using the SimaPro 5.1 database as a major source.

Transportation energy consumption from the manufacturers to the consumers was estimated based on Whirlpool assembly plants in Fort Smith, Arkansas, Evansville,

Indiana and Monterrey, Mexico[2]. The assumption is that refrigerator-freezers are produced in either of three facilities and then are delivered to some store in Ann Arbor by trailer with diesel. In order to estimate an appropriate distance between the manufacturing plant and the consumer who lives in Ann Arbor on the campus at the University of Michigan[3], the average distance from the three plants was calculated. The result is shown in Table 3.1. On the other hand, transportation between locations for raw materials acquisition and the manufacturing and assembly plants was not considered due to the complexity and poor data availability.

Table 3.1: Distance from major refrigerator plants

Location	Address	Distance to Ann Arbor
Fort Smith, Arkansas	6400 Jenny Lind Rd Fort Smith, AR 72908	1012 miles 1629 km
Evansville, Indiana	5401 Highway 41 N Evansville, IN 47711	463 miles 745 km
Monterrey, Mexico	N/A	1485 miles 2390 km
Average		987 miles 1588 km

3.1.3 Use

Previous LCA studies conducted in Europe, Japan and the U.S. indicate that 88% to 97% of total life cycle energy[4] is consumed in the use phase regardless of the product size or lifetime (Foley; JEMAI 1995). These studies assume constant energy consumption throughout the refrigerator-freezer service life and ignore the refrigerator-freezer's decline in efficiency over time. In order to measure electricity use, test standards need to be defined. This research collected energy consumption data from two different sources: the Association of Home Appliance Manufacturers (AHAM) and *Consumer Reports*. The Association of Home Appliance Manufacturers has outlined its test procedure to measure

[2] Personal communication with Karel Czanderna, VP GDP Food Stream Solutions, Whirlpool Corporation.
[3] Center for Sustainable Systems, which is located in 430 East University, Dana Building, Ann Arbor, MI 48109-1115, was used for estimating the average distance from plants in Arkansas and Indiana. The distance from Monterrey to Ann Arbor is based on http://www.timeanddate.com/
[4] Studies conducted in the U.S., Japan and Germany show that energy consumption in use phase account for 88%, 97%(without CFCs) and 95% respectively.

energy consumption under its own standard that the Department of Energy (DOE) also adopts (Yashar 2003). Under this standard, the ambient temperature of a refrigerator-freezer is 90 degrees Fahrenheit. This reflects the real-world condition in which the door is opened many times and the box has to chill newly loaded food. The target temperature for the refrigerator-freezer is 5 degrees Fahrenheit for the freezer compartment and 45 degrees Fahrenheit for the refrigerator compartment. There is no specific humidity required for this test. On the other hand, *Consumer Reports* tests energy consumption with tougher standards than the DOE procedure for the energy-guide stickers. The temperature in the center of the refrigerator is expected to be 37 degrees Fahrenheit and that in the center of the freezer is expected to be 0 degrees Fahrenheit.

Two studies were selected for energy consumption data: *Consumer Reports* and AHAM. *Consumer Reports* provides energy consumption of top-mounted refrigerator-freezer models having a capacity[5] between 20 and 22 cubic feet. This range had the most available data from *Consumer Reports* from 1985 to 2002 and reflected consumers' trend. Average energy consumption at each year was calculated and year with missing data at particular year were estimated by the average between available data. Association of Home Appliance Manufacturers also reports energy consumption of refrigerator-freezer models based on shipment-weighted average of all sizes and models. The annual AHAM energy consumption data reports 669 kilowatt hour per year for 1997 model years whereas *Consumer Reports* shows 752 kilowatt hour per year. However, energy consumption for refrigerator-freezers changes slowly over time because of the deterioration of blowing agent and refrigerants. This factor is discussed in Chapter 4.

3.1.4 Repair and Maintenance

The repair history of refrigerator brands from *Consumer Reports* varies. *Consumer Reports* data are based on questionnaires from approximately 80,000 respondents over several years. Respondents report whether their refrigerator-freezer has ever been repaired or had a serious problem. The percentage of models with and without icemaker in need of repair is also reported. Repair rates range from 5% to 10%. Although brands' repair histories vary, some brand such as Whirlpool refrigerator-freezers have

[5] The capacity means a capacity that manufacturers claim. Usually, this is smaller than a usable capacity.

relatively fewer percentages than others. However, energy consumed for repairs is considered negligible because of a data for energy consumed for repairs and the low percentage of repairs needed.

Energy consumption required for maintenance, including cleaning coils by coil brush and replacing gaskets, does not require much energy. In addition, some researchers measured change in energy consumption after maintenance. Meier et al. monitored electricity savings from maintainace as the New York Refrigerator Monitoring Project. Twenty-seven refrigerators about 16 years old were made subject to inspection by a professional repairperson. After cleaning the coils and replacing the gaskets, the refrigerators were monitored for a second year. As a result, however, no apparent efficiency improvement was observed (Meier 1993; Meier, Megowan et al. 1993; Meier 1995). Hence, in this research, it is assumed that no maintainace is needed during the lifetime of refrigerator.

3.1.5 End-of-Life

At the end of a product's service life, a refrigerator-freezer is generally recycled. Typically, a refrigerator-freezer is shredded and the ferrous materials and other metals are recovered. According to U.S. Environmental Protection Agency (US EPA), some companies, which received a US EPA Stratospheric Ozone Protection award in 2004 for including proper CFC-containing foam disposal in their operations, recycle almost all the parts of refrigerator/freezer, especially CFC-containing insulation foams (US EPA 2004).

Most used refrigerator-freezers are disposed of by solid waste service providers, recyclers, retailers (when the user buys a new one), or contractors of a bounty program who collect the refrigerators. Refrigerants and compressor oil are required to be removed and disposed properly under the US EPA regulations. In the city of Ann Arbor, it costs 25 dollars to dispose of a refrigerator-freezer although it depends on the location and there are some places where it costs no fee (City of Ann Arbor 2003; ARIC 2004). After the refrigerant is properly removed in the facility, most refrigerator-freezers go to the scrap yard where the refrigerator-freezer is sent to an automatic shredder. In this process, at least 20 percent of the blowing agent is emitted into the atmosphere. Then, magnets are used to separate steel and iron from aluminum, copper and other metals, all of which are

collected for recycling. After this process, materials including plastics and polyurethane that remain are generally delivered to mostly a landfill for disposal. While these materials may be technically recyclable, it is not cost-effective to separate them for recycling purposes. As a result, approximately 80 percent of the materials in refrigerator-freezer are typically recycled (US EPA 2004).

The transportation method and energy consumption between consumers and the shredding plant also needs to be estimated. In Washtenaw County, the distance between Ann Arbor and the shredding plant is assumed to be 20 miles. Within this distance, the used refrigerator-freezer is delivered by truck with diesel fuel. The process after shredding the refrigerator-freezer is out of the system boundary of this study since the refrigerator-freezer itself no longer exists, and these materials are not reincorporated into the manufacture of new refrigerator-freezers. The product system having recycled materials would be analyzed to the environmental burdens after the shredding process.

3.2 Results

Based on material composition data of average 1997 U.S. top/bottom refrigerator and data from AHAM for the use phase, primary energy consumption in each phase was calculated with SimaPro5.1. The results are shown in Figure 3.2 below.

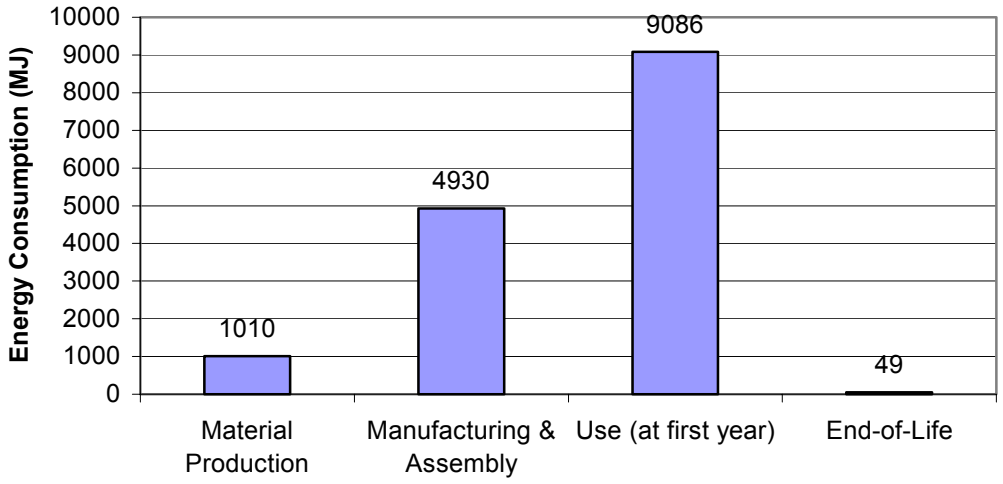

Figure 3.2: Primary energy consumption of 1997 model refrigerator-freezers in each life cycle phase at first year (MJ)

CHAPTER IV

Dynamic Life Cycle Inventory Parameters

4.1 Material Contents

There has been little incentive to change materials composition of mid-sized refrigerator-freezers with the exception of the refrigerant. Differences of materials composition before and after implementation of the Montreal Protocol on substances (e.g., CFCs as blowing agents and refrigerants) that deplete the ozone layer are considered to be negligible (JEMAI 1995). In fact, the total weight between materials composition before and after phasing out of CFCs is just slightly different: 78.51 kg and 80.85 kg, respectively. Therefore, materials composition and weight of the refrigerator-freezer are assumed to be constant during the 36-year time horizon.

4.2 Energy Intensity

Typically, energy intensity is represented as the ratio between total energy consumption and gross domestic product for an economic system. Since these economic measures are sensitive to inflation and prices, this research applies physical units (BTU/MJ) rather than economic units (BTU/dollar) to energy intensity. The energy intensity model in the current research is primarily based on the energy intensities used in the previous study of LCO of vehicle replacement (Kim 2003). Energy intensity indices including materials production, manufacturing/assembly, and end-of-life are shown in Appendix B1.

Materials production energy intensity

The major refrigerator-freezer materials including ferrous materials, aluminum, and plastics, numerous materials processing sectors, including the steel, aluminum and petrochemical industries as well as infrastructure such as the public utility, transportation and mining sectors need to be considered to analyze energy intensity trends. This study uses the method and results of the models in the previous LCO study (Kim 2003).

Manufacturing Energy Intensity

A variety of industries are involved with manufacturing and assembling refrigerators. Thus, the average energy intensities of entire industries are used for the manufacturing energy intensities. For the historical trends, the Manufacturing Energy Consumption Surveys were used as a primary source, while the Annual Energy Outlook 2001 was used for future forecasts.

Electricity production (Grid Efficiency)

According to EIA Annual Energy Review 2002, net electricity generation from fossil-fueled plants, nuclear plants and geothermal energy plants has changed slightly over the years (2.8% to 4.4%). Energy consumption required to generate 1 kilowatt hour has been constant through 2002 (EIA 2004). Therefore, the heat rates for electricity are assumed to be constant between 1985 and 2020.

End-of-life energy intensity

The energy intensity associated with the end-of-life phase is modeled using the petroleum refining industry. The energy intensity of the refining industry was flat between 1985 and 1998, and Annual Energy Outlook 2001 was used to forecast future energy intensity (Kim 2003).

4.3 Energy Efficiency

4.3.1 Energy Standards

Energy standards have been effective in influencing the energy cost of appliances. Since 1986 when the first federal standard for energy efficiency of electric appliances began to be negotiated, there have been three critical regulatory evens that made dramatic improvements to the energy efficiency of refrigerator-freezers. In 1990 the first DOE standard took effect and set energy consumption of refrigerators under 976 kWh per year on average. By 1993, the first DOE standard was updated to set energy consumption below 686 kWh per year. This standard successfully decreased energy consumption by 36 percent from 1986 level. In 2001, the second update went into effect. This latest

update set energy consumption below 476 kWh and reduced energy consumption by 56 percent from 1986 levels (Baldwin 2003).

Energy consumption of refrigerators has been reduced by more than half since 1985. For the base case analysis, it is estimated that energy efficiency will not improve after the year of 2002. Besides this estimation, two scenarios were adopted: 1% energy improvement per year, and 2% of energy improvement per year.

4.3.2 Deterioration of Energy Performance

Deterioration of the blowing agent is another factor that affects energy performance. Deeg et al. (1998) reported a study of aging effects on full refrigerators, which was developed by Wilkes et al. (1999) for one of several projects sponsored by the Appliance Research Consortium (ARC) to evaluate alternative replacement blowing agents. Those two studies revealed that polyurethane foam blown with HFC-245fa had superior aging characteristics relative to the other blowing agents including HCFC-141b, HFC-134a, and cyclopentane (Deeg, Johnson et al. 1998; Wikes, Gabbard et al. 1999). As can be seen in Figure 4.1, the HFC-245fa foam shows a significant decrease in performance for a three-year testing period under DOE test procedures.

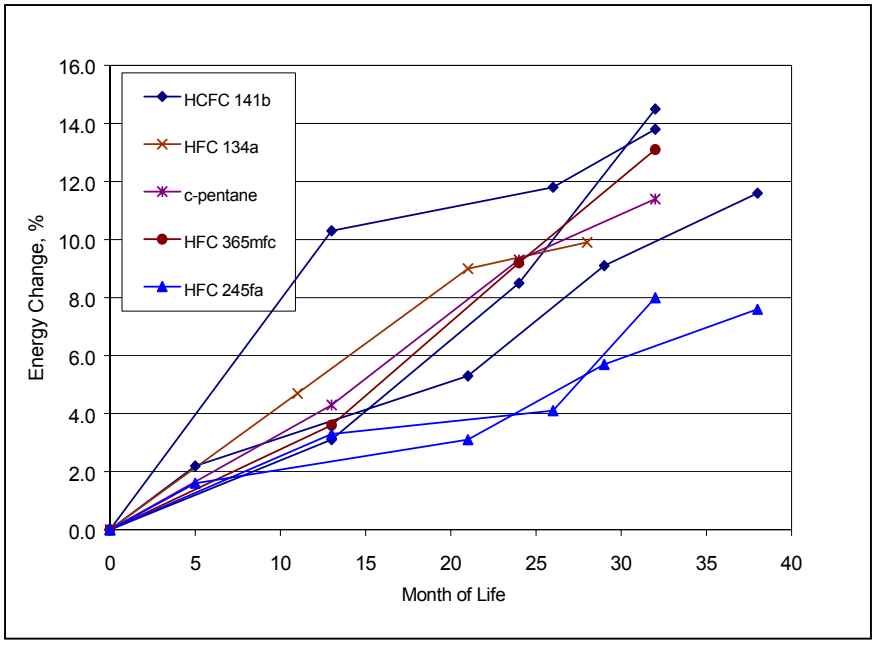

Figure 4.1: Energy change with aging (Johnson 2000)

Johnson (Whirlpool) developed a mathematical model for the changes in energy consumption over time as a part of his total environmental warming impact (TEWI) analysis. The annual increase in energy consumption, ΔE, was:

$$\Delta E = r\,[(20-n)/20]^{x}$$

where:

r = initial aging rate for the blowing agent in question (2.5% per year for HFC-245fa, and 4.5% per year for the other blowing agents)

n = year

x = a factor (1.4 for HFC-245fa, and 2.4 for the other blowing agents) chosen to match the expected final energy consumption, considering the data from Wilkes et al (1999).

The aging rate in the previous equation may be higher than in real-world conditions because the testing temperature was higher than inside an actual refrigerator (Johnson 2002).

The Montreal Protocol banned industries in developed countries from producing CFCs after July 1st, 1989 and phased out CFCs by January 1st, 1996. Since the middle 1980s, industries also shifted to the production of CFC substitutes such as hydrocholorofluorocarbons (HCFCs), hydrofluocarbons (HFCs) and hydrocarbons (HCs). Nowadays, most refrigerators use HCFC-141b as a blowing agent and HFC-134a as a refrigerant in the U.S., although other countries have developed isobutene, cyclopentane or ammonia for blowing agents (ARAP 2002). Most developed countries have already phased out CFCs and the developing countries are scheduled to phase them out by 2010. Thus, U.S. manufacturers faced reduction of use of CFCs and development of substitutes. Although *Consumer Reports* issued a 1996 report that there was still uncertainty whether CFC-free refrigerator-freezers had the same long-term performance and reliability as the refrigerator-freezers with CFCs, this major change did not affect the new refrigerator-freezer in terms of their aesthetics, performance and material composition. Sekhar et al (2003) found that a CFC-12 refrigerator model retrofitted with substitute refrigerant mixture of HFCa/HC290/HC600a reduced energy consumption by 4 to 11% and improved the actual COP by 3 to 8%. In fact, the energy efficiency of the refrigerators

sold after the phasing out CFCs has increased by 20 percent since 1996 (Sekhar, Lal et al. 2003).

With Johnson's model, the aging rate of foam blown with HCFC-141b, HFC-134a, and c-pentane decreased more rapidly than it did for foam blown with HFC-245fa. However, the initial advantage for HFC-245fa remained the dominant factor. Since there is no research and data available for CFCs used with models before phasing out, the models containing CFCs are assumed to increase energy consumption at the same rate as do the models with HCFC-141b mainly due to the data limitation.

The choice of blowing agent also influences the thermal conductivity of the insulating foam. Energy consumption varies significantly for a given product design and wall thickness, depending on foam properties, which are influenced by the choice of blowing agent. Hence, the choice of blowing agent can affect the maximum efficiency that is attainable for a product design over many years (Johnson 2000).

The list of the blowing agents used in the refrigerator-freezer models is as follows.

- Model year (1985 to 1995): CFC-11
- Model year (1996 to 2002): HCFC-141b
- Model year (2003 to 2020): HFC-245fa

4.4 Life-Cycle Cost Analysis

To calculate electricity price and purchase cost, gross domestic product implicit price deflators were used and the year of 1985 was applied for a baseline. The data is based on the model year between 1985 and 2020.

Based on Average Retail Prices of Electricity by the EIA, the average residential electricity cost between 1985 and 2002 was calculated (EIA 2002). According to the Annual Energy Outlook 2004, U.S. electricity prices are expected to decline by 8% from 2002 to 2008, and remain relatively stable until 2011. From 2011 they are forecasted to increase gradually by 0.3% annually until 2025. Each model-year electricity cost was also adjusted to the 1985 dollar (EIA 2004).

The price of the top-mounted refrigerator-freezer is relatively less costly than other models. The average price, from 1985 to 2002, of top-mounted refrigerator-freezers

having a capacity between 20 and 22 cubic feet was estimated by using data from *Consumer Reports*. In the event of missing data, prices were estimated by the average price between two years for which the data were available. To estimate the future prices after 2003, the linear regression method was applied since the refrigerator price itself has not fluctuated very much between 1985 and 2020. Each refrigerator price was adjusted to the 1985 dollar. The result is shown in the Appendix B4.

CHAPTER V

Results and Discussion

5.1 Model Application to Refrigerator-Freezers

The LCO model was applied to household refrigerator-freezers to evaluate the optimal lifetimes and to recommend replacement plans from life cycle energy and economic perspectives. The time horizon of the simulation is set between 1985 and 2020 and the maximum physical lifetime of any refrigerator-freezer is assumed to be 20 years.

5.2 Optimal Lifetimes of Refrigerator-Freezers

Table 5.1 gives the results of LCO model simulations for the household refrigerator-freezers. The numbers in the fourth column represent the optimal lifetimes of refrigerators in order from left to right. The optimal set of lifetimes for the energy objective in the first row of Table 5.1 can be read, for example, "Keep the model year 1985 refrigerator-freezer for 2 years and retire it at the end of 1987, then buy a model year 1988 and keep it for 5 years…buy a model year 2009 and keep it until 2020."

Two sets of results were generated using refrigerator operating energy consumption data for the period 1985 to 2002 from two sources: data taken from *Consumer Reports* were average energy consumption per year based on the top-mounted refrigerator-freezers having capacity between 20 and 22 cubic feet, and data from AHAM were energy consumption per year based on shipment-weighted averages of all sizes and all models. Energy consumption data from *Consumer Reports* ranges from 1234 kilowatt hours in 1985 to 486 kilowatt hours in 2002. These data show a steeper decline in energy consumption than AHAM data that decrease from 1058 kilowatt hours in 1985 to 520 kilowatt hours in 2002.

For the future forecast from 2002 to 2020, three scenarios were set: energy consumption decreased by 0, 1 and 2% per year. The total life cycle energy consumption for energy optimization scenarios between 1985 and 2020 ranges from 328 to 364 GJ, while that for cost optimization scenarios ranges from 446 to 407 GJ. The total life cycle cost for cost optimization scenarios is between 2,338 and 2528 dollars, whereas that for

energy optimization scenarios requires 3,010 to 3,619 dollars. The energy optimization scenarios cost approximately 700 to 1200 dollars more than the cost minimization scenarios. On the other hand, energy minimization scenarios consume an average of 80 GJ less than the cost minimization scenarios.

The number of replacements for optimal energy consumption is 4 to 6 during the time horizon between 1985 and 2020. This result suggests that a consumer needs to replace an old refrigerator with a new one more frequently to minimize total energy consumption. On the other hand, optimal lifetimes determined by life cycle cost are comparable to the average observed lifetime (14 years) and expected lifetime (20 years) in the real world (AHAM 1990; NFO 1996). The 0% scenario has one replacement after 2002, while the 1% and 2% scenarios have two replacements. There is no clear difference between the 1% and 2% scenarios.

In addition, the difference in total life cycle energy consumption between results based on the data from *Consumer Reports* and AHAM is associated with differences in refrigerator size and testing procedures. The average size of refrigerators from AHAM data is smaller than that from *Consumer Reports*—20 to 22 cu. ft. Also, *Consumer Reports* has a more stringent test standard for monitoring energy consumption than AHAM.

Table 5.1: Optimal refrigerator-freezer lifetimes for 36-year time frame between 1985 and 2020

Use phase data source (1985-2002)	Objective minimized	Energy Improvement (beyond 2002)	Optimal lifetimes (years)	Energy (GJ)	Cost (1985$)
Consumer Reports	Energy	0%/yr. of 2002	2,5,4,6,7,12	364	3,619
		1%/yr. of 2002	2,5,4,6,5,7,7	358	3,796
		2%/yr. of 2002	2,5,4,6,5,7,7	351	3,785
	Cost	0%/yr. of 2002	18,18	446	2,528
		1%/yr. of 2002	18,18	445	2,525
		2%/yr. of 2002	18,18	443	2,524
AHAM	Energy	0%/yr. of 2002	4,4,9,7,12	342	3,010
		1%/yr. of 2002	4,4,9,5,7,7	336	3,186
		2%/yr. of 2002	4,4,9,5,7,7	328	3,175
	Cost	0%/yr. of 2002	16,20	411	2,341
		1%/yr. of 2002	18,18	408	2,340
		2%/yr. of 2002	18,18	407	2,338

5.3 Determinants of Optimal Lifetime

5.3.1 Technology Improvement

Technology improvement reduces energy consumption in the use phase. In other words, the more technology improves, the more energy consumption decreases, and the more frequently refrigerator-freezers need to be replaced with new ones. Technology improvement is a main factor in determining optimal lifetimes.

When the first oil price shock happened in 1972, refrigerator-freezers consumed approximately 1800 kilowatt hours per year (Baldwin 2003). With better insulation, compressors, and refrigerants, energy consumption of refrigerators has declined to less than 500 kilowatt hours per year today. Driven by the California standard in 1977, the National Appliance Energy Conservation Act of 1987 (NAECA) established minimum efficiency standards for a variety of household appliances that went into effect in 1990, 1993 and 2001 for refrigerator-freezers. Under the standards, refrigerator products including refrigerators, refrigerator-freezers, and freezers are categorized by adjusted volume, features, types and blowing agents. Each product has a different efficiency level at which DOE considers it technically feasible to comply based on its engineering analyses of those classes of refrigerator products (DOE 1997).

Refrigerator-freezers have become access-friendly, spacious, and multifunctional with other features such as icemakers and automatic defrost systems. Despite this trend, a typical 2001 model refrigerator uses about 70% less energy than one from the early 1970s (ASAP 2000). As shown in Table 5.1, technology improvement driven by the standards influences optimal lifetimes. In particular, the model results showed considerably short lifetimes (2 to 5 years) in earlier model years.

To estimate future technology improvement, three scenarios were examined: future energy efficiency beyond 2002 increases 0% per year, 1% per year, and 2% per year. According to the simulation results, the future energy efficiency scenarios of this research have a small correlation with optimal lifetimes. Regardless of the technology improvement scenarios, the optimal lifetimes of refrigerator-freezers for energy are considerably shorter than actual lifetimes of current refrigerator-freezers. In addition, the optimal lifetimes for the cost objective remain almost unchanged with the increasing future energy efficiency scenarios.

5.3.2 Deterioration of Energy Efficiency

A refrigerator-freezer is one of the longest life-span household appliances, which has a 20-year expected lifetime (ARIC 2004). Energy performance of refrigerator-freezers, however, is not consistent throughout the product lifetime. The faster deterioration occurs, the shorter the optimal lifetimes to minimize cumulative energy consumption. During a product lifetime, there are conditions that affect annual energy use. Recent research reveals that leakage of blowing agents causes the deterioration of energy efficiency. Due to the loss of blowing agents and other gases inside, insulation foam degrades during the refrigerator's lifetime (Johnson 2002). Since the lifetime of the refrigerator-freezer is considerably long, a high deterioration rate strongly affects energy consumption during the use phase. As can be seen in Table 5.1, this influences optimal lifetimes and replacement timings. Optimal lifetimes before model year 2002 are relatively shorter than those after model year 2002. Even scenarios with 0% energy efficiency improvement per year require replacement due to deterioration. In addition, other factors such as a dirt accumulation on the condenser coils, an over- or under-charged refrigerant level, and some type of door seal or cabinet damage may affect energy efficiency. Unfortunately, quantitative analyses regarding these deterioration factors are unavailable and not included in this analysis.

5.3.3 Marginal versus Fixed Energy Consumption

Although energy consumption in the use phase has been decreased by more than 60% since 1990, the use phase still dominates total energy consumption among other phases. For instance, the production of producing one top-mounted refrigerator-freezer 1997 model requires approximately 5000 MJ, which a 2001 refrigerator model consumes during one year of operation. For the LCO model, fixed environmental burdens are created during the materials production, manufacturing and assembling, and end-of-life phases, whereas the marginal environmental burdens are associated with the use and maintenance phases (Kim 2003). Comparison between fixed and marginal energy consumption for refrigerators and automobiles is shown in Table 5.2.

Table 5.2: Comparison between fixed and marginal energy consumption

		Refrigerator-freezers model year 1997 (MJ)	Automobiles model year 1997[6] (MJ)
For 1 year	Fixed	5,989	124,919
	Marginal	9,086	86,310
	Fixed vs. Marginal	40%: 60%	60%: 40%
For 10 years	Fixed	5,989	124,919
	Marginal	102,323	858,410[7]
	Fixed vs. Marginal	5.5%: 94.5%	12.7%: 87.3%

This demonstrates that marginal energy consumption dominates total life cycle energy consumption over the years. This research also reveals that optimal lifetimes tend to be longer as the ratio of fixed to marginal energy consumption becomes greater.

5.3.4 Policy Implications

The first DOE energy efficiency standards for refrigerator-freezers became effective in 1990 and were subsequently updated in 1993 and 2001. Manufacturers successfully adopted these standards and reduced energy consumption. On the other hand, from the consumer's perspective, the reason to purchase new units or replace old units varies. According to AHAM, saturation[8] of the full-size refrigerator[9] in households was for 93.1% in 2001. This shows that refrigerators are one of the highest saturation home appliances. Average length of ownership of currently owned refrigerators is 8.5 years and average useful lifetime of refrigerators is 14 years (NFO 1996; AHAM 2001). It appears rare for households to own a full-size refrigerator for the full duration of the product's physical lifetime of over 20 years. Refrigerators are replaced for a variety of reasons: the appliance died/needed costly repairs (35 percent) and then owners are moving (34 percent), and they tend to be passed on to other users more often other home appliances, with one quarter to one third being sold or given away (AHAM 2001). According to U.S. Census Bureau (1998), half of all people 15 years and over have lived in their current

[6] This is based on the baseline of 1995 and energy consumption in use phase and end-of-life phases at first year was used (Kim 2003).
[7] It is assumed that maintenance occurs three times for ten years: 4th, 7th and 10th year.
[8] Saturation is defined by AHAM as the percentage of U.S. households with access to a particular type of appliance.
[9] Full-size refrigerators include two door side freezers, two door top freezers, two door bottom freezers, one exterior door models, built-in refrigerators/freezers, and compact refrigerators.

residence longer than 5.2 years and half have lived shorter in their current in their current residence than 5.2 years (Hansen 1998). This also shows that moving is another important factor that affects the refrigerator replacement regardless of product efficiency, a new energy standard, or product durability. In fact, there is a relatively smaller percentage exchanged for replacement with a new/updated model (23 percent). These trends show that the energy efficiency standards have not influenced consumer behaviors although they actually have improved energy efficiency of refrigerator-freezers. In order to replace old, inefficient refrigerators, programs that provide economic benefits would be necessary. Although the simulation results show that frequent replacements reduce life cycle energy, it would be very uneconomical and burdensome for consumers to replace their refrigerators with a brand-new unit every two to seven years. Federal and local governments, retailers and manufactures need to develop incentive programs that would allow consumers to receive more benefits when they replace older model refrigerators with new models.

For the New York City Housing Authority (NYCHA), New York Power Authority (NYPA) conducted an eight-year project between 1996 and 2003, in order to replace old, inefficiency refrigerators at public housing with new compact units consuming less than half the energy and using a more environmentally friendly refrigerant gas. Also, New York City Housing Authority (NYCHA) had corroborated with an appliance recycler in Syracuse, which removed all salvageable components from the older units and recycles millions of pounds of aluminum, copper steel and cardboard. According to a report (Pratt et al 1998), in 1997 the project replaced 20,000 existing refrigerators in public housings with 15 cubic foot top-freezer automatic-defrost refrigerators (Maytag) rated at 437 kilowatt hours per year. Consortium for Energy Efficiency (CEE) and U.S. Departments of Housing and Urban Development (HUD) and Energy (DOE) sponsored the groundwork that enabled housing authorities throughout the Unites States to bulk purchase energy-efficient appliances. The U.S. Department of Energy (DOE) helped develop and plan the project through the Energy Star® Partnership program conducted by its Pacific North West National Laboratory (PNNL), which designed the metering protocol an occupant used in a 1997 occupant survey, supplied and calibrated the metering equipment, and managed and analyzed the data collected by

NYPA. This project successfully saved 543 kilowatt hour per year per household, reduced power requirements at peak demand by 0.068 kilowatt per household and achieved a general understanding of savings as a function of refrigerator label ratings, occupant effects, indoor and compartment temperatures, appliance and characteristics. With this effort, more than 100 additional public housing authorities and electric utilities from North Carolina to Alaska have launched similar replacement projects, adopting the NYPA-NYCHA model to save money and electricity (NYPA 2004).

New York State Energy Research and Development Authority (NYSERDA) also conducted its own refrigerator replacement project in 1998. The primary object of the project was to discover and document the most effective methods for conducting refrigerator replacement programs for the ultimate objective of cost-effective energy savings based on three scenarios of service delivery: (1) a total of 54 inefficient refrigerators were replaced at an 80-unit multifamily complex in Geneseo, New York, (2) forty new refrigerators were replaced in single-family homes in the Rochester area, and (3) a total of 636 new units were replaced in New York City multifamily buildings. All old units were removed and decommissioned in an environmentally appropriate manner. With two refrigerator monitoring systems developed by Synertech System Corporation, extensive measurements were taken on old units in the field and Synertech's environmental chamber. Energy savings per unit replaced for the three sites were 946 kWh per year, 1723 kWh per year, and 456 kWh per year. Percent energy savings raged from 48.5 to 79.3 under the three scenarios, and savings-to-investment ratios[10] ranged from 1:81 to 4:63. The difference in temperature between ambient air and the conditioned areas of a refrigerator is strongly correlated with energy use, averaging 2.5 percent per degree F. It is concluded that refrigerator replacements are practical, cost-effective measures that should be included in the energy services. This project concludes that replacement of energy-inefficient refrigerators is an appropriate and useful means to reducing environmental burdens associated with home refrigeration (Kinney, Lewis et al. 1998).

[10] The ratios if savings to investments (SIRs) were computed assuming that: a) project costs include administrative overhead as well as costs for the new units, decommission, and transpiration; b) the cost of electricity for residential customers of RG&E, 12.4 cents per kilowatt hour (kWh) and of Con Ed, 16.1 cents per kWh, will track inflation; c) the lifetime of the new units will be 20 years; d) the discount factor (to account for a present full payment whose stream of benefits will occur over time) is 4.8 percent.

CHAPTER VI

Conclusion

6.1 Research Scope and Key Findings

The refrigerator-freezer is an indispensable electric appliance for modern society, but consumes a significant fraction of household energy. The refrigerator –freezer accounts for 9 to 25% of the U.S. household energy consumption (US EPA 2004). Although federal energy efficiency standards have been regulating the energy efficiencies of refrigerator-freezers, households still use old-inefficient models mainly for economic reasons. This research analyses optimal lifetimes of refrigerators based on the life cycle optimization (LCO) model developed for vehicle replacement. Previous research regarding life cycle optimization of vehicle replacement presents a new scheme of optimal product lifetimes from an LCA perspective (Kim 2003). From the materials production to the end-of-life phase, annual energy consumptions were calculated with the assistance of an LCA software tool called SimaPro 5.1. Also, life cycle costs occurring during the purchase, use and disposal of refrigerators-freezer model years between 1985 and 2020 were determined. Major modeling factors such as deterioration of refrigerator energy efficiency and future refrigerator energy performance were developed based on historical data and available forecasts. Also, energy intensities of materials production, manufacturing and end-of-life were incorporated into the calculation. Energy and cost optimizations were conducted by a computer model based on a dynamic programming algorithm over a time horizon between 1985 and 2020. Key results and findings of this research are summarized below.

- The optimal replacement intervals that minimize primary energy consumption are 2 to 12 years based on the energy efficiency trends from *Consumer Reports*, and 4 to 12 years based on those from AHAM. The total primary energy consumption between 1985 and 2020 from energy optimization scenarios is 328 to 364 GJ (equivalent to 54 to 60 barrels of crude oil).

- The optimal replacement intervals that minimize life cycle cost are 18 and 18 years based on the energy efficiency trends from *Consumer Reports*, and 16 and 20 years based on those from AHAM. The optimal lifetimes are comparable to the average expected lifetime of refrigerators—20 years and slightly longer than the average observed lifetime—14 years (AHAM 1990; NFO 1996; ARIC 2004). The total life cycle costs between 1985 and 2020 from the cost optimization scenarios are 2,338 to 2,528 dollars.
- The energy optimization scenarios require 17 to 21% lower energy (70 to 90 GJ) than cost optimization scenarios, while they require 29 to 49% more costs (700 to 1,200 dollars) than cost optimization scenarios.
- The energy optimization scenarios require 5 to 6 replacements, while cost optimization scenarios require only 1 replacement during the time horizon.
- Cost optimization results are similar to each other across historical energy efficiency trends and future efficiency scenarios since electricity costs account for only a small fraction of life cycle costs.

6.2 Policy Implications

This research answers the question: from a cost and environmental perspective-*should consumers replace a refrigerator-freezer that is still running well?* In fact, as the results of this research suggest, there is a significant cost difference (29 to 49%) between energy optimization plans and cost minimization scenarios during the 36-year time horizon. There exists a tradeoff between the optimal lifetimes for energy and cost objectives. According to the simulation results, replacing refrigerators more frequently could save significant amount (17 to 21%) of primary energy use. However, consumers would keep their inefficient refrigerators from an economic perspective because the electricity cost savings by operating new, efficient models are relatively small compared with the purchasing costs of new models. In fact, the average useful lifetime of refrigerators is 14 years (NFO 1996). As shown in Chapter 5, scrappage programs that include multiple stakeholder participation could stimulate replacement of old refrigerators with new units. Those programs were successful mainly because the target refrigerator models were extremely old and inefficient (model year 1970s), and the

replacements were beneficial from both cost and energy standpoints. According to the current analysis, from both energy and cost optimization perspectives, model year 1985 and older refrigerators should be replaced NOW with a new unit. However, time horizon for appliance replacement tends to be short in the real world and consumers may be reluctant to replace old refrigerators. Therefore, incentive programs supported by governments need to be implemented to reduce energy use and CO_2 emissions from a long-term environmental perspective.

Another question for implementation of the optimal replacement plan is how to effectively disseminate useful information to consumers from manufactures, NGOs, or local or federal governments. Consumer education may be the key to mobilizing individuals to remove inefficient refrigerator-freezers both for cost and energy savings.

6.3 Future Research

The trend of refrigerator-freezers is shifting to bigger, multifunctional, access-friendly and aesthetically pleasing models. Market share of side-by-side refrigerator-freezers, which consume much more energy than top-mounted models, have been increasing rapidly (AHAM 2001). Thus, more consumers replace old top-mounted models with side-by-side models. A study that incorporates such trends would be necessary to provide more specific guidance to consumers.

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APPENDICES

APPENDIX A - Data Used to Construct Dynamic Life Cycle Inventories

TableA1: Characteristics of top-mounted refrigerator models for model years between 1980 and 2002 (Source: Consumer Reports)

	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)		price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1980	535	55	1104	13.9	17.0	1987	723	97	1180	12.0	19.3
	535	61	1224	13.6	17.2		669	81	988	12.5	20.2
	514	83	1656	14.6	18.4		634	89	1084	12.6	21.0
	517	64	1272	14.0	17.6		725	89	1088	13.4	21.5
	596	66	1320	12.7	16.2	average	688	89	1085	12.6	20.5
	524	71	1416	14.1	17.7	1988	720	80	1008	13.6	23.4
average	537	67	1332	13.8	17.4		691	80	1008	13.8	22.9
1983	625	101	1500	15.0	18.6		839	90	1128	13.1	23.1
	628	99	1464	14.9	18.6		633	81	1017	14.0	22.5
	642	97	1428	14.7	18.6		594	81	1017	14.2	22.0
	643	74	1092	16.0	19.0		674	78	987	14.8	22.1
	851	65	960	13.7	18.0		610	78	987	14.6	23.5
	654	93	1380	14.8	19.0		624	85	1074	15.0	23.6
	666	81	1200	14.5	18.1		629	91	1146	15.2	24.6
	678	74	1092	14.8	19.0		794	104	1304	14.7	24.1
	701	87	1380	14.8	19.0		640	104	1304	14.9	23.1
	703	74	1092	15.0	19.0		682	104	1304	14.8	24.5
	682	103	1524	15.9	19.6		672	104	1304	14.9	22.9
	739	97	1428	15.6	19.3		586	85	1074	14.6	21.2
average	684	87	1295	15.0	18.8		605	85	1074	15.2	26.1
1985	743	87	1124	13.9	23.0		609	106	1338	13.7	22.8
	666	85	1098	13.1	21.3	average	663	90	1130	14.4	23.3
	760	85	1098	14.4	22.3	1989	865	79	1026	14.7	25.2
	635	85	1092	13.9	22.2		776	84	1094	15.2	23.1
	668	94	1216	13.8	22.5		949	84	1089	15.4	28.1
	594	85	1092	14.1	21.7		818	89	1154	15.9	26.5
	616	89	1150	13.9	22.5		795	84	1094	15.3	25.1
	676	82	1052	15.9	25.0		842	89	1154	15.3	25.1
	657	82	1052	15.3	21.8		740	84	1094	15.4	24.2
	634	94	1216	14.2	21.9		723	84	1089	16.4	26.7
	684	96	1244	14.0	21.6		806	86	1116	16.7	27.7
	574	103	1327	13.1	21.1		759	89	1154	16.7	23.4
	566	103	1327	13.1	25.7		825	83	1077	15.9	22.4
	631	103	1327	13.1	21.1		856	91	1182	14.2	22.9
	695	106	1369	13.8	21.1		764	86	1116	16.2	23.6
	915	100	1284	13.5	20.5		631	83	1077	15.9	23.3
	672	89	1150	13.6	24.0		797	80	1038	15.7	26.4
	600	103	1327	13.3	20.8		794	80	1038	15.8	26.7
average	666	93	1197	13.9	22.2	average	796	85	1100	15.7	25.0

Electoricity costs are 7.75 in 1985, 8.2 in 1987, and 7.7 in 1989 (dollar/kWh)

TableA1: Continued

	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)		price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1992	610	71	865	13.8	20.1	1996	830	59	674	14.6	18.8
	505	81	980	14.8	22.1		670	59	674	13.8	18.1
	550	81	980	14.8	22.2		650	59	674	13.8	18.1
	530	79	955	14.8	19.8		630	70	799	13.7	18.2
	485	81	980	14.3	20.0		600	74	845	13.7	18.0
	530	93	1130	15.1	23.1	average	676	64	733	13.9	18.2
	555	76	925	14.6	21.4	1996	800	57	663	15.5	20.8
	600	81	980	14.0	23.2		850	57	663	16.0	20.9
	545	93	1130	14.4	22.6		850	55	640	16.7	21.6
	595	93	1130	14.4	22.7		810	55	640	16.2	20.7
	580	80	970	14.5	23.6		820	57	663	14.5	20.7
	615	80	970	15.1	25.5		760	72	837	16.4	20.6
	460	82	995	14.9	24.3		660	72	837	17.4	20.6
	515	80	965	14.8	18.5		930	71	826	15.5	21.8
	500	101	1225	14.8	24.8		900	79	919	16.8	21.6
	665	81	980	13.8	23.0		790	79	919	17.6	21.6
	675	76	925	14.6	22.6	average	817	65	760	16.3	21.1
	700	88	1065	13.9	23.2	1997	830	56	674		
	585	79	955	14.1	22.5		700	56	674		
average	568	83	1006	14.5	22.4		740	57	686		
1994	770	60	723	16.4			620	57	686	13.7	17.8
	920	62	747	16.1			700	68	818		
	810	62	747	16.2			550	71	854		
	780	62	747	16.3		average	690	61	732		[a]18.5
	840	64	771	16.2			820	55	662		
	955	70	843	16.6			850	55	662		
	630	70	843	17.0			800	53	638		
	625	72	867	16.0			850	55	662		
	700	72	867	16.0			750	69	830		
average	781.11	66	795	16.3			750	69	830		
							860	68	818		
							900	76	915		
						average	823	63	752		[a]21.5

[a]Estimated

Electoricity costs are 8.25 in 1992, 8.3 in 1994, 8.76 in 1996, and 8.31 in 1997 (cent/kWh)

TableA1: Continued

	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)		price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1998	780	47	566	14.5	18.5	2001	800	33	411	14.1	18.8
	750	52	627	15.5	19.1		800	35	436	14.1	18.8
	680	55	663	14.4	18.8		600	38	473	14.3	18.3
	700	58	699	14.1	17.8	average	733	35	440	14.2	18.6
	830	61	735	14.5	18.8	2002	825	36	434	14.4	18.5
	850	61	735	13.7	18.8		600	40	482	14.0	17.9
	580	64	771	13.7	18.8		750	35	422	14.1	18.8
	590	63	759	13.9	18.0		680	40	482	14.1	18.1
	600	78	940	15.2	18.2		940	37	446	14.1	18.8
average	706.67	60	722	14.4	18.5		680	40	482	14.3	18.3
1999	850	48	571	14.8	20.7		510	40	482	14.5	18.4
	760	54	643	15.2	20.6	average	712	38	461	14.2	18.4
	900	58	690	15.4	21.6		750	43	518	16.9	20.8
	870	66	786	15.6	21.6		850	39	470	15.1	20.7
	1100	77	917	15.5	21.5		1000	38	458	15.8	21.6
	800	66	786	15.0	21.6		800	38	458	16.0	20.6
	650	70	833	15.6	20.9		680	38	458	16.4	20.6
	750	81	964	17.1	21.6		650	44	530	16.5	21.7
	750	72	857	14.3	19.9		800	43	518	16.5	20.8
	570	78	929	16.2	20.6		1050	40	482	15.9	21.6
average	800	67	798	15.5	21.1	average	823	40	486	16.1	21.1
2000	800	49	595	13.4	18.5	2003	800			14.0	
	800	53	643	13.4	18.8		750			15.0	
	700	50	607	13.1	17.8		650			14.0	
	680	50	607	12.6	18.1		600			14.0	
	570	64	777	13.8	18.2		830			14.0	
	650	67	813	13.9	18.8		530			14.0	
	600	76	922	13.6	18.2		500			15.0	
	525	75	910	14.4	18.2		450			13.0	
average	666	61	734	13.5	18.3	average	639	40		14.1	18.5
	850	46	558	14.8	20.7		980			17.0	
	870	64	777	15.6	21.6		1100			16.0	
	1000	58	704	15.2	21.6		900			15.0	
	1100	73	886	15.5	21.5		850			16.0	
	650	67	813	15.6	20.9		750			17.0	
	570	74	898	16.2	20.6		800			17.0	
average	840	64	773	15.5	21.2		1200			16.0	
						average	940	40		16.3	21.5

Electoricity costs are 8.3 in 1998, 8.4 in 1999, 8.24 in 2000, 8.03 in 2001 and 8.3 in 2002 (cent/kWh)

TableA1: Continued

total	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1980	537	67	1332	13.8	17.4
1983	684	87	1295	15.0	18.8
1985	666	93	1197	13.9	22.2
1987	688	89	1085	12.6	20.5
1988	663	90	1130	14.4	23.3
1989	796	85	1100	15.7	25.0
1992	796	85	1100	15.7	22.4
1994	568	83	1006	14.5	n/a
1996	676	64	733	13.9	18.2
1996	817	65	760	16.3	21.1
1997	690	61	732	n/a	18.5
1998	823	63	752	n/a	21.5
1999	707	60	722	14.4	18.5
2000	800	67	798	15.5	21.1
2001	733	35	440	14.2	18.6
2002	712	38	461	14.2	18.4
2002	823	40	486	16.1	21.1
2003	639	40	n/a	14.1	18.5
2003	940	40	n/a	16.3	21.5
average	724	66	n/a	14.7	20.4

small	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1983	684	87	1295	15.0	18.8
1996	676	64	733	13.9	18.2
1997	690	61	732	n/a	18.5
1999	707	60	722	14.4	18.5
2001	733	35	440	14.2	18.6
2002	712	38	461	14.2	18.4
2003	639	40	n/a	14.1	18.5
average	692	55	n/a	14.3	18.5

mid	price (dollar)	cost/yr (dollar)	kWh/yr	usable (cu. ft.)	claimed (cu. ft)
1985	**665**	96	1234	13.8	21.3
1987	**676**	86	1053	12.8	20.9
1988	**590**	83	1046	14.4	21.6
1992	**550**	76	923	14.2	20.5
1994	**781**	66	795	16.3	n/a
1996	**817**	65	760	16.3	21.1
1997	**823**	63	752	n/a	21.5
1999	**806**	66	791	15.6	21.2
2000	**840**	64	773	15.5	21.2
2002	**823**	40	486	16.1	21.1
average	737	71	861	15.0	21.1

Table A2-1: Materials composition of average U.S. top/bottom refrigerators (1997 Model) (Source: AHAM)

Units with Freezer on Top or Bottom

Year	1997		
	kg	lbs	%
Average Weight	84.46	186.2	
Steel	47.55	104.83	56.3
Iron	4.56	10.05	5.4
Sub-Total: Ferrous Metal	52.11	114.89	61.7
Aluminum	2.11	4.66	2.5
Copper	2.70	5.96	3.2
Brass	0.17	0.37	0.2
Other Metal	0.25	0.56	0.3
Sub Total: Non-Ferrous Metal	5.24	11.54	6.2
Rubber	0.17	0.37	0.2
Fiber & Paper	0.08	0.19	0.1
Polypropylene	0.51	1.12	0.6
PS&HIPS	6.25	13.78	7.4
ABS	5.07	11.17	6
PVC	1.01	2.23	1.2
Polyurethane	5.57	12.29	6.6
Other Plastics	3.63	8.01	4.3
Asst. Mixed Plastics	1.44	3.17	1.7
Sub Total: Plastic	23.48	51.76	27.8
Fiberglass	0.08	0.19	0.1
Glass	2.87	6.33	3.4
Sub Total: Glass	2.96	6.52	3.5
Refrigerant	0.08	0.19	0.1
Oil	0.17	0.37	0.2
Other materials typically removed before processing	0	0	0
Sub Total: Materials typically removed before processing	0.25	0.56	0.3
Other	0.08	0.19	0.1
TOTAL	84.37	186.01	99.9

Note: no change in composition projected

Table A2-2: Materials composition of Japanese top-mounted refrigerator-freezer (1994 model) (Source: JEMAI 1995)

Capacity = 14 cu.ft./400L Four-door, top-freezer type

		Product weight		Package		Total weight		%		Others
Material		before	after	before	after	before	after	before	after	
Steel	coated steel sheet	10.31	10.82	0	0	10.31	10.82	13.13	13.38	
	plated steel sheet	11.18	11.07	0	0	11.18	11.07	14.24	13.69	
	stainless	0.24	0.56	0	0	0.24	0.56	0.31	0.69	
	electromagnetic	2.96	2.95	0	0	2.96	2.95	3.77	3.65	
	cold reduction	8.62	8.73	0	0	8.62	8.73	10.98	10.80	
	others	3.59	4.1	0	0	3.59	4.1	4.57	5.07	
	total	36.9	38.22	0	0	36.9	38.22	47.00	47.27	
Copper	wire	1.38	1.56	0	0	1.38	1.56	1.76	1.93	
	pipe and others	1.8	1.68	0	0	1.8	1.68	2.29	2.08	
	total	3.18	3.24	0	0	3.18	3.24	4.05	4.01	
Aluminum		0.98	1.07	0	0	0.98	1.07	1.25	1.32	
Other metals		0.07	0.07	0	0	0.07	0.07	0.09	0.09	
ABS		6.27	6.19	0	0	6.27	6.19	7.99	7.66	
PS		8.33	8.28	0.38	0.37	8.71	8.65	10.61	10.24	
PP		8.49	8.6	0.06	0.06	8.55	8.66	10.81	10.64	
PE		0.33	0.33	0.07	0.07	0.4	0.4	0.42	0.41	
PVC		2.2	2.2	0	0	2.2	2.2	2.80	2.72	
PET		0.01	0.01	0	0	0.01	0.01	0.01	0.01	
Other thermoplastic resins		1.38	1.4	0	0	1.38	1.4	1.76	1.73	
PUR		6.82	7.66	0	0	6.82	7.66	8.69	9.47	
Phenolic		0.06	0.06	0	0	0.06	0.06	0.08	0.07	
Polyester		0	0	0	0	0	0	0	0.00	
Acrylic		0.14	0.14	0	0	0.14	0.14	0.18	0.17	
Other thermosetting resins		0.15	0.15	0.01	0.01	0.15	0.16	0.19	0.19	
Refrigerant	CFCs	0.2		0		0.2		0.25		FC-12, R-502
	CFC's substitute		0.18		0		0.18		0.22	CFC-22, HFC-134a
Foaming agent	CFCs	0.84		0		0.84		1.07		CFC-11
	CFC's substitute		0.69		0		0.69		0.85	CFC141b, 142, HC
Refrigerant oil	mineral oil	0.18		0		0.18		0.23	0	
	esters oil		0.24		0		0.24		0.30	
Glass		0.24	0.24	0	0	0.24	0.24	0.31	0.30	
Wood		0	0	0.34	0.33	0.34	6.76	0	0	
Paper		0.06	0.06	6.47	6.7	6.53	1.81	0.08	0.07	
Other		1.69	1.81	0.01	0.01	1.7	1.81	2.15	2.24	
TOTAL		78.51	80.85	7.33	7.55	85.84	88.4	100.0	100.0	

Table A3: Refrigerators energy efficiency and consumption trends[b] (Source: AHAM)

	Adjusted Volume[a]/Unit[b]		Energy Consumption/Unit[b]		Efficiency[b]	
	Cu. Ft.	% Change vs. 1980	kWh/yr.	% Change vs. 1980	Energy Factor	% Change vs. 1980
1980	19.60	--	1278	--	5.59	--
1981	19.86	+1.3%	1190	-6.9%	6.09	+8.9%
1982	19.97	+1.9	1191	-6.8	6.12	+9.5
1983	20.31	+3.6	1160	-9.2	6.39	+14.3
1984	20.51	+4.6	1139	-10.9	6.57	+17.5
1985	19.47	-0.7	1058	-17.2	6.72	+20.2
1986	20.08	+2.4	1074	-16.0	6.83	+22.2
1987	19.89	+1.5	974	-23.8	7.45	+33.3
1988	20.08	+2.4	964	-24.6	7.60	+36.0
1989	19.91	+1.6	934	-26.9	7.78	+39.2
1990	20.45	+4.3	916	-28.3	8.15	+45.8
1991	19.82	+1.1	857	-32.9	8.44	+51.0
1992	19.78	+0.9	821	-35.8	8.80	+57.4
1993	20.11	+2.6	660	-48.4	11.13	+99.1
1994	20.03	+2.2	653	-48.9	11.19	+100.2
1995	19.95	+1.8	649	-49.2	11.22	+100.7
1996	20.31	+3.6	661	-48.3	11.22	+100.7
1997	20.43	+4.2	669	-47.7	10.63	+90.1
1998	NA	NA	NA	NA	NA	NA
1999	20.64	+5.3	690	-46.0	10.40	+86.2
2000	21.90	+11.7	704	-44.9	11.11	+98.7
2001	21.94	+11.9	565	-55.8	12.58	+125.0
2002	22.15	+13.0	520	-59.3	15.17	+171.3

[a] Adjusted volume = 1.63 x freezer volume (cubic feet) + refrigerator volume (cubit feet)
[b] Shipment Weighted Averages

APPENDIX B – Dynamic Life Cycle Inventories

Table B1: Energy intensity indices between the calendar years 1985 and 2020 using 1997 as a baseline year (Source: Kim 2003)

Year	Materials Production				Manufacturing/ Maintenance	Transportation /End-of-Life
	Ferrous Materials	Aluminum	Plastics	Average (Other Materials)		
1985	1.300	1.128	1.000	1.139	0.954	1.000
1986	1.289	1.109	1.000	1.129	0.950	1.000
1987	1.276	1.088	1.000	1.119	0.946	1.000
1988	1.264	1.069	1.000	1.108	0.942	1.000
1989	1.225	1.062	1.000	1.094	0.951	1.000
1990	1.188	1.054	1.000	1.080	0.961	1.000
1991	1.150	1.048	1.000	1.065	0.970	1.000
1992	1.136	1.046	1.000	1.060	0.991	1.000
1993	1.123	1.044	1.000	1.055	1.011	1.000
1994	1.109	1.042	1.000	1.050	1.031	1.000
1995	1.073	1.028	1.000	1.033	1.024	1.000
1996	1.036	1.013	1.000	1.017	1.023	1.000
1997	1.000	1.000	1.000	1.000	1.000	1.000
1998	0.965	0.986	1.000	0.985	0.999	1.000
1999	0.965	0.984	1.000	0.983	0.987	1.026
2000	0.943	0.976	0.995	0.972	0.972	1.032
2001	0.924	0.967	0.992	0.962	0.971	1.058
2002	0.903	0.959	0.989	0.951	0.952	1.055
2003	0.888	0.950	0.986	0.943	0.942	1.067
2004	0.876	0.941	0.981	0.934	0.931	1.067
2005	0.861	0.934	0.978	0.927	0.912	1.067
2006	0.849	0.927	0.976	0.918	0.896	1.084
2007	0.836	0.920	0.973	0.911	0.882	1.096
2008	0.826	0.913	0.970	0.905	0.866	1.088
2009	0.817	0.906	0.968	0.899	0.853	1.085
2010	0.806	0.899	0.965	0.893	0.839	1.080
2011	0.797	0.893	0.962	0.886	0.826	1.077
2012	0.786	0.888	0.959	0.880	0.813	1.069
2013	0.779	0.882	0.959	0.876	0.800	1.075
2014	0.770	0.876	0.957	0.870	0.787	1.071
2015	0.764	0.871	0.954	0.866	0.774	1.069
2016	0.756	0.865	0.951	0.861	0.763	1.066
2017	0.750	0.861	0.949	0.856	0.750	1.058
2018	0.745	0.857	0.949	0.852	0.737	1.054
2019	0.737	0.853	0.946	0.848	0.725	1.048
2020	0.732	0.849	0.943	0.844	0.713	1.044

Table B2: Approximate heat rates for electricity (Btu per Kilowatt hour)

Year	Electricity Net Generation			Electricity Consumption[e]
	Fossil-Fueled Plants[a,b]	Nuclear Plants[c]	Geothermal Energy Plants[d]	
1973 **Total**	10389	10903	21674	3412
1974 **Total**	10442	11161	21674	3412
1975 **Total**	10406	11013	21611	3412
1976 **Total**	10373	11047	21611	3412
1977 **Total**	10435	10769	21611	3412
1978 **Total**	10361	10941	21611	3412
1979 **Total**	10353	10879	21545	3412
1980 **Total**	10388	10908	21639	3412
1981 **Total**	10453	11030	21639	3412
1982 **Total**	10454	11073	21629	3412
1983 **Total**	10520	10905	21290	3412
1984 **Total**	10440	10843	21303	3412
1985 **Total**	10447	10622	21263	3412
1986 **Total**	10446	10579	21263	3412
1987 **Total**	10419	10442	21263	3412
1988 **Total**	10324	10602	21096	3412
1989 **Total**	10432	10583	21096	3412
1990 **Total**	10402	10582	21096	3412
1991 **Total**	10436	10484	20997	3412
1992 **Total**	10342	10471	20914	3412
1993 **Total**	10309	10504	20914	3412
1994 **Total**	10316	10452	20914	3412
1995 **Total**	10312	10507	20914	3412
1996 **Total**	10340	10503	20960	3412
1997 **Total**	10213	10494	20960	3412
1998 **Total**	10197	10491	21017	3412
1999 **Total**	10226	10450	21017	3412
2000 **Total**	10201	10429	21017	3412
2001 **Total**	10174	10448	21017	3412
2002 **Total**	[P]10033	10439	21017	3412
2003 **Total**	[P]10107	[P]10439	21017	3412
2004 **Total**	[E]10107	[E]10439	21017	3412

a. Through 2000, used as the thermal conversion factor for used wood and waste electricity net generation at electric utilities. For all years, used as the thermal conversion factor for hydroelectric, solar, and wind electricity net generation.
b. Through 2000, heat rates are for electric utilities only. Beginning in 2001, heat rates are for the electric power sector, which comprises electricity-only and combined-heat-and-power (CHP) plants within the NAICS 22 category whose primary business is to sell electricity, or electricity and heat, to the public.
c. Used as the thermal conversion factor for nuclear electricity net generation.
d. Used as the thermal conversion factor for geothermal electricity net generation.
e. Used as the thermal conversion factor for electricity retail sales, and electricity imports and exports.

R=Revised. P=Preliminary. E=Estimate.

Web Page: http://www.eia.gov/emeu/mer/append.html (Source: EIA 2002)

Table B3: Electricity price based on 1985 dollar (cents per kilowatt hour)

MY	Real (1985 dollars)
1985	7.39
1986	7.26
1987	7.07
1988	6.87
1989	6.77
1990	6.67
1991	6.61
1992	6.59
1993	6.52
1994	6.43
1995	6.31
1996	6.16
1997	6.09
1998	5.89
1999	5.74
2000	5.68
2001	5.81
2002	5.63
2003	5.65
2004	5.56
2005	5.48
2006	5.41
2007	5.34
2008	5.31
2009	5.32
2010	5.30
2011	5.29
2012	5.34
2013	5.35
2014	5.38
2015	5.40
2016	5.42
2017	5.40
2018	5.41
2019	5.38
2020	5.39

Table B4: Purchase price based on 1985 dollar (dollar per unit)
(Source: Consumer Reports)

MY	Real Price (1985 dollars)
1985	665
1986	656
1987	642
1988	542
1989	511
1990	484
1991	457
1992	434
1993	518
1994	599
1995	600
1996	602
1997	595
1998	581
1999	568
2000	578
2001	560
2002	606
2003	564
2004	564
2005	563
2006	563
2007	563
2008	562
2009	562
2010	562
2011	562
2012	561
2013	561
2014	561
2015	560
2016	560
2017	560
2018	559
2019	559
2020	559

Table B5-1: Electricity consumption in use phase based on Consumer Reports data with 0% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1234	1282	1325	1362	1394	1421	1444	1463	1478	1490	1500	1508	1513	1517	1520	1522	1523	1523	1524	1524
1986	1143	1189	1228	1263	1292	1317	1338	1356	1370	1382	1391	1398	1403	1407	1409	1411	1412	1412	1412	1412
1987	1053	1095	1131	1163	1190	1213	1233	1249	1262	1273	1281	1287	1292	1296	1298	1300	1300	1301	1301	1301
1988	1046	1087	1123	1154	1181	1204	1224	1240	1253	1263	1272	1278	1283	1286	1288	1290	1291	1291	1291	1291
1989	1018	1058	1093	1124	1150	1172	1191	1206	1219	1229	1238	1244	1248	1252	1254	1255	1256	1257	1257	1257
1990	997	1036	1071	1100	1126	1148	1166	1182	1194	1204	1212	1218	1223	1226	1228	1230	1230	1231	1231	1231
1991	969	1007	1041	1070	1095	1116	1134	1148	1161	1170	1178	1184	1188	1192	1194	1195	1196	1196	1196	1196
1992	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1141	1146	1149	1151	1152	1153	1153	1153	1153
1993	890	926	956	983	1006	1026	1042	1056	1067	1076	1083	1088	1092	1095	1097	1099	1099	1100	1100	1100
1994	847	881	910	935	957	976	991	1004	1015	1024	1030	1035	1039	1042	1044	1045	1046	1046	1046	1046
1995	804	836	863	887	908	926	941	953	963	971	978	982	986	989	991	992	992	993	993	993
1996	760	791	817	840	859	876	890	902	911	919	925	930	933	935	937	938	939	939	939	939
1997	752	782	808	830	850	866	880	892	901	909	915	919	923	925	927	928	929	929	929	929
1998	775	806	832	856	876	893	907	919	928	936	942	947	951	953	955	956	957	957	957	957
1999	798	829	857	881	901	919	933	946	956	964	970	975	979	981	983	984	985	985	985	985
2000	826	858	887	912	933	951	966	979	989	998	1004	1009	1013	1016	1018	1019	1019	1020	1020	1020
2001	656	682	705	724	741	756	768	778	786	793	798	802	805	807	809	809	810	810	810	810
2002	486	506	523	537	550	560	569	577	583	588	592	595	597	598	599	600	601	601	601	601
2003	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2004	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2005	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2006	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2007	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2008	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2009	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2010	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2011	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2012	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2013	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2014	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2015	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2016	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2017	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2018	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2019	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2020	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582

Table B5-2: Electricity consumption in use phase based on Consumer Reports data with 1% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1234	1282	1325	1362	1394	1421	1444	1463	1478	1490	1500	1508	1513	1517	1520	1522	1523	1523	1524	1524
1986	1143	1189	1228	1263	1292	1317	1338	1356	1370	1382	1391	1398	1403	1407	1409	1411	1412	1412	1412	1412
1987	1053	1095	1131	1163	1190	1213	1233	1249	1262	1273	1281	1287	1292	1296	1298	1300	1300	1301	1301	1301
1988	1046	1087	1123	1154	1181	1204	1224	1240	1253	1263	1272	1278	1283	1286	1288	1290	1291	1291	1291	1291
1989	1018	1058	1093	1124	1150	1172	1191	1206	1219	1229	1238	1244	1248	1252	1254	1255	1256	1257	1257	1257
1990	997	1036	1071	1100	1126	1148	1166	1182	1194	1204	1212	1218	1223	1226	1228	1230	1230	1231	1231	1231
1991	969	1007	1041	1070	1095	1116	1134	1148	1161	1170	1178	1184	1188	1192	1194	1195	1196	1196	1196	1196
1992	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1141	1146	1149	1151	1152	1153	1153	1153	1153
1993	890	926	956	983	1006	1026	1042	1056	1067	1076	1083	1088	1092	1095	1097	1099	1099	1100	1100	1100
1994	847	881	910	935	957	976	991	1004	1015	1024	1030	1035	1039	1042	1044	1045	1046	1046	1046	1046
1995	804	836	863	887	908	926	941	953	963	971	978	982	986	989	991	992	992	993	993	993
1996	760	791	817	840	859	876	890	902	911	919	925	930	933	935	937	938	939	939	939	939
1997	752	782	808	830	850	866	880	892	901	909	915	919	923	925	927	928	929	929	929	929
1998	775	806	832	856	876	893	907	919	928	936	942	947	951	953	955	956	957	957	957	957
1999	798	829	857	881	901	919	933	946	956	964	970	975	979	981	983	984	985	985	985	985
2000	826	858	887	912	933	951	966	979	989	998	1004	1009	1013	1016	1018	1019	1019	1020	1020	1020
2001	656	682	705	724	741	756	768	778	786	793	798	802	805	807	809	809	810	810	810	810
2002	486	506	523	537	550	560	569	577	583	588	592	595	597	598	599	600	601	601	601	601
2003	482	493	503	513	522	530	537	544	549	555	559	563	566	569	571	573	574	575	576	576
2004	477	488	498	508	516	524	532	538	544	549	554	557	561	563	566	567	569	569	570	570
2005	472	483	493	502	511	519	526	533	538	543	548	552	555	558	560	562	563	564	564	564
2006	467	478	488	497	506	514	521	527	533	538	542	546	549	552	554	556	557	558	558	559
2007	462	473	483	492	501	508	515	522	527	532	537	540	544	546	548	550	551	552	553	553
2008	457	468	478	487	495	503	510	516	522	527	531	535	538	540	543	544	545	546	547	547
2009	452	463	473	482	490	498	504	511	516	521	525	529	532	535	537	538	540	540	541	541
2010	448	458	468	477	485	492	499	505	511	515	520	523	526	529	531	533	534	535	535	535
2011	443	453	463	471	479	487	494	500	505	510	514	518	521	523	525	527	528	529	529	529
2012	438	448	457	466	474	481	488	494	499	504	508	512	515	517	520	521	522	523	523	524
2013	433	443	452	461	469	476	483	489	494	499	503	506	509	512	514	515	516	517	518	518
2014	428	438	447	456	464	471	477	483	488	493	497	501	504	506	508	509	511	511	512	512
2015	423	433	442	451	458	465	472	478	483	487	491	495	498	500	502	504	505	506	506	506
2016	418	428	437	445	453	460	466	472	477	482	486	489	492	494	496	498	499	500	500	500
2017	413	423	432	440	448	455	461	467	472	476	480	483	486	489	491	492	493	494	494	495
2018	409	418	427	435	443	449	456	461	466	471	474	478	481	483	485	486	487	488	489	489
2019	404	413	422	430	437	444	450	456	461	465	469	472	475	477	479	481	482	482	483	483
2020	399	408	417	425	432	439	445	450	455	459	463	466	469	471	473	475	476	477	477	477

Table B5-3: Electricity consumption in use phase based on Consumer Reports data with 2% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1058	1100	1136	1168	1195	1219	1238	1254	1268	1278	1287	1293	1298	1301	1304	1305	1306	1307	1307	1307
1986	1074	1117	1154	1186	1214	1237	1257	1273	1287	1298	1306	1313	1318	1321	1324	1325	1326	1326	1326	1327
1987	974	1013	1046	1075	1101	1122	1140	1155	1167	1177	1185	1191	1195	1198	1200	1202	1202	1203	1203	1203
1988	964	1002	1035	1064	1089	1110	1128	1143	1155	1165	1172	1178	1183	1186	1188	1189	1190	1190	1191	1191
1989	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1142	1146	1149	1151	1152	1153	1153	1154	1154
1990	916	952	984	1011	1035	1055	1072	1086	1098	1107	1114	1120	1124	1127	1129	1130	1131	1131	1131	1131
1991	857	891	921	946	968	987	1003	1016	1027	1035	1042	1048	1051	1054	1056	1057	1058	1058	1058	1058
1992	821	853	882	906	928	946	961	973	984	992	998	1004	1007	1010	1012	1013	1014	1014	1014	1014
1993	660	686	709	729	746	760	772	782	791	797	803	807	810	812	813	814	815	815	815	815
1994	653	679	701	721	738	752	764	774	782	789	794	798	801	803	805	806	806	806	807	807
1995	649	675	697	717	733	748	760	769	778	784	789	793	796	798	800	801	801	801	802	802
1996	661	687	710	730	747	761	774	784	792	799	804	808	811	813	815	816	816	816	816	816
1997	669	695	719	739	756	771	783	793	802	808	814	818	821	823	824	825	826	826	826	826
1998	680	706	730	750	768	783	795	806	814	821	826	831	834	836	837	838	839	839	839	839
1999	690	717	741	762	780	795	807	818	827	834	839	843	847	849	850	851	852	852	852	852
2000	704	732	756	777	795	811	824	835	843	851	856	861	864	866	868	869	869	869	870	870
2001	565	587	607	624	638	651	661	670	677	683	687	691	693	695	696	697	698	698	698	698
2002	520	541	559	574	588	599	609	617	623	628	632	636	638	640	641	642	642	642	642	642
2003	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2004	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2005	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2006	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2007	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2008	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2009	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2010	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2011	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2012	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2013	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2014	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2015	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2016	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2017	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2018	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2019	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622
2020	520	532	543	554	563	572	580	587	593	599	604	608	612	615	617	619	620	621	622	622

Table B5 -4: Electricity consumption in use phase based on AHAM data with 0% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1234	1282	1325	1362	1394	1421	1444	1463	1478	1490	1500	1508	1513	1517	1520	1522	1523	1523	1524	1524
1986	1143	1189	1228	1263	1292	1317	1338	1356	1370	1382	1391	1398	1403	1407	1409	1411	1412	1412	1412	1412
1987	1053	1095	1131	1163	1190	1213	1233	1249	1262	1273	1281	1287	1292	1296	1298	1300	1300	1301	1301	1301
1988	1046	1087	1123	1154	1181	1204	1224	1240	1253	1263	1272	1278	1283	1286	1288	1290	1291	1291	1291	1291
1989	1018	1058	1093	1124	1150	1172	1191	1206	1219	1229	1238	1244	1248	1252	1254	1255	1256	1257	1257	1257
1990	997	1036	1071	1100	1126	1148	1166	1182	1194	1204	1212	1218	1223	1226	1228	1230	1230	1231	1231	1231
1991	969	1007	1041	1070	1095	1116	1134	1148	1161	1170	1178	1184	1188	1192	1194	1195	1196	1196	1196	1196
1992	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1141	1146	1149	1151	1152	1153	1153	1153	1153
1993	890	926	956	983	1006	1026	1042	1056	1067	1076	1083	1088	1092	1095	1097	1099	1099	1100	1100	1100
1994	847	881	910	935	957	976	991	1004	1015	1024	1030	1035	1039	1042	1044	1045	1046	1046	1046	1046
1995	804	836	863	887	908	926	941	953	963	971	978	982	986	989	991	992	992	993	993	993
1996	760	791	817	840	859	876	890	902	911	919	925	930	933	935	937	938	939	939	939	939
1997	752	782	808	830	850	866	880	892	901	909	915	919	923	925	927	928	929	929	929	929
1998	775	806	832	856	876	893	907	919	928	936	942	947	951	953	955	956	957	957	957	957
1999	798	829	857	881	901	919	933	946	956	964	970	975	979	981	983	984	985	985	985	985
2000	826	858	887	912	933	951	966	979	989	998	1004	1009	1013	1016	1018	1019	1019	1020	1020	1020
2001	656	682	705	724	741	756	768	778	786	793	798	802	805	807	809	809	810	810	810	810
2002	486	506	523	537	550	560	569	577	583	588	592	595	597	598	599	600	601	601	601	601
2003	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2004	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2005	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2006	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2007	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2008	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2009	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2010	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2011	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2012	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2013	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2014	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2015	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2016	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2017	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2018	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2019	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582
2020	486	498	508	518	527	535	542	549	555	560	565	569	572	575	577	579	580	581	582	582

Table B5-5: Electricity consumption in use phase based on AHAM data with 0% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1058	1100	1136	1168	1195	1219	1238	1254	1268	1278	1287	1293	1298	1301	1304	1305	1306	1307	1307	1307
1986	1074	1117	1154	1186	1214	1237	1257	1273	1287	1298	1306	1313	1318	1321	1324	1325	1326	1326	1326	1327
1987	974	1013	1046	1075	1101	1122	1140	1155	1167	1177	1185	1191	1195	1198	1200	1202	1202	1203	1203	1203
1988	964	1002	1035	1064	1089	1110	1128	1143	1155	1165	1172	1178	1183	1186	1188	1189	1190	1190	1191	1191
1989	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1142	1146	1149	1151	1152	1153	1153	1154	1154
1990	916	952	984	1011	1035	1055	1072	1086	1098	1107	1114	1120	1124	1127	1129	1130	1131	1131	1131	1131
1991	857	891	921	946	968	987	1003	1016	1027	1035	1042	1048	1051	1054	1056	1057	1058	1058	1058	1058
1992	821	853	882	906	928	946	961	973	984	992	998	1004	1007	1010	1012	1013	1014	1014	1014	1014
1993	660	686	709	729	746	760	772	782	791	797	803	807	810	812	813	814	815	815	815	815
1994	653	679	701	721	738	752	764	774	782	789	794	798	801	803	805	806	806	806	807	807
1995	649	675	697	717	733	748	760	769	778	784	789	793	796	798	800	801	801	801	802	802
1996	661	687	710	730	747	761	774	784	792	799	804	808	811	813	815	816	816	816	816	816
1997	669	695	719	739	756	771	783	793	802	808	814	818	821	823	824	825	826	826	826	826
1998	680	706	730	750	768	783	795	806	814	821	826	831	834	836	837	838	839	839	839	839
1999	690	717	741	762	780	795	807	818	827	834	839	843	847	849	850	851	852	852	852	852
2000	704	732	756	777	795	811	824	835	843	851	856	861	864	866	868	869	869	869	870	870
2001	565	587	607	624	638	651	661	670	677	683	687	691	693	695	696	697	698	698	698	698
2002	520	541	559	574	588	599	609	617	623	628	632	636	638	640	641	642	642	642	642	642
2003	515	527	538	548	558	566	574	581	587	593	598	602	606	608	611	613	614	615	615	616
2004	510	521	532	543	552	560	568	575	581	587	592	596	599	602	605	607	608	609	609	609
2005	504	516	527	537	546	555	562	569	575	581	586	590	593	596	599	600	602	603	603	603
2006	499	511	522	532	541	549	557	563	570	575	580	584	587	590	592	594	595	596	597	597
2007	494	505	516	526	535	543	551	558	564	569	574	578	581	584	586	588	589	590	591	591
2008	489	500	511	520	529	538	545	552	558	563	568	572	575	578	580	582	583	584	584	585
2009	484	495	505	515	524	532	539	546	552	557	562	565	569	572	574	576	577	578	578	578
2010	478	490	500	509	518	526	533	540	546	551	555	559	563	565	568	569	571	571	572	572
2011	473	484	494	504	512	520	528	534	540	545	549	553	557	559	562	563	564	565	566	566
2012	468	479	489	498	507	515	522	528	534	539	543	547	550	553	555	557	558	559	560	560
2013	463	474	484	493	501	509	516	522	528	533	537	541	544	547	549	551	552	553	553	553
2014	458	468	478	487	496	503	510	516	522	527	531	535	538	541	543	545	546	547	547	547
2015	452	463	473	482	490	498	504	511	516	521	525	529	532	535	537	538	540	540	541	541
2016	447	458	467	476	484	492	499	505	510	515	519	523	526	529	531	532	533	534	535	535
2017	442	452	462	471	479	486	493	499	504	509	513	517	520	522	524	526	527	528	528	529
2018	437	447	456	465	473	480	487	493	498	503	507	511	514	516	518	520	521	522	522	522
2019	432	442	451	460	467	475	481	487	492	497	501	505	508	510	512	514	515	516	516	516
2020	426	436	446	454	462	469	475	481	486	491	495	499	502	504	506	508	509	509	510	510

Table B5 -6: Electricity consumption in use phase based on AHAM data with 1% energy improvement projection (kWh)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	1058	1100	1136	1168	1195	1219	1238	1254	1268	1278	1287	1293	1298	1301	1304	1305	1306	1307	1307	1307
1986	1074	1117	1154	1186	1214	1237	1257	1273	1287	1298	1306	1313	1318	1321	1324	1325	1326	1326	1326	1327
1987	974	1013	1046	1075	1101	1122	1140	1155	1167	1177	1185	1191	1195	1198	1200	1202	1202	1203	1203	1203
1988	964	1002	1035	1064	1089	1110	1128	1143	1155	1165	1172	1178	1183	1186	1188	1189	1190	1190	1191	1191
1989	934	971	1003	1031	1055	1076	1093	1107	1119	1128	1136	1142	1146	1149	1151	1152	1153	1153	1154	1154
1990	916	952	984	1011	1035	1055	1072	1086	1098	1107	1114	1120	1124	1127	1129	1130	1131	1131	1131	1131
1991	857	891	921	946	968	987	1003	1016	1027	1035	1042	1048	1051	1054	1056	1057	1058	1058	1058	1058
1992	821	853	882	906	928	946	961	973	984	992	998	1004	1007	1010	1012	1013	1014	1014	1014	1014
1993	660	686	709	729	746	760	772	782	791	797	803	807	810	812	813	814	815	815	815	815
1994	653	679	701	721	738	752	764	774	782	789	794	798	801	803	805	806	806	806	807	807
1995	649	675	697	717	733	748	760	769	778	784	789	793	796	798	800	801	801	801	802	802
1996	661	687	710	730	747	761	774	784	792	799	804	808	811	813	815	816	816	816	816	816
1997	669	695	719	739	756	771	783	793	802	808	814	818	821	823	824	825	826	826	826	826
1998	680	706	730	750	768	783	795	806	814	821	826	831	834	836	837	838	839	839	839	839
1999	690	717	741	762	780	795	807	818	827	834	839	843	847	849	850	851	852	852	852	852
2000	704	732	756	777	795	811	824	835	843	851	856	861	864	866	868	869	869	869	870	870
2001	565	587	607	624	638	651	661	670	677	683	687	691	693	695	696	697	698	698	698	698
2002	520	541	559	574	588	599	609	617	623	628	632	636	638	640	641	642	642	642	642	642
2003	510	521	532	543	552	560	568	575	581	587	592	596	599	602	605	607	608	609	609	609
2004	499	511	522	532	541	549	557	563	570	575	580	584	587	590	592	594	595	596	597	597
2005	489	500	511	520	529	538	545	552	558	563	568	572	575	578	580	582	583	584	584	585
2006	478	490	500	509	518	526	533	540	546	551	555	559	563	565	568	569	571	571	572	572
2007	468	479	489	498	507	515	522	528	534	539	543	547	550	553	555	557	558	559	560	560
2008	458	468	478	487	496	503	510	516	522	527	531	535	538	541	543	545	546	547	547	547
2009	447	458	467	476	484	492	499	505	510	515	519	523	526	529	531	532	533	534	535	535
2010	437	447	456	465	473	480	487	493	498	503	507	511	514	516	518	520	521	522	522	522
2011	426	436	446	454	462	469	475	481	486	491	495	499	502	504	506	508	509	509	510	510
2012	416	426	435	443	451	457	464	470	475	479	483	486	489	492	494	495	496	497	497	498
2013	406	415	424	432	439	446	452	458	463	467	471	474	477	479	481	483	484	485	485	485
2014	395	404	413	421	428	435	441	446	451	455	459	462	465	467	469	470	471	472	472	473
2015	385	394	402	410	417	423	429	434	439	443	447	450	453	455	457	458	459	460	460	460
2016	374	383	391	399	405	412	417	423	427	431	435	438	440	443	444	446	447	447	448	448
2017	364	372	380	388	394	400	406	411	415	419	423	426	428	430	432	433	434	435	435	435
2018	354	362	369	376	383	389	394	399	403	407	411	413	416	418	420	421	422	422	423	423
2019	343	351	359	365	372	377	383	387	392	395	399	401	404	406	407	408	409	410	410	410
2020	333	341	348	354	360	366	371	376	380	383	386	389	391	393	395	396	397	398	398	398

Table B6-1: Energy consumption in use phase based on Consumer Reports data with 0% energy improvement projection (MJ)

MY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	14903	15492	16008	16454	16838	17165	17440	17668	17855	18006	18124	18216	18283	18332	18365	18386	18398	18404	18406	18406
1986	13814	14360	14838	15252	15608	15911	16166	16377	16551	16690	16800	16885	16947	16993	17023	17043	17054	17059	17061	17061
1987	12725	13229	13669	14050	14378	14657	14891	15087	15246	15375	15476	15554	15612	15653	15681	15699	15709	15714	15716	15717
1988	12630	13130	13567	13945	14271	14548	14781	14974	15133	15260	15361	15438	15496	15537	15565	15582	15593	15598	15599	15600
1989	12293	12779	13204	13573	13890	14159	14386	14574	14728	14853	14950	15025	15081	15122	15149	15166	15176	15181	15183	15183
1990	12040	12516	12932	13293	13603	13867	14090	14274	14425	14547	14642	14716	14771	14810	14837	14854	14863	14868	14870	14870
1991	11702	12165	12570	12921	13222	13479	13695	13874	14021	14139	14232	14304	14357	14395	14421	14437	14447	14451	14453	14453
1992	11280	11727	12117	12455	12745	12993	13201	13374	13515	13629	13719	13788	13839	13876	13901	13917	13926	13930	13932	13932
1993	10757	11183	11555	11877	12154	12390	12588	12753	12888	12997	13082	13148	13197	13232	13256	13271	13280	13284	13286	13286
1994	10234	10639	10992	11299	11563	11787	11976	12133	12261	12365	12446	12509	12555	12588	12611	12626	12634	12638	12639	12640
1995	9710	10095	10430	10721	10972	11184	11364	11512	11634	11732	11809	11869	11913	11945	11966	11980	11988	11992	11993	11993
1996	9187	9550	9868	10144	10380	10582	10751	10892	11007	11100	11173	11229	11271	11301	11321	11334	11342	11345	11347	11347
1997	9086	9445	9760	10032	10266	10465	10633	10772	10886	10978	11050	11106	11147	11177	11197	11210	11217	11221	11222	11222
1998	9361	9731	10055	10336	10577	10782	10955	11098	11216	11310	11385	11442	11484	11515	11536	11549	11556	11560	11561	11562
1999	9636	10017	10350	10639	10887	11099	11276	11424	11545	11642	11719	11778	11822	11853	11874	11888	11896	11900	11901	11901
2000	9976	10371	10716	11015	11272	11490	11674	11827	11952	12053	12132	12193	12239	12271	12293	12308	12316	12319	12321	12321
2001	7926	8240	8514	8752	8956	9129	9276	9397	9497	9577	9640	9688	9724	9750	9768	9779	9785	9788	9789	9790
2002	5877	6109	6312	6489	6640	6769	6877	6967	7041	7100	7147	7183	7210	7229	7242	7250	7255	7257	7258	7258
2003	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2004	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2005	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2006	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2007	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2008	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2009	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2010	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2011	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2012	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2013	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2014	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2015	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2016	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2017	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2018	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2019	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028
2020	5877	6013	6140	6257	6365	6463	6552	6632	6704	6768	6823	6871	6912	6946	6973	6994	7010	7020	7026	7028

Table B6-2: Energy consumption in use phase based on Consumer Reports data with 1% energy improvement projection (MJ)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	14903	15492	16008	16454	16838	17165	17440	17668	17855	18006	18124	18216	18283	18332	18365	18386	18398	18404	18406	18406
1986	13814	14360	14838	15252	15608	15911	16166	16377	16551	16690	16800	16885	16947	16993	17023	17043	17054	17059	17061	17061
1987	12725	13229	13669	14050	14378	14657	14891	15087	15246	15375	15476	15554	15612	15653	15681	15699	15709	15714	15716	15717
1988	12630	13130	13567	13945	14271	14548	14781	14974	15133	15260	15361	15438	15496	15537	15565	15582	15593	15598	15599	15600
1989	12293	12779	13204	13573	13890	14159	14386	14574	14728	14853	14950	15025	15081	15122	15149	15166	15176	15181	15183	15183
1990	12040	12516	12932	13293	13603	13867	14090	14274	14425	14547	14642	14716	14771	14810	14837	14854	14863	14868	14870	14870
1991	11702	12165	12570	12921	13222	13479	13695	13874	14021	14139	14232	14304	14357	14395	14421	14437	14447	14451	14453	14453
1992	11280	11727	12117	12455	12745	12993	13201	13374	13515	13629	13719	13788	13839	13876	13901	13917	13926	13930	13932	13932
1993	10757	11183	11555	11877	12154	12390	12588	12753	12888	12997	13082	13148	13197	13232	13256	13271	13280	13284	13286	13286
1994	10234	10639	10992	11299	11563	11787	11976	12133	12261	12365	12446	12509	12555	12588	12611	12626	12634	12638	12639	12640
1995	9710	10095	10430	10721	10972	11184	11364	11512	11634	11732	11809	11869	11913	11945	11966	11980	11988	11992	11993	11993
1996	9187	9550	9868	10144	10380	10582	10751	10892	11007	11100	11173	11229	11271	11301	11321	11334	11342	11345	11347	11347
1997	9086	9445	9760	10032	10266	10465	10633	10772	10886	10978	11050	11106	11147	11177	11197	11210	11217	11221	11222	11222
1998	9361	9731	10055	10336	10577	10782	10955	11098	11216	11310	11385	11442	11484	11515	11536	11549	11556	11560	11561	11562
1999	9636	10017	10350	10639	10887	11099	11276	11424	11545	11642	11719	11778	11822	11853	11874	11888	11896	11900	11901	11901
2000	9976	10371	10716	11015	11272	11490	11674	11827	11952	12053	12132	12193	12239	12271	12293	12308	12316	12319	12321	12321
2001	7926	8240	8514	8752	8956	9129	9276	9397	9497	9577	9640	9688	9724	9750	9768	9779	9785	9788	9789	9790
2002	5877	6109	6312	6489	6640	6769	6877	6967	7041	7100	7147	7183	7210	7229	7242	7250	7255	7257	7258	7258
2003	5818	5953	6079	6194	6301	6398	6486	6566	6637	6700	6755	6803	6843	6877	6903	6924	6940	6950	6956	6958
2004	5759	5893	6017	6132	6237	6333	6421	6500	6570	6632	6687	6734	6774	6807	6834	6854	6870	6880	6885	6888
2005	5700	5833	5956	6069	6174	6269	6355	6433	6503	6565	6619	6665	6705	6738	6764	6784	6799	6809	6815	6817
2006	5641	5773	5894	6007	6110	6204	6290	6367	6436	6497	6550	6597	6636	6668	6694	6715	6729	6739	6745	6747
2007	5583	5713	5833	5944	6046	6140	6224	6301	6369	6429	6482	6528	6567	6599	6625	6645	6659	6669	6675	6677
2008	5524	5652	5772	5882	5983	6075	6159	6234	6302	6362	6414	6459	6497	6529	6555	6575	6589	6599	6604	6606
2009	5465	5592	5710	5819	5919	6010	6093	6168	6235	6294	6346	6390	6428	6460	6485	6505	6519	6529	6534	6536
2010	5406	5532	5649	5756	5855	5946	6028	6102	6168	6226	6278	6322	6359	6390	6415	6435	6449	6458	6464	6466
2011	5348	5472	5587	5694	5792	5881	5962	6035	6101	6159	6209	6253	6290	6321	6346	6365	6379	6388	6394	6396
2012	5289	5412	5526	5631	5728	5816	5897	5969	6034	6091	6141	6184	6221	6251	6276	6295	6309	6318	6323	6325
2013	5230	5352	5465	5569	5664	5752	5831	5903	5967	6023	6073	6116	6152	6182	6206	6225	6239	6248	6253	6255
2014	5171	5292	5403	5506	5601	5687	5766	5836	5900	5956	6005	6047	6083	6112	6136	6155	6169	6178	6183	6185
2015	5113	5232	5342	5444	5537	5623	5700	5770	5833	5888	5936	5978	6014	6043	6067	6085	6098	6107	6113	6114
2016	5054	5171	5280	5381	5474	5558	5635	5704	5766	5820	5868	5909	5944	5974	5997	6015	6028	6037	6042	6044
2017	4995	5111	5219	5318	5410	5493	5569	5637	5699	5753	5800	5841	5875	5904	5927	5945	5958	5967	5972	5974
2018	4936	5051	5158	5256	5346	5429	5504	5571	5631	5685	5732	5772	5806	5835	5858	5875	5888	5897	5902	5904
2019	4878	4991	5096	5193	5283	5364	5438	5505	5564	5617	5663	5703	5737	5765	5788	5805	5818	5827	5832	5833
2020	4819	4931	5035	5131	5219	5299	5373	5438	5497	5550	5595	5635	5668	5696	5718	5735	5748	5756	5761	5763

Table B6-3: Energy consumption in use phase based on Consumer Reports data with 2% energy improvement projection (MJ)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	14903	15492	16008	16454	16838	17165	17440	17668	17855	18006	18124	18216	18283	18332	18365	18386	18398	18404	18406	18406
1986	13814	14360	14838	15252	15608	15911	16166	16377	16551	16690	16800	16885	16947	16993	17023	17043	17054	17059	17061	17061
1987	12725	13229	13669	14050	14378	14657	14891	15087	15246	15375	15476	15554	15612	15653	15681	15699	15709	15714	15716	15717
1988	12630	13130	13567	13945	14271	14548	14781	14974	15133	15260	15361	15438	15496	15537	15565	15582	15593	15598	15599	15600
1989	12293	12779	13204	13573	13890	14159	14386	14574	14728	14853	14950	15025	15081	15122	15149	15166	15176	15181	15183	15183
1990	12040	12516	12932	13293	13603	13867	14090	14274	14425	14547	14642	14716	14771	14810	14837	14854	14863	14868	14870	14870
1991	11702	12165	12570	12921	13222	13479	13695	13874	14021	14139	14232	14304	14357	14395	14421	14437	14447	14451	14453	14453
1992	11280	11727	12117	12455	12745	12993	13201	13374	13515	13629	13719	13788	13839	13876	13901	13917	13926	13930	13932	13932
1993	10757	11183	11555	11877	12154	12390	12588	12753	12888	12997	13082	13148	13197	13232	13256	13271	13280	13284	13286	13286
1994	10234	10639	10992	11299	11563	11787	11976	12133	12261	12365	12446	12509	12555	12588	12611	12626	12634	12638	12639	12640
1995	9710	10095	10430	10721	10972	11184	11364	11512	11634	11732	11809	11869	11913	11945	11966	11980	11988	11992	11993	11993
1996	9187	9550	9868	10144	10380	10582	10751	10892	11007	11100	11173	11229	11271	11301	11321	11334	11342	11345	11347	11347
1997	9086	9445	9760	10032	10266	10465	10633	10772	10886	10978	11050	11106	11147	11177	11197	11210	11217	11221	11222	11222
1998	9361	9731	10055	10336	10577	10782	10955	11098	11216	11310	11385	11442	11484	11515	11536	11549	11556	11560	11561	11562
1999	9636	10017	10350	10639	10887	11099	11276	11424	11545	11642	11719	11778	11822	11853	11874	11888	11896	11900	11901	11901
2000	9976	10371	10716	11015	11272	11490	11674	11827	11952	12053	12132	12193	12239	12271	12293	12308	12316	12319	12321	12321
2001	7926	8240	8514	8752	8956	9129	9276	9397	9497	9577	9640	9688	9724	9750	9768	9779	9785	9788	9789	9790
2002	5877	6109	6312	6489	6640	6769	6877	6967	7041	7100	7147	7183	7210	7229	7242	7250	7255	7257	7258	7258
2003	5759	5893	6017	6132	6237	6333	6421	6500	6570	6632	6687	6734	6774	6807	6834	6854	6870	6880	6885	6888
2004	5641	5773	5894	6007	6110	6204	6290	6367	6436	6497	6550	6597	6636	6668	6694	6715	6729	6739	6745	6747
2005	5524	5652	5772	5882	5983	6075	6159	6234	6302	6362	6414	6459	6497	6529	6555	6575	6589	6599	6604	6606
2006	5406	5532	5649	5756	5855	5946	6028	6102	6168	6226	6278	6322	6359	6390	6415	6435	6449	6458	6464	6466
2007	5289	5412	5526	5631	5728	5816	5897	5969	6034	6091	6141	6184	6221	6251	6276	6295	6309	6318	6323	6325
2008	5171	5292	5403	5506	5601	5687	5766	5836	5900	5956	6005	6047	6083	6112	6136	6155	6169	6178	6183	6185
2009	5054	5171	5280	5381	5474	5558	5635	5704	5766	5820	5868	5909	5944	5974	5997	6015	6028	6037	6042	6044
2010	4936	5051	5158	5256	5346	5429	5504	5571	5631	5685	5732	5772	5806	5835	5858	5875	5888	5897	5902	5904
2011	4819	4931	5035	5131	5219	5299	5373	5438	5497	5550	5595	5635	5668	5696	5718	5735	5748	5756	5761	5763
2012	4701	4811	4912	5006	5092	5170	5242	5306	5363	5414	5459	5497	5530	5557	5579	5595	5608	5616	5621	5623
2013	4584	4690	4789	4880	4964	5041	5110	5173	5229	5279	5322	5360	5392	5418	5439	5456	5468	5476	5480	5482
2014	4466	4570	4666	4755	4837	4912	4979	5041	5095	5143	5186	5222	5253	5279	5300	5316	5327	5335	5340	5341
2015	4349	4450	4544	4630	4710	4782	4848	4908	4961	5008	5049	5085	5115	5140	5160	5176	5187	5195	5199	5201
2016	4231	4330	4421	4505	4582	4653	4717	4775	4827	4873	4913	4947	4977	5001	5021	5036	5047	5054	5059	5060
2017	4114	4209	4298	4380	4455	4524	4586	4643	4693	4737	4776	4810	4839	4862	4881	4896	4907	4914	4918	4920
2018	3996	4089	4175	4255	4328	4395	4455	4510	4559	4602	4640	4673	4700	4723	4742	4756	4767	4774	4778	4779
2019	3879	3969	4052	4130	4201	4265	4324	4377	4425	4467	4503	4535	4562	4584	4602	4616	4626	4633	4637	4639
2020	3761	3848	3930	4005	4073	4136	4193	4245	4291	4331	4367	4398	4424	4445	4463	4476	4486	4493	4497	4498

Table B6-4: Energy consumption in use phase based on AHAM data with 0% energy improvement projection (MJ)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	12781	13287	13729	14112	14441	14722	14957	15153	15314	15443	15544	15623	15681	15722	15751	15769	15779	15784	15786	15786
1986	12974	13488	13937	14326	14660	14944	15184	15383	15545	15676	15780	15859	15918	15960	15989	16007	16018	16023	16025	16025
1987	11766	12232	12639	12992	13295	13553	13770	13950	14098	14217	14310	14382	14436	14474	14500	14517	14526	14531	14533	14533
1988	11646	12107	12509	12858	13158	13414	13629	13807	13953	14071	14163	14235	14288	14326	14351	14368	14377	14382	14383	14384
1989	11283	11730	12120	12458	12749	12996	13204	13377	13519	13633	13723	13792	13843	13880	13905	13921	13930	13934	13936	13936
1990	11066	11504	11886	12218	12503	12746	12950	13120	13258	13370	13458	13526	13576	13612	13637	13652	13661	13666	13667	13667
1991	10353	10763	11121	11431	11698	11925	12116	12275	12404	12509	12591	12655	12702	12735	12758	12773	12781	12785	12787	12787
1992	9918	10311	10654	10951	11206	11424	11607	11759	11883	11983	12062	12123	12168	12201	12223	12236	12244	12248	12250	12250
1993	7973	8289	8564	8803	9009	9184	9331	9453	9553	9633	9697	9746	9782	9808	9826	9837	9843	9846	9848	9848
1994	7889	8201	8474	8710	8913	9086	9232	9353	9452	9531	9594	9642	9678	9704	9721	9733	9739	9742	9743	9743
1995	7840	8151	8422	8657	8859	9031	9175	9295	9394	9473	9535	9583	9619	9644	9662	9673	9679	9682	9683	9684
1996	7985	8301	8577	8817	9023	9198	9345	9467	9567	9648	9712	9760	9797	9823	9841	9852	9858	9861	9862	9863
1997	8082	8402	8681	8924	9132	9309	9458	9582	9683	9765	9829	9879	9915	9942	9960	9971	9978	9981	9982	9982
1998	8209	8534	8818	9064	9275	9455	9606	9732	9835	9918	9983	10034	10071	10098	10116	10127	10134	10137	10138	10139
1999	8336	8666	8954	9204	9418	9601	9755	9883	9987	10071	10138	10189	10227	10254	10272	10284	10291	10294	10295	10295
2000	8505	8841	9135	9390	9609	9796	9953	10083	10190	10276	10343	10395	10434	10462	10481	10493	10499	10503	10504	10504
2001	6826	7096	7332	7536	7712	7862	7988	8092	8178	8247	8301	8343	8374	8396	8411	8421	8426	8429	8430	8430
2002	6282	6531	6748	6936	7098	7236	7351	7448	7527	7590	7640	7678	7707	7727	7741	7750	7755	7758	7759	7759
2003	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2004	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2005	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2006	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2007	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2008	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2009	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2010	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2011	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2012	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2013	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2014	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2015	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2016	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2017	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2018	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2019	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513
2020	6282	6428	6564	6689	6804	6909	7004	7090	7167	7235	7294	7345	7389	7425	7454	7477	7493	7504	7511	7513

Table B6 -5: Energy consumption in use phase based on AHAM data with 1% energy improvement projection (MJ)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	12781	13287	13729	14112	14441	14722	14957	15153	15314	15443	15544	15623	15681	15722	15751	15769	15779	15784	15786	15786
1986	12974	13488	13937	14326	14660	14944	15184	15383	15545	15676	15780	15859	15918	15960	15989	16007	16018	16023	16025	16025
1987	11766	12232	12639	12992	13295	13553	13770	13950	14098	14217	14310	14382	14436	14474	14500	14517	14526	14531	14533	14533
1988	11646	12107	12509	12858	13158	13414	13629	13807	13953	14071	14163	14235	14288	14326	14351	14368	14377	14382	14383	14384
1989	11283	11730	12120	12458	12749	12996	13204	13377	13519	13633	13723	13792	13843	13880	13905	13921	13930	13934	13936	13936
1990	11066	11504	11886	12218	12503	12746	12950	13120	13258	13370	13458	13526	13576	13612	13637	13652	13661	13666	13667	13667
1991	10353	10763	11121	11431	11698	11925	12116	12275	12404	12509	12591	12655	12702	12735	12758	12773	12781	12785	12787	12787
1992	9918	10311	10654	10951	11206	11424	11607	11759	11883	11983	12062	12123	12168	12201	12223	12236	12244	12248	12250	12250
1993	7973	8289	8564	8803	9009	9184	9331	9453	9553	9633	9697	9746	9782	9808	9826	9837	9843	9846	9848	9848
1994	7889	8201	8474	8710	8913	9086	9232	9353	9452	9531	9594	9642	9678	9704	9721	9733	9739	9742	9743	9743
1995	7840	8151	8422	8657	8859	9031	9175	9295	9394	9473	9535	9583	9619	9644	9662	9673	9679	9682	9683	9684
1996	7985	8301	8577	8817	9023	9198	9345	9467	9567	9648	9712	9760	9797	9823	9841	9852	9858	9861	9862	9863
1997	8082	8402	8681	8924	9132	9309	9458	9582	9683	9765	9829	9879	9915	9942	9960	9971	9978	9981	9982	9982
1998	8209	8534	8818	9064	9275	9455	9606	9732	9835	9918	9983	10034	10071	10098	10116	10127	10134	10137	10138	10139
1999	8336	8666	8954	9204	9418	9601	9755	9883	9987	10071	10138	10189	10227	10254	10272	10284	10291	10294	10295	10295
2000	8505	8841	9135	9390	9609	9796	9953	10083	10190	10276	10343	10395	10434	10462	10481	10493	10499	10503	10504	10504
2001	6826	7096	7332	7536	7712	7862	7988	8092	8178	8247	8301	8343	8374	8396	8411	8421	8426	8429	8430	8430
2002	6282	6531	6748	6936	7098	7236	7351	7448	7527	7590	7640	7678	7707	7727	7741	7750	7755	7758	7759	7759
2003	6219	6364	6498	6622	6736	6839	6934	7019	7095	7162	7221	7272	7315	7351	7380	7402	7418	7429	7435	7438
2004	6156	6299	6432	6555	6667	6770	6864	6948	7023	7090	7148	7199	7241	7277	7305	7327	7343	7354	7360	7363
2005	6093	6235	6367	6488	6599	6701	6794	6877	6952	7018	7075	7125	7167	7202	7231	7252	7268	7279	7285	7288
2006	6031	6171	6301	6421	6531	6632	6724	6806	6880	6945	7002	7052	7093	7128	7156	7178	7194	7204	7210	7212
2007	5968	6107	6235	6354	6463	6563	6654	6735	6808	6873	6929	6978	7020	7054	7082	7103	7119	7129	7135	7137
2008	5905	6042	6170	6287	6395	6494	6584	6664	6737	6801	6856	6905	6946	6980	7007	7028	7044	7054	7060	7062
2009	5842	5978	6104	6220	6327	6425	6514	6593	6665	6728	6784	6831	6872	6905	6932	6953	6969	6979	6985	6987
2010	5779	5914	6038	6154	6259	6356	6444	6523	6593	6656	6711	6758	6798	6831	6858	6879	6894	6904	6910	6912
2011	5717	5850	5973	6087	6191	6287	6374	6452	6522	6583	6638	6684	6724	6757	6783	6804	6819	6829	6835	6837
2012	5654	5785	5907	6020	6123	6218	6303	6381	6450	6511	6565	6611	6650	6683	6709	6729	6744	6754	6759	6762
2013	5591	5721	5842	5953	6055	6149	6233	6310	6378	6439	6492	6537	6576	6608	6634	6654	6669	6679	6684	6686
2014	5528	5657	5776	5886	5987	6080	6163	6239	6307	6366	6419	6464	6502	6534	6560	6580	6594	6604	6609	6611
2015	5465	5592	5710	5819	5919	6010	6093	6168	6235	6294	6346	6391	6428	6460	6485	6505	6519	6529	6534	6536
2016	5402	5528	5645	5752	5851	5941	6023	6097	6163	6222	6273	6317	6355	6386	6411	6430	6444	6454	6459	6461
2017	5340	5464	5579	5685	5783	5872	5953	6026	6092	6149	6200	6244	6281	6311	6336	6355	6369	6379	6384	6386
2018	5277	5400	5513	5618	5715	5803	5883	5955	6020	6077	6127	6170	6207	6237	6262	6280	6294	6304	6309	6311
2019	5214	5335	5448	5552	5647	5734	5813	5885	5948	6005	6054	6097	6133	6163	6187	6206	6219	6229	6234	6236
2020	5151	5271	5382	5485	5579	5665	5743	5814	5877	5932	5981	6023	6059	6089	6112	6131	6144	6154	6159	6161

Table B6-6: Energy consumption in use phase based on AHAM data with 2% energy improvement projection (MJ)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	12781	13287	13729	14112	14441	14722	14957	15153	15314	15443	15544	15623	15681	15722	15751	15769	15779	15784	15786	15786
1986	12974	13488	13937	14326	14660	14944	15184	15383	15545	15676	15780	15859	15918	15960	15989	16007	16018	16023	16025	16025
1987	11766	12232	12639	12992	13295	13553	13770	13950	14098	14217	14310	14382	14436	14474	14500	14517	14526	14531	14533	14533
1988	11646	12107	12509	12858	13158	13414	13629	13807	13953	14071	14163	14235	14288	14326	14351	14368	14377	14382	14383	14384
1989	11283	11730	12120	12458	12749	12996	13204	13377	13519	13633	13723	13792	13843	13880	13905	13921	13930	13934	13936	13936
1990	11066	11504	11886	12218	12503	12746	12950	13120	13258	13370	13458	13526	13576	13612	13637	13652	13661	13666	13667	13667
1991	10353	10763	11121	11431	11698	11925	12116	12275	12404	12509	12591	12655	12702	12735	12758	12773	12781	12785	12787	12787
1992	9918	10311	10654	10951	11206	11424	11607	11759	11883	11983	12062	12123	12168	12201	12223	12236	12244	12248	12250	12250
1993	7973	8289	8564	8803	9009	9184	9331	9453	9553	9633	9697	9746	9782	9808	9826	9837	9843	9846	9848	9848
1994	7889	8201	8474	8710	8913	9086	9232	9353	9452	9531	9594	9642	9678	9704	9721	9733	9739	9742	9743	9743
1995	7840	8151	8422	8657	8859	9031	9175	9295	9394	9473	9535	9583	9619	9644	9662	9673	9679	9682	9683	9684
1996	7985	8301	8577	8817	9023	9198	9345	9467	9567	9648	9712	9760	9797	9823	9841	9852	9858	9861	9862	9863
1997	8082	8402	8681	8924	9132	9309	9458	9582	9683	9765	9829	9879	9915	9942	9960	9971	9978	9981	9982	9982
1998	8209	8534	8818	9064	9275	9455	9606	9732	9835	9918	9983	10034	10071	10098	10116	10127	10134	10137	10138	10139
1999	8336	8666	8954	9204	9418	9601	9755	9883	9987	10071	10138	10189	10227	10254	10272	10284	10291	10294	10295	10295
2000	8505	8841	9135	9390	9609	9796	9953	10083	10190	10276	10343	10395	10434	10462	10481	10493	10499	10503	10504	10504
2001	6826	7096	7332	7536	7712	7862	7988	8092	8178	8247	8301	8343	8374	8396	8411	8421	8426	8429	8430	8430
2002	6282	6531	6748	6936	7098	7236	7351	7448	7527	7590	7640	7678	7707	7727	7741	7750	7755	7758	7759	7759
2003	6156	6299	6432	6555	6667	6770	6864	6948	7023	7090	7148	7199	7241	7277	7305	7327	7343	7354	7360	7363
2004	6031	6171	6301	6421	6531	6632	6724	6806	6880	6945	7002	7052	7093	7128	7156	7178	7194	7204	7210	7212
2005	5905	6042	6170	6287	6395	6494	6584	6664	6737	6801	6856	6905	6946	6980	7007	7028	7044	7054	7060	7062
2006	5779	5914	6038	6154	6259	6356	6444	6523	6593	6656	6711	6758	6798	6831	6858	6879	6894	6904	6910	6912
2007	5654	5785	5907	6020	6123	6218	6303	6381	6450	6511	6565	6611	6650	6683	6709	6729	6744	6754	6759	6762
2008	5528	5657	5776	5886	5987	6080	6163	6239	6307	6366	6419	6464	6502	6534	6560	6580	6594	6604	6609	6611
2009	5402	5528	5645	5752	5851	5941	6023	6097	6163	6222	6273	6317	6355	6386	6411	6430	6444	6454	6459	6461
2010	5277	5400	5513	5618	5715	5803	5883	5955	6020	6077	6127	6170	6207	6237	6262	6280	6294	6304	6309	6311
2011	5151	5271	5382	5485	5579	5665	5743	5814	5877	5932	5981	6023	6059	6089	6112	6131	6144	6154	6159	6161
2012	5026	5142	5251	5351	5443	5527	5603	5672	5733	5788	5835	5876	5911	5940	5963	5981	5995	6003	6008	6010
2013	4900	5014	5120	5217	5307	5389	5463	5530	5590	5643	5689	5729	5763	5792	5814	5832	5845	5853	5858	5860
2014	4774	4885	4988	5083	5171	5250	5323	5388	5447	5498	5544	5583	5616	5643	5665	5682	5695	5703	5708	5710
2015	4649	4757	4857	4950	5035	5112	5183	5246	5303	5354	5398	5436	5468	5495	5516	5533	5545	5553	5558	5560
2016	4523	4628	4726	4816	4899	4974	5043	5105	5160	5209	5252	5289	5320	5346	5367	5383	5395	5403	5408	5409
2017	4397	4500	4594	4682	4762	4836	4903	4963	5017	5064	5106	5142	5172	5198	5218	5234	5245	5253	5257	5259
2018	4272	4371	4463	4548	4626	4698	4763	4821	4873	4920	4960	4995	5025	5049	5069	5084	5095	5103	5107	5109
2019	4146	4243	4332	4415	4490	4560	4623	4679	4730	4775	4814	4848	4877	4901	4920	4935	4946	4953	4957	4959
2020	4020	4114	4201	4281	4354	4421	4482	4537	4587	4630	4668	4701	4729	4752	4771	4785	4796	4803	4807	4808

Table B7-1: Electricity costs based on Consumer Reports
with 0% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	91	95	98	101	103	105	107	108	109	110	111	111	112	112	112	112	113	113	113	113
1986	83	86	89	92	94	96	97	98	99	100	101	101	102	102	102	102	102	102	102	102
1987	75	77	80	82	84	86	87	88	89	90	91	91	91	92	92	92	92	92	92	92
1988	72	75	77	79	81	83	84	85	86	87	87	88	88	88	89	89	89	89	89	89
1989	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1990	66	69	71	73	75	77	78	79	80	80	81	81	82	82	82	82	82	82	82	82
1991	64	67	69	71	72	74	75	76	77	77	78	78	79	79	79	79	79	79	79	79
1992	62	64	66	68	69	71	72	73	74	74	75	75	75	76	76	76	76	76	76	76
1993	58	60	62	64	66	67	68	69	70	70	71	71	71	71	72	72	72	72	72	72
1994	54	57	59	60	62	63	64	65	65	66	66	67	67	67	67	67	67	67	67	67
1995	51	53	54	56	57	58	59	60	61	61	62	62	62	62	62	63	63	63	63	63
1996	47	49	50	52	53	54	55	56	56	57	57	57	57	58	58	58	58	58	58	58
1997	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	57	57	57	57	57
1998	46	47	49	50	52	53	53	54	55	55	56	56	56	56	56	56	56	56	56	56
1999	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	56	57	57	57	57
2000	47	49	50	52	53	54	55	56	56	57	57	57	58	58	58	58	58	58	58	58
2001	38	40	41	42	43	44	45	45	46	46	46	47	47	47	47	47	47	47	47	47
2002	27	28	29	30	31	32	32	32	33	33	33	33	34	34	34	34	34	34	34	34
2003	28	28	29	29	30	30	31	31	31	32	32	32	32	33	33	33	33	33	33	33
2004	27	28	28	29	29	30	30	31	31	31	31	32	32	32	32	32	32	32	32	32
2005	27	27	28	28	29	29	30	30	30	31	31	31	31	32	32	32	32	32	32	32
2006	26	27	28	28	29	29	29	30	30	30	31	31	31	31	31	31	31	31	31	31
2007	26	27	27	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31	31
2008	26	26	27	28	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31
2009	26	26	27	28	28	28	29	29	30	30	30	30	30	31	31	31	31	31	31	31
2010	26	26	27	27	28	28	29	29	29	30	30	30	30	30	31	31	31	31	31	31
2011	26	26	27	27	28	28	29	29	29	30	30	30	30	30	31	31	31	31	31	31
2012	26	27	27	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31	31
2013	26	27	27	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31	31
2014	26	27	27	28	28	29	29	30	30	30	30	31	31	31	31	31	31	31	31	31
2015	26	27	27	28	28	29	29	30	30	30	31	31	31	31	31	31	31	31	31	31
2016	26	27	28	28	29	29	29	30	30	30	31	31	31	31	31	31	31	31	32	32
2017	26	27	27	28	28	29	29	30	30	30	30	31	31	31	31	31	31	31	31	31
2018	26	27	28	28	29	29	29	30	30	30	31	31	31	31	31	31	31	31	31	31
2019	26	27	27	28	28	29	29	30	30	30	30	31	31	31	31	31	31	31	31	31
2020	26	27	27	28	28	29	29	30	30	30	30	31	31	31	31	31	31	31	31	31

Table B7-2: Electricity costs based on Consumer Reports
with 1% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	91	95	98	101	103	105	107	108	109	110	111	111	112	112	112	112	113	113	113	113
1986	83	86	89	92	94	96	97	98	99	100	101	101	102	102	102	102	102	102	102	102
1987	75	77	80	82	84	86	87	88	89	90	91	91	91	92	92	92	92	92	92	92
1988	72	75	77	79	81	83	84	85	86	87	87	88	88	88	89	89	89	89	89	89
1989	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1990	66	69	71	73	75	77	78	79	80	80	81	81	82	82	82	82	82	82	82	82
1991	64	67	69	71	72	74	75	76	77	77	78	78	79	79	79	79	79	79	79	79
1992	62	64	66	68	69	71	72	73	74	74	75	75	75	76	76	76	76	76	76	76
1993	58	60	62	64	66	67	68	69	70	70	71	71	71	71	72	72	72	72	72	72
1994	54	57	59	60	62	63	64	65	65	66	66	67	67	67	67	67	67	67	67	67
1995	51	53	54	56	57	58	59	60	61	61	62	62	62	62	62	63	63	63	63	63
1996	47	49	50	52	53	54	55	56	56	57	57	57	57	58	58	58	58	58	58	58
1997	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	57	57	57	57	57
1998	46	47	49	50	52	53	53	54	55	55	56	56	56	56	56	56	56	56	56	56
1999	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	56	57	57	57	57
2000	47	49	50	52	53	54	55	56	56	57	57	57	58	58	58	58	58	58	58	58
2001	38	40	41	42	43	44	45	45	46	46	46	47	47	47	47	47	47	47	47	47
2002	27	28	29	30	31	32	32	32	33	33	33	33	34	34	34	34	34	34	34	34
2003	27	28	28	29	29	30	30	31	31	31	32	32	32	32	32	32	32	33	33	33
2004	26	27	28	28	29	29	30	30	30	31	31	31	31	31	31	32	32	32	32	32
2005	26	26	27	28	28	28	29	29	30	30	30	30	30	31	31	31	31	31	31	31
2006	25	26	26	27	27	28	28	29	29	29	29	30	30	30	30	30	30	30	30	30
2007	25	25	26	26	27	27	28	28	28	28	29	29	29	29	29	29	29	29	29	30
2008	24	25	25	26	26	27	27	27	28	28	28	28	29	29	29	29	29	29	29	29
2009	24	25	25	26	26	26	27	27	27	28	28	28	28	28	29	29	29	29	29	29
2010	24	24	25	25	26	26	26	27	27	27	28	28	28	28	28	28	28	28	28	28
2011	23	24	24	25	25	26	26	26	27	27	27	27	28	28	28	28	28	28	28	28
2012	23	24	24	25	25	26	26	26	27	27	27	27	27	28	28	28	28	28	28	28
2013	23	24	24	25	25	25	26	26	26	27	27	27	27	27	27	28	28	28	28	28
2014	23	24	24	25	25	25	26	26	26	27	27	27	27	27	27	27	27	27	28	28
2015	23	23	24	24	25	25	25	26	26	26	27	27	27	27	27	27	27	27	27	27
2016	23	23	24	24	25	25	25	26	26	26	26	27	27	27	27	27	27	27	27	27
2017	22	23	23	24	24	25	25	25	25	26	26	26	26	26	26	27	27	27	27	27
2018	22	23	23	24	24	24	25	25	25	25	26	26	26	26	26	26	26	26	26	26
2019	22	22	23	23	24	24	24	25	25	25	25	25	26	26	26	26	26	26	26	26
2020	22	22	22	23	23	24	24	24	25	25	25	25	25	25	26	26	26	26	26	26

Table B7-3: Electricity costs based on Consumer Reports
with 2% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	91	95	98	101	103	105	107	108	109	110	111	111	112	112	112	112	113	113	113	113
1986	83	86	89	92	94	96	97	98	99	100	101	101	102	102	102	102	102	102	102	102
1987	75	77	80	82	84	86	87	88	89	90	91	91	91	92	92	92	92	92	92	92
1988	72	75	77	79	81	83	84	85	86	87	87	88	88	88	89	89	89	89	89	89
1989	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1990	66	69	71	73	75	77	78	79	80	80	81	81	82	82	82	82	82	82	82	82
1991	64	67	69	71	72	74	75	76	77	77	78	78	79	79	79	79	79	79	79	79
1992	62	64	66	68	69	71	72	73	74	74	75	75	75	76	76	76	76	76	76	76
1993	58	60	62	64	66	67	68	69	70	70	71	71	71	71	72	72	72	72	72	72
1994	54	57	59	60	62	63	64	65	65	66	66	67	67	67	67	67	67	67	67	67
1995	51	53	54	56	57	58	59	60	61	61	62	62	62	62	62	63	63	63	63	63
1996	47	49	50	52	53	54	55	56	56	57	57	57	57	58	58	58	58	58	58	58
1997	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	57	57	57	57	57
1998	46	47	49	50	52	53	53	54	55	55	56	56	56	56	56	56	56	56	56	56
1999	46	48	49	51	52	53	54	54	55	55	56	56	56	56	56	56	57	57	57	57
2000	47	49	50	52	53	54	55	56	56	57	57	57	58	58	58	58	58	58	58	58
2001	38	40	41	42	43	44	45	45	46	46	46	47	47	47	47	47	47	47	47	47
2002	27	28	29	30	31	32	32	32	33	33	33	33	34	34	34	34	34	34	34	34
2003	27	28	28	29	29	30	30	30	31	31	31	32	32	32	32	32	32	32	32	32
2004	26	27	27	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31	31
2005	25	26	26	27	27	28	28	28	29	29	29	29	29	30	30	30	30	30	30	30
2006	24	25	25	26	26	27	27	27	28	28	28	28	28	29	29	29	29	29	29	29
2007	23	24	24	25	25	26	26	26	27	27	27	27	27	28	28	28	28	28	28	28
2008	23	23	24	24	25	25	25	26	26	26	26	27	27	27	27	27	27	27	27	27
2009	22	23	23	24	24	24	25	25	25	26	26	26	26	26	26	26	27	27	27	27
2010	22	22	23	23	23	24	24	24	25	25	25	25	25	26	26	26	26	26	26	26
2011	21	22	22	22	23	23	24	24	24	24	24	25	25	25	25	25	25	25	25	25
2012	21	21	22	22	22	23	23	23	24	24	24	24	24	25	25	25	25	25	25	25
2013	20	21	21	22	22	22	23	23	23	23	24	24	24	24	24	24	24	24	24	24
2014	20	20	21	21	22	22	22	22	23	23	23	23	23	23	24	24	24	24	24	24
2015	19	20	20	21	21	21	22	22	22	22	23	23	23	23	23	23	23	23	23	23
2016	19	19	20	20	21	21	21	21	22	22	22	22	22	22	23	23	23	23	23	23
2017	18	19	19	20	20	20	20	21	21	21	21	21	22	22	22	22	22	22	22	22
2018	18	18	19	19	19	20	20	20	20	21	21	21	21	21	21	21	21	21	21	21
2019	17	18	18	18	19	19	19	19	20	20	20	20	20	20	20	21	21	21	21	21
2020	17	17	18	18	18	18	19	19	19	19	19	20	20	20	20	20	20	20	20	20

Table B7-4: Electricity costs based on AHAM data
with 0% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	78	81	84	86	88	90	91	93	94	94	95	96	96	96	96	96	97	97	97	97
1986	78	81	84	86	88	90	91	92	93	94	95	95	96	96	96	96	96	96	96	96
1987	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1988	66	69	71	73	75	76	78	79	79	80	81	81	81	82	82	82	82	82	82	82
1989	63	66	68	70	71	73	74	75	76	76	77	77	78	78	78	78	78	78	78	78
1990	61	63	66	67	69	70	71	72	73	74	74	75	75	75	75	75	75	75	75	75
1991	57	59	61	63	64	65	66	67	68	68	69	69	69	70	70	70	70	70	70	70
1992	54	56	58	60	61	62	63	64	65	65	66	66	66	67	67	67	67	67	67	67
1993	43	45	46	48	49	50	50	51	52	52	52	53	53	53	53	53	53	53	53	53
1994	42	44	45	46	47	48	49	50	50	51	51	51	52	52	52	52	52	52	52	52
1995	41	43	44	45	46	47	48	49	49	49	50	50	50	50	50	50	51	51	51	51
1996	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1997	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1998	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
1999	40	41	43	44	45	46	46	47	47	48	48	48	49	49	49	49	49	49	49	49
2000	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
2001	33	34	35	36	37	38	38	39	39	40	40	40	40	40	40	40	40	41	41	41
2002	29	30	31	32	33	34	34	35	35	35	36	36	36	36	36	36	36	36	36	36
2003	29	30	31	31	32	32	33	33	34	34	34	34	35	35	35	35	35	35	35	35
2004	29	30	30	31	31	32	32	33	33	33	34	34	34	34	34	34	34	35	35	35
2005	29	29	30	30	31	31	32	32	33	33	33	33	34	34	34	34	34	34	34	34
2006	28	29	29	30	30	31	31	32	32	32	33	33	33	33	33	34	34	34	34	34
2007	28	28	29	30	30	31	31	31	32	32	32	32	33	33	33	33	33	33	33	33
2008	28	28	29	29	30	30	31	31	32	32	32	32	32	33	33	33	33	33	33	33
2009	28	28	29	29	30	30	31	31	32	32	32	32	33	33	33	33	33	33	33	33
2010	28	28	29	29	30	30	31	31	31	32	32	32	32	33	33	33	33	33	33	33
2011	27	28	29	29	30	30	31	31	31	32	32	32	32	32	33	33	33	33	33	33
2012	28	28	29	30	30	31	31	31	32	32	32	32	33	33	33	33	33	33	33	33
2013	28	28	29	30	30	31	31	31	32	32	32	33	33	33	33	33	33	33	33	33
2014	28	29	29	30	30	31	31	32	32	32	32	33	33	33	33	33	33	33	33	33
2015	28	29	29	30	30	31	31	32	32	32	33	33	33	33	33	33	34	34	34	34
2016	28	29	29	30	31	31	31	32	32	32	33	33	33	33	33	34	34	34	34	34
2017	28	29	29	30	30	31	31	32	32	32	33	33	33	33	33	33	33	34	34	34
2018	28	29	29	30	30	31	31	32	32	32	33	33	33	33	33	33	34	34	34	34
2019	28	29	29	30	30	31	31	32	32	32	32	33	33	33	33	33	33	33	33	33
2020	28	29	29	30	30	31	31	32	32	32	33	33	33	33	33	33	33	34	34	34

Table B7-5: Electricity costs based on AHAM data
with 1% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	78	81	84	86	88	90	91	93	94	94	95	96	96	96	96	96	97	97	97	97
1986	78	81	84	86	88	90	91	92	93	94	95	95	96	96	96	96	96	96	96	96
1987	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1988	66	69	71	73	75	76	78	79	79	80	81	81	81	82	82	82	82	82	82	82
1989	63	66	68	70	71	73	74	75	76	76	77	77	78	78	78	78	78	78	78	78
1990	61	63	66	67	69	70	71	72	73	74	74	75	75	75	75	75	75	75	75	75
1991	57	59	61	63	64	65	66	67	68	68	69	69	69	70	70	70	70	70	70	70
1992	54	56	58	60	61	62	63	64	65	65	66	66	66	67	67	67	67	67	67	67
1993	43	45	46	48	49	50	50	51	52	52	52	53	53	53	53	53	53	53	53	53
1994	42	44	45	46	47	48	49	50	50	51	51	51	52	52	52	52	52	52	52	52
1995	41	43	44	45	46	47	48	49	49	49	50	50	50	50	50	50	51	51	51	51
1996	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1997	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1998	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
1999	40	41	43	44	45	46	46	47	47	48	48	48	49	49	49	49	49	49	49	49
2000	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
2001	33	34	35	36	37	38	38	39	39	40	40	40	40	40	40	40	40	41	41	41
2002	29	30	31	32	33	34	34	35	35	35	36	36	36	36	36	36	36	36	36	36
2003	29	30	30	31	32	32	32	33	33	34	34	34	34	34	35	35	35	35	35	35
2004	28	29	30	30	31	31	32	32	32	33	33	33	33	33	34	34	34	34	34	34
2005	28	28	29	29	30	30	31	31	32	32	32	32	33	33	33	33	33	33	33	33
2006	27	28	28	29	29	30	30	30	31	31	31	32	32	32	32	32	32	32	32	32
2007	26	27	28	28	29	29	29	30	30	30	31	31	31	31	31	31	31	31	32	32
2008	26	27	27	28	28	29	29	29	30	30	30	30	31	31	31	31	31	31	31	31
2009	26	26	27	27	28	28	29	29	29	30	30	30	30	30	31	31	31	31	31	31
2010	25	26	26	27	27	28	28	29	29	29	29	30	30	30	30	30	30	30	30	30
2011	25	26	26	27	27	28	28	28	29	29	29	29	29	30	30	30	30	30	30	30
2012	25	26	26	27	27	27	28	28	28	29	29	29	29	30	30	30	30	30	30	30
2013	25	25	26	26	27	27	28	28	28	29	29	29	29	29	29	29	30	30	30	30
2014	25	25	26	26	27	27	27	28	28	28	29	29	29	29	29	29	29	29	29	29
2015	24	25	26	26	26	27	27	28	28	28	28	29	29	29	29	29	29	29	29	29
2016	24	25	25	26	26	27	27	27	28	28	28	28	29	29	29	29	29	29	29	29
2017	24	24	25	25	26	26	27	27	27	27	28	28	28	28	28	28	28	28	29	29
2018	24	24	25	25	26	26	26	27	27	27	27	28	28	28	28	28	28	28	28	28
2019	23	24	24	25	25	26	26	26	26	27	27	27	27	27	28	28	28	28	28	28
2020	23	24	24	24	25	25	26	26	26	26	27	27	27	27	27	27	27	27	27	28

Table B7 -6: Electricity costs based on AHAM data
with 2% energy improvement projection (1985$)

MY	Refrigerator-freezer Age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1985	78	81	84	86	88	90	91	93	94	94	95	96	96	96	96	96	97	97	97	97
1986	78	81	84	86	88	90	91	92	93	94	95	95	96	96	96	96	96	96	96	96
1987	69	72	74	76	78	79	81	82	83	83	84	84	85	85	85	85	85	85	85	85
1988	66	69	71	73	75	76	78	79	79	80	81	81	81	82	82	82	82	82	82	82
1989	63	66	68	70	71	73	74	75	76	76	77	77	78	78	78	78	78	78	78	78
1990	61	63	66	67	69	70	71	72	73	74	74	75	75	75	75	75	75	75	75	75
1991	57	59	61	63	64	65	66	67	68	68	69	69	69	70	70	70	70	70	70	70
1992	54	56	58	60	61	62	63	64	65	65	66	66	66	67	67	67	67	67	67	67
1993	43	45	46	48	49	50	50	51	52	52	52	53	53	53	53	53	53	53	53	53
1994	42	44	45	46	47	48	49	50	50	51	51	51	52	52	52	52	52	52	52	52
1995	41	43	44	45	46	47	48	49	49	49	50	50	50	50	50	50	51	51	51	51
1996	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1997	41	42	44	45	46	47	48	48	49	49	50	50	50	50	50	50	50	50	50	50
1998	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
1999	40	41	43	44	45	46	46	47	47	48	48	48	49	49	49	49	49	49	49	49
2000	40	42	43	44	45	46	47	47	48	48	49	49	49	49	49	49	49	49	49	49
2001	33	34	35	36	37	38	38	39	39	40	40	40	40	40	40	40	40	41	41	41
2002	29	30	31	32	33	34	34	35	35	35	36	36	36	36	36	36	36	36	36	36
2003	29	29	30	31	31	32	32	33	33	33	33	34	34	34	34	34	34	34	34	34
2004	28	28	29	30	30	30	31	31	32	32	32	32	33	33	33	33	33	33	33	33
2005	27	27	28	29	29	29	30	30	31	31	31	31	32	32	32	32	32	32	32	32
2006	26	26	27	28	28	28	29	29	30	30	30	30	30	31	31	31	31	31	31	31
2007	25	26	26	27	27	27	28	28	28	29	29	29	29	30	30	30	30	30	30	30
2008	24	25	25	26	26	27	27	27	28	28	28	28	29	29	29	29	29	29	29	29
2009	24	24	25	25	26	26	27	27	27	27	28	28	28	28	28	28	28	28	28	28
2010	23	24	24	25	25	25	26	26	26	27	27	27	27	27	27	28	28	28	28	28
2011	23	23	24	24	24	25	25	25	26	26	26	26	27	27	27	27	27	27	27	27
2012	22	23	23	24	24	24	25	25	25	26	26	26	26	26	26	26	26	27	27	27
2013	22	22	23	23	24	24	24	25	25	25	25	25	26	26	26	26	26	26	26	26
2014	21	22	22	23	23	23	24	24	24	24	25	25	25	25	25	25	25	25	25	25
2015	21	21	22	22	23	23	23	23	24	24	24	24	24	25	25	25	25	25	25	25
2016	20	21	21	22	22	22	23	23	23	23	24	24	24	24	24	24	24	24	24	24
2017	20	20	21	21	21	22	22	22	22	23	23	23	23	23	23	23	23	23	23	23
2018	19	20	20	20	21	21	21	22	22	22	22	22	23	23	23	23	23	23	23	23
2019	18	19	19	20	20	20	21	21	21	21	21	22	22	22	22	22	22	22	22	22
2020	18	18	19	19	19	20	20	20	20	21	21	21	21	21	21	21	21	21	21	21