United States Environmental Protection Agency
Office of Air and Radiation
EPA 430-R-97-032
October 1997

EPA

The Sino - US CFC-Free Super-Efficient Refrigerator Project Progress Report: Prototype Design & Testing

Summer 1997

The Sino-US CFC-Free Super-Efficient Refrigerator Project
Progress Report: Prototype Development and Testing

by

H. Alan Fine
Fine Consulting, Incorporated
Lexington, KY

Leng Xiaozhuang
ICF Incorporated
Beijing, China

Reinhard Radermacher and Imam Haider
University of Maryland
College Park, MD

Steven M. Nadel
American Council for an Energy Efficient Economy
Washington, DC

David G. Fridley
Lawrence Berkeley National Laboratory
Berkeley, CA

Ray Phillips
ICF Incorporated
Washington, DC

Jeanne Briskin
US Environmental Protection Agency
Washington, DC

ACKNOWLEDGMENT

The authors wish to thank the many colleagues of Mr. Leng Xiaozhuang at the China Household Electronic Appliance Research Institute (CHEARI) and Professor Reinhard Radermacher at the Center for Environmental Energy Engineering of the University of Maryland who designed and built the laboratory models and performed most of the testing and experimentation described in this report. Madame Yang Mianmian and Mr. Shi Jiafan of the Haier Group are also gratefully acknowledged for their important role in the production and testing of the prototype refrigerators. Mr. Edward Wuesthoff of Americold and his co-workers who developed and built the numerous compressor prototypes are also gratefully acknowledged. The authors also thank ICI and Phillips Petroleum Co., who provided refrigerants and foaming agent chemicals used in the development and production of the prototype.

Mr. Cheng Weixue of the China National Environmental Protection Agency, Mr. Zeng Yaozhang of the China National Council of Light Industry, and Mr. Yang Jiahua of the China Household Electric Appliance Research Institute greatly helped in the development and direction of this project in China, and deserve our sincere appreciation. Madame Zhao Jiqing, previously of the National Council for Light Industry, and John Hoffman, previously of US-EPA's Atmospheric Pollution Prevention Division, were instrumental in the initial development and success of the project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
ACEEE	American Council for an Energy Efficient Economy
BCD	Chinese designation for refrigerator-freezers (abbreviation of Chinese “bing cang dong”), generally followed by the refrigerator-freezer volumetric size in liters (e.g., BCD-220)
CFC	chlorofluorocarbon
CHEARI	China Household Electric Appliance Research Institute (formerly BHEARI, Beijing Household Electric Appliance Research Institute)
COP	coefficient of performance
DME	di-methyl ether
EC	energy consumption, generally expressed in kilowatt hours per day (kWh/24h)
EPA	US Environmental Protection Agency
ERA	EPA Refrigerator Analysis computer program
FF	fresh food compartment
FZ	freezer compartment
GEF	Global Environment Facility
GWP	global warming potential
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HT	high temperature
HTHX	high temperature suction-line heat exchanger
ISO	International Standards Organization
kWh	kilowatt-hours
LBNL	Lawrence Berkeley National Laboratory
L-M	Lorenz-Meutzner cycle
LT	low temperature
LTHX	low temperature suction-line heat exchanger
MLI	Ministry of Light Industry (now NCLI)
ML-M	modified Lorenz-Meutzner cycle
nC5	normal pentane
NCLI	China National Council of Light Industry (formerly MLI)
NEPA	China National Environmental Protection Agency
O&M	Ogilvy & Mather
OD	outer diameter
ODP	ozone depletion potential
R(xy)	refrigerant (xy) (ASHRAE 1992)
RMB	renminbi (Chinese currency)
tWh	terawatt-hours

U. Md.	University of Maryland
UNDP	United Nations Development Programme

SUMMARY

This report describes the Sino-US project to promote the transformation of the Chinese domestic refrigerator industry to the production of chlorofluorocarbon (CFC)-free, super-efficient models. Technologies examined in this effort include non-CFC refrigerants and foam-blowing agents, alternate refrigeration cycles, more efficient compressors, optimization of condenser and evaporator designs, increased insulation thickness, and improvements to door gaskets and controls.

Work completed through December 1995 at the China Household Electric Appliance Research Institute (CHEARI), the Haier Group, and the University of Maryland (U. Of Md.) includes the building and testing of Chinese refrigerators that contain a wide variety of energy efficiency improvements and no CFCs. Chinese consumer opinion research on the marketing of ozone-friendly, energy-efficient refrigerators has also been undertaken. Field testing was undertaken for one year in three Chinese cities to test the performance of units under actual operating conditions.

The key findings of these activities are:

- Laboratory tests on a 220-liter, manual-defrost, bottom-freezer refrigerator popular in the Chinese market (the BCD-220 produced by the Haier Group, one of China's leading manufacturers) have demonstrated that conversion from (CFCs) to alternative refrigerants and foam-blowing agents can be achieved along with substantial energy savings. Table 1 shows the effect of technology improvements on energy savings. The savings indicated in Table 1 are indicative of the highest achieved in laboratory testing of all combinations of efficiency measures. The final prototype model, however, did not include the Lorenz cycle modification.

Table 1. Summary of Laboratory Test Results

Energy Savings	Technology Improvement Employed
~20%	Lorenz cycle with non-CFC refrigerant blend
~20%	Increased foam insulation (about 2 cm) to sides, back, bottom, and doors of cabinet
~40%	Increased foam insulation and improved compressor
~50%	Increased insulation, improved compressor, and Lorenz cycle with non-CFC refrigerant blend

- Laboratory test results for an improved CFC-free prototype, employing many of the tested efficiency measures, demonstrated about 40 percent energy savings.

- Chinese consumer opinion research has shown:
  - Quality is the most important factor when a household refrigerator purchase is considered; and
  - Chinese consumers say they are willing to pay 20 percent more for a high quality product which consumes 40 percent less energy than currently available models.

- Field testing has demonstrated that:
  - The new models showed significant energy savings in the field, though savings were lower than in laboratory tests;
  - Storage capacity and performance in maintaining food at the desired temperature are key factors in household acceptance of the new model; and
  - Noise level was found to be a concern with the new model.

Next steps for work to be completed under the project include modification of the prototype in response to consumer opinion research and field test results, and certification in accordance with internationally accepted standards. This work will be followed by application of energy efficient CFC-free design techniques to other Haier products, such as Haier's new BCD-268 model.

For other refrigerator manufacturers, the Sino-US Refrigerator Project demonstrates that it is technologically feasible to redesign household refrigerators commonly in use in China and other countries so as to simultaneously replace CFCs and significantly improve the refrigerator's energy efficiency. This substantial increase in energy efficiency can be obtained by adopting technically proven measures used individually by manufacturers in the past, but not heretofore combined in a single nonozone-depleting energy-efficient product design. The prototype developed through this project demonstrates that combination of these measures can result in significant energy savings. These savings provide substantial economic and environmental benefits, as well as cost savings to consumers and a potential competitive benefit to manufacturers that adopt energy-efficient CFC-free technology.

I. INTRODUCTION

A. Project Background

The Sino-US CFC-Free, Super-Efficient Refrigerator Project was initiated in 1989 as part of a formal agreement between the China National Environmental Protection Agency (NEPA) and the US Environmental Protection Agency (EPA). The project was undertaken to accelerate phase-out of the use of CFCs and to reduce growth in energy demand in China's residential sector. It also offered a unique opportunity to improve the energy efficiency of refrigerators produced in China while simultaneously redesigning products and production facilities for the phase-out of CFCs.

Impetus for the Project Due to the CFC Phase-out

As a potential signatory to the Montreal Protocol, China was preparing to embark upon a program to phase out the use of CFCs. China subsequently ratified the Vienna Convention for Ozone Layer Protection in September 1989 and signed the Montreal Protocol in June 1991. This committed China to phase out CFC production by the year 2010.

As shown in Table 2 below, domestic refrigerator production and associated CFC consumption have grown rapidly in China. Given expected continued rapid growth, China was concerned about the potential costs of replacing CFCs. Improved energy efficiency offered a way for the country to partially offset the additional investment costs associated with transition to substitute refrigerants and foam-blowing agents. Thus, this project has assisted China in developing the technical information and expertise to facilitate the phase-out of CFCs.

Impetus for Project Due to Growing Demand for Scarce Electricity in China

As indicated in Table 3, residential electricity use in China has grown at an average annual rate of 16 percent and the residential share of total electricity consumption has jumped from 7 to 12 percent. The rapid increase in the ownership of domestic appliances is a major factor driving the surge in residential electricity consumption. Table 4 shows that particularly in urban areas, per capita ownership of many appliances is nearing developed country levels. Energy efficiency improvements resulting from the efforts of this project could help offset this increasing demand for electricity. In addition, a reduced rate of growth in electricity consumption in the residential sector offers an important cost-effective strategy to control the growth of emissions of carbon dioxide and other pollutants (such as SO_2, NOx, particulates, and heavy metals) from power plants. Demand reduction will in turn reduce the need to build additional coal-fired power plants, and will make available capital that could be more profitably used in other ways.

Table 2. Refrigerator Production and CFC Consumption

Year	Production (millions)	CFC-12 Use (tons)	CFC-11 Use (tons)
1985	1.5	NA	NA
1986	2.3	NA	NA
1987	4.0	NA	NA
1988	7.6	NA	NA
1989	6.7	NA	NA
1990	4.6	NA	NA
1991	4.7	1,145	5,000
1992	4.9	1,308	5,650
1993	6.0	1,722	6,740
1994	7.6	NA	NA
1995	9.3	1,962*	8,155*
2000	12.1*	2,629*	10,915*

*estimates of refrigerator production growth and CFC use assuming unconstrained CFC use.

Source: Chinese government statistics from State Statistical Bureau, *China Daily*, and China Leading Group for Ozone Layer Protection.

NA: not available

Table 3. Residential Electricity Consumption

Year	Residential Electricity Consumption tWh	Annual Growth %	Total Electricity Consumption tWh	Annual Growth %	Residential Share of Total %
1985	22		323		7
1986	25	11	353	10	7
1987	29	16	391	11	7
1988	34	20	432	10	8
1989	40	15	461	7	9
1990	48	22	491	7	10
1991	54	13	532	8	10
1992	64	18	590	11	11
1993	73	14	637	8	12
1994	87	19	725	14	12
Annual Average		16		9	

Source: State Statistical Bureau.

Table 4. Growth in Ownership of Domestic Appliances

Appliance	Ownership per 100 Urban Households			Ownership per 100 Beijing Households: 1995
	1985	1993	1995	
Refrigerators	7	57	66	104
Color Televisions	17	79	90	114
Washing Machines	48	86	89	100
Air Conditioners	0	2	8	12
Fans	74	151	167	138

Source: China State Statistical Bureau.

B. Project Goals

The overall goal of the Sino-US project is the transformation of China's domestic refrigerator industry to the production of CFC-free, energy-efficient products. Interim goals have included:

- design of a prototype Chinese CFC-free, super-efficient refrigerator
- pilot production and field testing of prototype units
- conversion of a production line in a single factory for demonstration purposes to manufacture the new product
- stimulation of consumer acceptance and demand for the new product through a labeling and marketing program to highlight the advantages of CFC-free, energy-efficient refrigerators
- demonstration of the commercial viability of the product to other manufacturers and technical assistance to the rest of the refrigerator industry to transfer design and technology
- transformation of the market to allow mass production of the new product by a majority of major refrigerator manufacturers

- development of local suppliers of materials and components for energy-efficient CFC-free refrigerators so as to reduce costs and increase the technology's sustainability.

C. Project Description

The project has been designed in stages to accomplish the overall and interim goals described above.

Stage 1 involved development of a CFC-free, super-efficient refrigerator design that has been thoroughly tested for reliability, performance, and safety in China's three major climate zones. Components of this stage included:

- development and testing of a large number of test models containing a wide variety of CFC-free refrigerants and foam-blowing agents, advanced refrigeration cycles, and other energy saving technologies

- evaluation of test results and the design of an initial prototype model incorporating the combination of improvements that resulted in the most reliable operation and the lowest energy consumption for the CFC-free, super-efficient unit

- construction and testing of initial prototypes

- design of the final prototype

- temporary modification of a refrigerator line to manufacture approximately 200 prototypes

- field testing, including life cycle testing, to ensure reliable performance in China's three major climate zones (represented by Beijing, Shanghai, and Guangzhou) with respect to temperature and humidity

- safety and performance testing by industrial experts

- feasibility studies to identify the steps and costs of a factory changeover for production of the new CFC-free, super-efficient refrigerator

- initial consumer opinion research to:
  - develop an understanding of consumer demand, purchasing criteria, and priorities for refrigerator purchasers
  - determine consumer perceptions, attitudes, and priorities towards identification and promotion of CFC-free, high-efficiency refrigerators
  - understand consumer perceptions and attitudes regarding CFC elimination and energy efficiency.

Stage 2 of the project involved the conversion of a demonstration refrigerator production line to manufacture reliable, CFC-free, energy-efficient refrigerators. Stage 2 has included:

- determination of technical requirements and costs for conversion of the selected demonstration production line at the Haier factory in Qingdao, China

- obtaining approval for funding under the Montreal Protocol Fund to convert the demonstration line from the use of CFC-11 and CFC-12 to cyclopentane and isobutane for the foam-blowing agent and refrigerant, respectively:
  - bilateral funding from Germany for conversion to cyclopentane foam-blowing technology
  - bilateral funding from the United States for conversion to isobutane refrigerant

- conversion of the line from the use of CFC-11 blown foam to cyclopentane-blown foam insulation in late 1995

- conversion of the line from the use of CFC-12 refrigerant to isobutane in mid 1996

- incorporation of energy-efficient design changes into other standard production models (Yang 1995).

Stage 3 of the project builds on the successful completion of the first two stages and focuses on consumer education (through labeling and marketing programs), technical outreach (through seminars and other forms of technical assistance), and development of an incentive program to promote production of CFC-free, energy-efficient models by other manufacturers. A program is also being developed to transfer energy-efficient compressor designs to China for local production. This stage of the project has received initial funding from the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP). Additional GEF and other multilateral funding is currently being sought to allow for full implementation of this work.

D. Project Participants

The project's initial stages have been carried out through a bilateral agreement between the US and China under the joint leadership of EPA and NEPA. The final stage of the project, transfer of CFC-free energy efficient technology to other manufacturers, is to be carried out multilaterally with funding from the GEF through UNDP. Other participants and their primary activities have included:

- **National Council of Light Industry** (NCLI) — Chinese national government agency responsible for oversight of the refrigerator industry
- **China Household Electric Appliance Research Institute** (CHEARI) — refrigerator design and testing
- **Haier Group** — prototype production and factory line conversion at refrigerator factory in Qingdao, China
- **University of Maryland** (U. Md.) — refrigerator design and testing
- **American Council for an Energy Efficient Economy** (ACEEE) — Chinese consumer market research, field test design, and participation in development of labeling criteria
- **Americold** — design, testing, and batch production of high-efficiency hydrocarbon compressors
- **Ogilvy & Mather** (O&M) — consumer market research and development of consumer education program
- **Other participating Chinese refrigerator factories** — including Hangtian, Shangling, Snowflake, Wanbao, and Zhongyi contributed during the initial research and development stage
- **Other participating Chinese research institutions** — including Qinghua University and Xian Jiaotong University contributed during the initial research and development stage.

E. Organization of the Report

The remainder of this report is organized as follows:

- Chapter II presents theoretical analyses undertaken with the EPA Refrigeration Analysis (ERA) model to evaluate the potential improvements in energy efficiency for various CFC-free refrigerator design options that could be manufactured and used in China.

- Chapter III describes the laboratory test program whereby the most promising design options identified using the ERA model were tested and further developed in a laboratory setting.

- Chapter IV describes field testing undertaken to evaluate and document the reduction in energy use of CFC-free, energy-efficient prototypes under actual operating conditions in Chinese households.

- Chapter V presents consumer preference research undertaken to evaluate Chinese consumer views of CFC-free, energy-efficient products and to design a marketing program to promote them.

- Chapter VI details the conclusions of the report.

- Chapter VII presents references for the report.

Appendices A through D provide additional detailed information regarding laboratory test results, field test data, consumer opinion research results, and field testing data tables.

II. ERA CALCULATIONS

The EPA Refrigerator Analysis (ERA) model is a simulation tool for estimating household refrigerator energy consumption (USEPA 1993a, USEPA 1993b). ERA estimates the energy use of different refrigerator design options by modeling the effect of: thermodynamic properties of a wide variety of alternative refrigerants; insulation values of potential foaming agent substitutes; alternative refrigerant cycles; condenser and evaporator size; heat transfer properties of alternative cabinet structures, sizes, and materials; and, different levels of compressor efficiency. It treats the refrigerator cabinet, cycle, and controls as a system rather than as isolated components. The model can be used to simulate energy use comparable to both closed-door and open-door tests (discussed further below).

Model runs are begun by inputting design data for the baseline refrigerator (here, the Haier BCD-220). Individual design parameters are then altered and evaluated in order to determine the possible energy savings associated with individual energy-efficiency measures, as illustrated in Figures 1-3. These figures show the effect on energy use of a series of measures for each of three refrigeration cycles: the original cycle, conventional cycle, and Lorenz cycle.

Even though ERA has been extensively tested and compared to test results for actual refrigerator performance (USEPA 1994), the results of ERA calculations are only used to indicate trends and promising areas of future work.

A. Closed-Door Performance

Following development of an ERA model for the baseline BCD-220 refrigerator, a series of calculations were performed to show the cumulative potential for energy savings of a wide variety of technical options. The results of these calculations predict potential energy conservation of over 50 percent, as shown in Table 5. The results indicate that the energy savings associated with implementing the modifications for the three cycles are as follows:

- 15-20 percent energy savings result from each of the following refrigerator modifications:
  - switching from the original 1.1-coefficient of performance (COP) to a 1.3-COP compressor
  - switching from the original to a Lorenz cycle
  - additional foam insulation.

- 10-15 percent energy savings result from the following refrigerator modification:
  - switching from 1.3 to 1.45-COP compressor.

- 5-10 percent energy savings result from each of the following refrigerator modifications:

- improved gasket region design
- use of isobutane refrigerant
- switching from vapor to liquid-line anti-sweat heaters
- switching from the original to the conventional cycle.

- 0-5 percent energy savings result from each of the following refrigerator modifications:
  - use of R152a refrigerant
  - system optimization (re-size evaporators and condenser).

- 5-10 percent *increase* in energy consumption results from switching from CFC-11 to cyclopentane blown foam.

Table 5. ERA Energy Savings Projections for Various Cycles and Modifications (Closed Door Performance)

	Energy Savings*		
Modification	**Original Cycle**	**Conventional Cycle**	**Lorenz Cycle**
Liquid-line anti-sweat	6%	6%	6%
THICKER I**	15%	15%	15%
1.3-COP compressor	19%	19%	19%
Modify gasket	9%	9%	9%
Alternative refrigerant or refrigeration system	R12 to R134a 0%	R12 conventional cycle 5%	HCFC/HFC blend Lorenz cycle 16%
Alternative refrigerant	R134a to R600a 8%	R12 to R152a 3%	Hydrocarbon blend -1%
1.45 -COP compressor	11%	11%	11%
CFC-11 to cyclopentane foam	-8%	-8%	-8%
THICKER III**	4%	5%	5%
Total Savings	53%	52%	56%

*calculated as marginal savings relative to sum of previous measures. Negative savings indicate increased energy use.

** See chapter 3, section A under *Cabinet Description* for definition and technical specifications.

Figure 1. ERA Analysis of Haier BCD-220 with Original Cycle

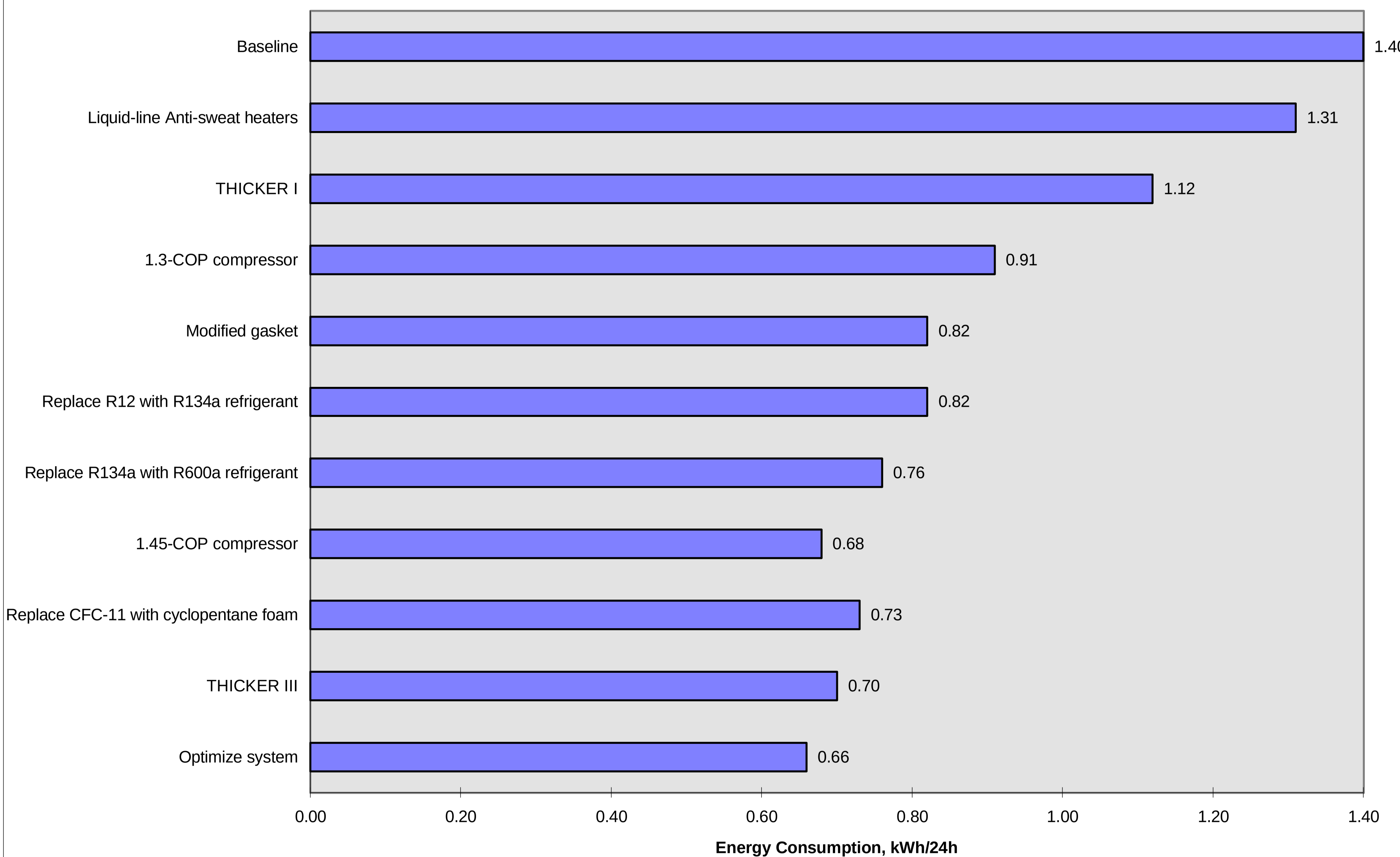


Figure 2. ERA Analysis of Haier BCD-220 with Conventional Cycle

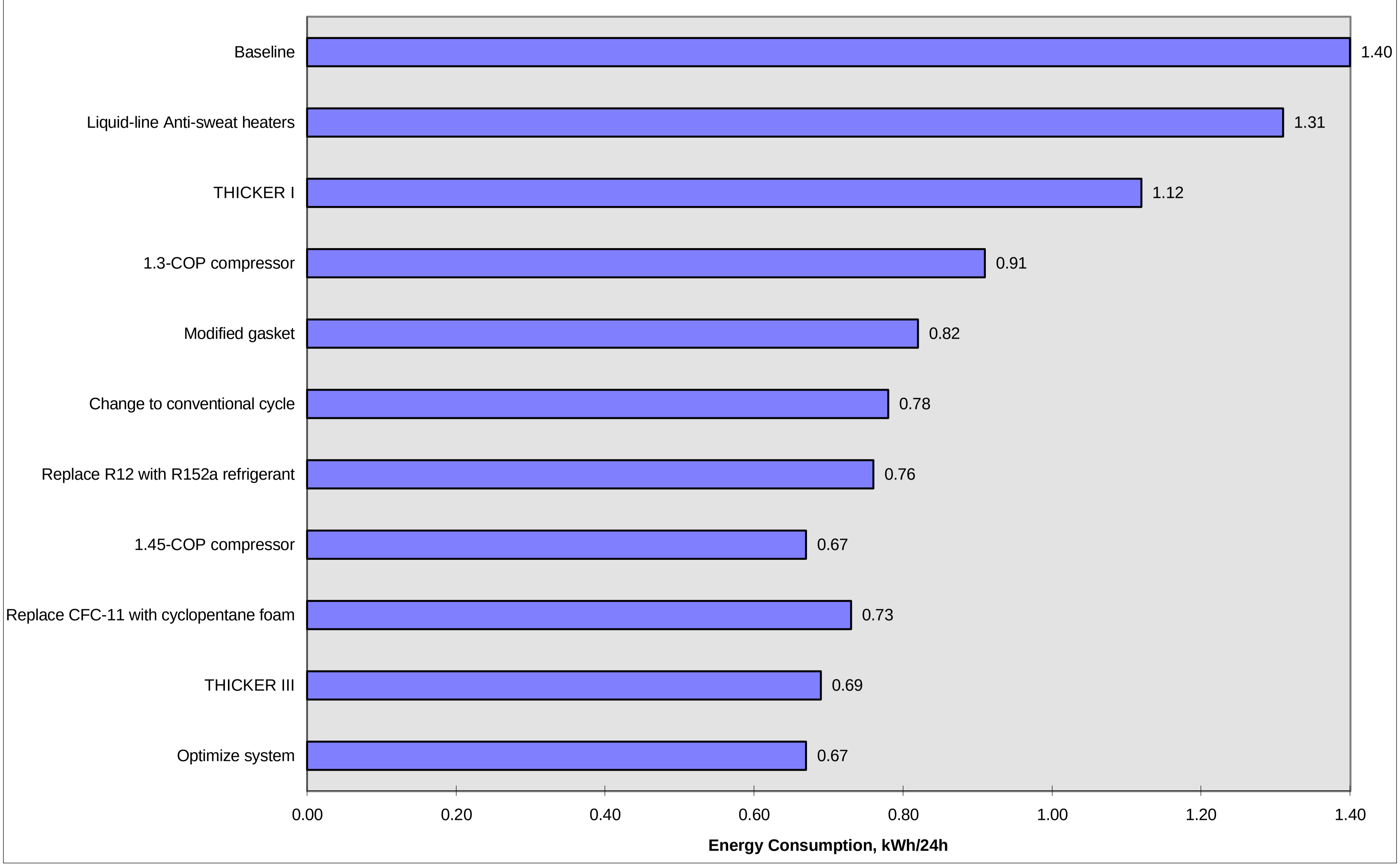
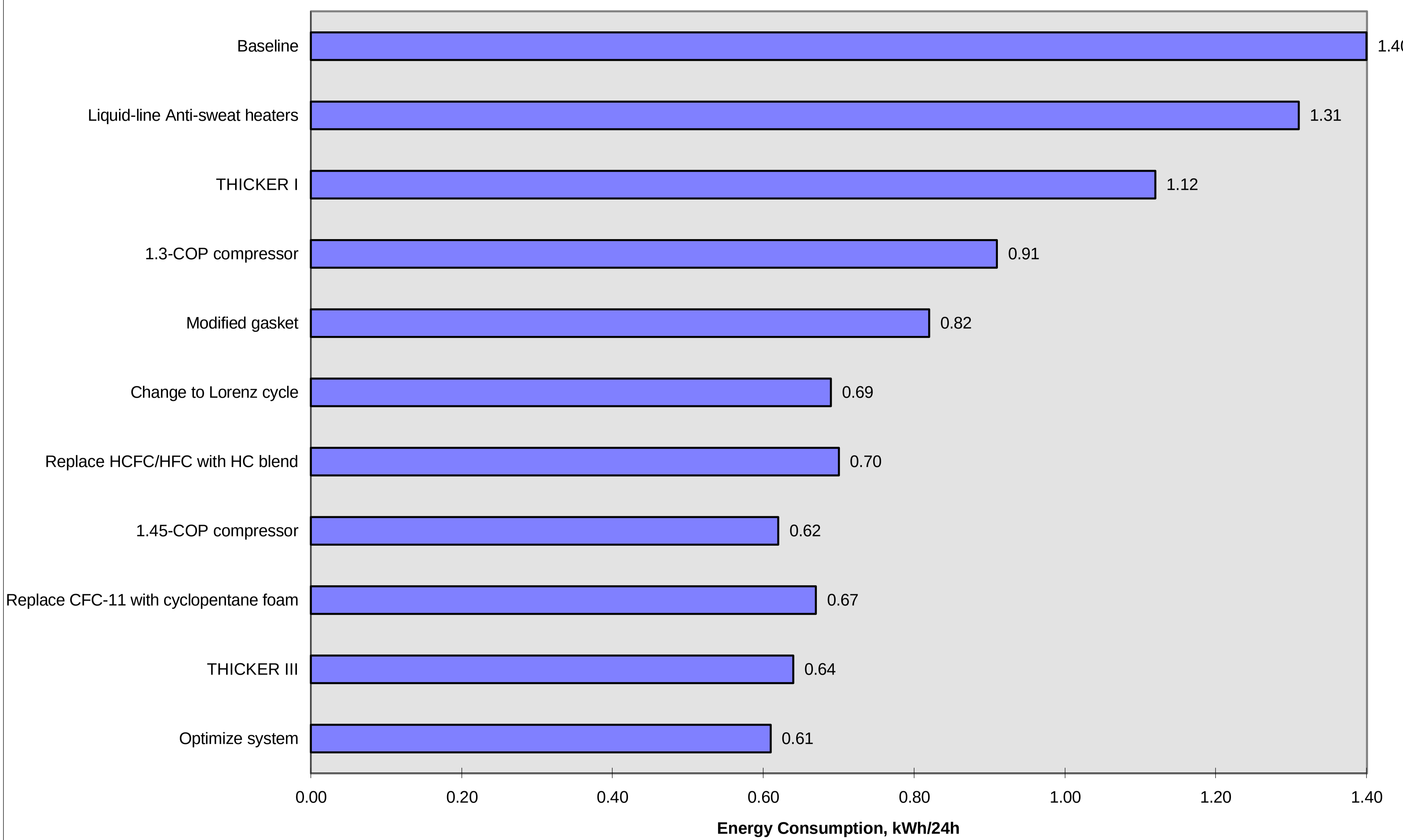


Figure 3. ERA Analysis of Haier BCD-220 with Lorenz Cycle



The ERA model was also used to evaluate the impact of energy use associated with changing the temperature at which the fresh food and freezer compartment are maintained. The results of these analyses as presented in Table 6 show that, with an ambient temperature of 32°C, a 1°C increase in the fresh food compartment (FF) temperature results in an approximately 2.3 percent decrease in energy consumption, while a 1°C increase in freezer compartment (FZ) temperature produces an approximately 1.3 percent decrease in energy consumption in the BCD 220 baseline refrigerator. Table 6 also shows similar results for a CFC-free, energy-efficient prototype. Measurements presented in Appendix A for the baseline unit at 25°C show that the effects may be even larger than those predicted by ERA.

Table 6. Energy Usage Changes with FF and FZ Temperature Changes

Ambient Temperature	% Change in Energy Use per Degree C Temperature Increase	
	BCD-220	Prototype
32°C	FF: -2.3 FZ: -1.3	FF: -1.1 FZ: -1.1
25°C	FF: -1.9 FZ: -2.0	FF: -3.0 FZ: -1.4

B. Open-Door Performance

The ERA model was also used to evaluate the impact of opening the refrigerator door throughout the day on energy use by the baseline model and CFC-free, energy-efficient prototype. The results of these simulations are presented in Table 7. Calculations for up to five fresh food door openings of 15 second duration and up to 2.5 freezer openings of 20 second duration indicate:

- daily energy consumption of the baseline unit will increase over 50 percent with frequent door openings compared to a unit whose door remains closed all day

- energy consumption of a CFC-free, energy-efficient prototype will increase 80 percent with frequent door openings, but will still maintain 40 percent energy savings compared to the baseline unit

- energy savings of the prototype relative to the baseline unit will decrease as the number of door openings increases.

ERA calculates the daily energy consumption assuming quasi-steady cabinet heat flow and cycle-averaged operating efficiencies. The underlying assumption is that the effects of cabinet load dynamics and the uncertainties associated with corrections to describe refrigeration cycling behavior are small relative to the difference between alternative cabinet and cycle designs. Calculations with door openings are again only to be used to identify trends.

As Table 7 shows, door openings substantially increase energy consumption in both baseline and CFC-free prototype units. The absolute energy savings of the prototype unit over the baseline unit also increased from 0.7 kWh/24h without openings to 0.9 kWh/24h with frequent openings. Door openings increase the total load and compressor run time, but the proportion of the total load due to conduction through the cabinet decreases and hence, relative savings decreased from approximately 49 percent to 41 percent.

Table 7. ERA Calculations with Door Openings

Door Openings / Hour		Baseline Energy Usage		Prototype		
Fresh Food[1]	Freezer[2]			Energy Usage		Rel. Energy Savings[4]
		kWh/24h	%[3]	kWh/24h	%	%
0	0	1.40	100	0.71	100	49
1	0.5	1.55	111	0.82	115	47
1	1	1.61	115	0.87	123	46
3	1.5	1.86	133	1.06	149	43
3	3	2.04	146	1.18	166	42
5	2.5	2.17	155	1.28	180	41

[1] 15 seconds per opening
[2] 20 seconds per opening
[3] percentage of closed-door energy usage
[4] percentage of baseline energy usage with the same number of openings

III. LABORATORY TEST PROGRAM

A. Method

To develop prototype designs with CFC substitutes and substantially improved energy efficiency, CFC-free test models were built and tested with a wide variety of technologies. This program involved:

- exchange of information between Chinese and US participants to facilitate technology transfer activities

- identification of key personnel and organizations

- selection of key refrigerator and compressor factories

- assessment of equipment, testing capabilities (including refrigerator test cells and compressor testing equipment), and ability to revamp factories

- identification of promising non-CFC refrigerants and foam-blowing agents

- identification of promising energy-efficient technologies

- laboratory and factory studies of alternative refrigerants to determine performance, cost of changeover, safety, materials availability, materials compatibility, and compressor performance

- determination of compressor size, type, and compatible lubricating oil for compressors that would run reliably with non-CFC refrigerants.
    - refrigerants considered for standard refrigeration cycles included:
        - HFC-134a and HFC-152a
        - HCFC-22/HFC-152a blends
        - isobutane (R600a)
        - hydrocarbon (HC) blends.
    - refrigerants considered for Lorenz cycles included:
        - HCFC/HFC blends
        - HC blends.

- consideration of additional energy savings necessary, if any, to compensate for higher global warming potential (GWP) alternative refrigerants such as HFC-134a (Table 8)

Table 8. Ozone Depleting Potential and Global Warming Potential of Select Refrigerants and Foam-blowing Agents

Chemical	ODP[1]	GWP[2]
CFC-11	1.0	4,000
CFC-12	0.82	8,500
HCFC-22	0.04	1,700
HCFC-123	0.014	93
HCFC-124	0.03	480
HCFC-141b	0.10	630
HCFC-142b	0.05	2,000
HFC-32	0	580
HFC-134a	0	1,300
HFC-152a	0	140
Isobutane	0	3[3]
Cyclopentane	0	11[3]

[1]Ozone Depletion Potential (CFC-11 = 1.0), model-derived with 2-D model and normalized to recommended atmospheric lifetimes (WMO 1994). The Montreal Protocol also uses an ODP of 1 for CFC-12.
[2]Global Warming Potential (CO_2 = 1.0), direct effect with 100 year time horizon (IPCC 1995).
[3] James Sand, S. Fischer, V. Baxter, "Energy and Global Warming Impacts of Next Generation Refrigeration and Air Conditioning Technologies," International Conference on Ozone Protection Technologies: Conference Proceedings, 21-23 October 1996, Washington, DC, p. 454. The figure cited for isobutane is that listed for normal butane.

- determination of the amount, location, and type of non-CFC foam insulation required to optimize refrigerator performance. Insulation systems considered in the program included:

  - micro-cell HCFC-141b blown foam
  - cyclopentane blown foam, a zero-ozone depletion potential (ODP) alternative.

- determination of the compatibility of non-CFC foam with other materials in the unit

- determination of the durability and structural suitability of the foam through testing in the laboratory and at the factory

- redesign of condenser, evaporators, and anti-sweat devices

- determination of other changes necessary to optimize the performance of the CFC-free design

- construction of initial prototype cabinets with the CFC-free foam

- construction, operation, and testing of initial prototype refrigerators based on standard and Lorenz refrigeration cycles

- identification of criteria for choosing the preferred combination of refrigerant, cycle, component, and cabinet

- selection of the final prototype design(s)

- construction and initial testing of the redesigned unit prior to final prototype production.

Many models incorporating different refrigeration cycles, cabinet styles, and components were built and tested.

1. Cycle Descriptions

The baseline model contained a dual evaporator, single-compressor vapor compression cycle. A valve controlled temperature in both compartments by directing the flow of the refrigerant through both evaporators or through the freezer evaporator only (Figure 4). With this model as the starting point, the testing program included the following new cycle designs:

- **Conventional cycle —** the original cycle without the valve and freezer-evaporator-only option, the anti-sweat heaters moved from before the condenser (vapor-line) to after the condenser (liquid-line), and a wire-tube condenser in place of the shutter condenser employed in the original model (Figure 5)

- **Lorenz cycle —** the conventional cycle with a heat-exchanger inserted between the freezer and fresh food evaporators, the anti-sweat heater moved from before the condenser (vapor-line) to after the condenser (liquid-line), and a wire-tube condenser in place of the shutter condenser employed in the original model (Figure 6)

- **Lorenz-Meutzner (L-M) cycles —** the conventional cycle using refrigerant blends with a significant temperature glide, both without (Figure 7) and with (Figure 8) a control valve (Radermacher et al. 1994, Radermacher et al. 1995a and Radermacher et al. 1995b)

- **Modified Lorenz-Meutzner (ML-M) cycles —** the L-M cycle with an intercooler inserted between the freezer and fresh food evaporators, both without (Figure 9) and with (Figure 10) a control valve (Radermacher et al. 1994, Radermacher et al. 1995a, and Radermacher et al. 1995b)

- **Haier cycle —** the conventional system with a valve allowing refrigerant to bypass the fresh food evaporator for added temperature control (Figure 11).

A variety of compressors, evaporators, condensers, and heat exchangers were studied in combination with the different cycles. Descriptions of these components are given in Tables 9, 10, and 11.

Figure 4. Original Cycle

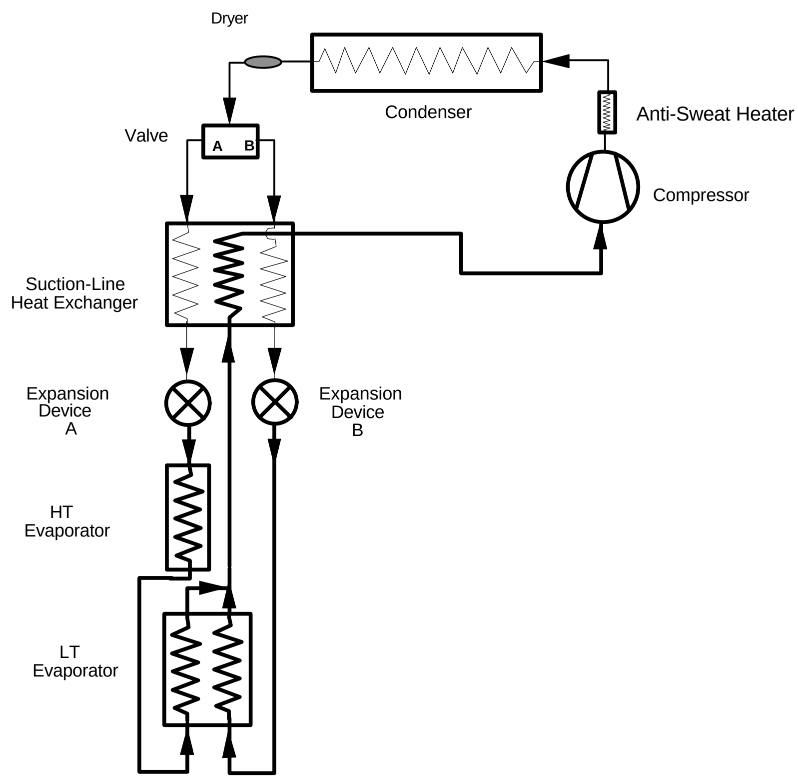


Figure 5. Conventional Cycle

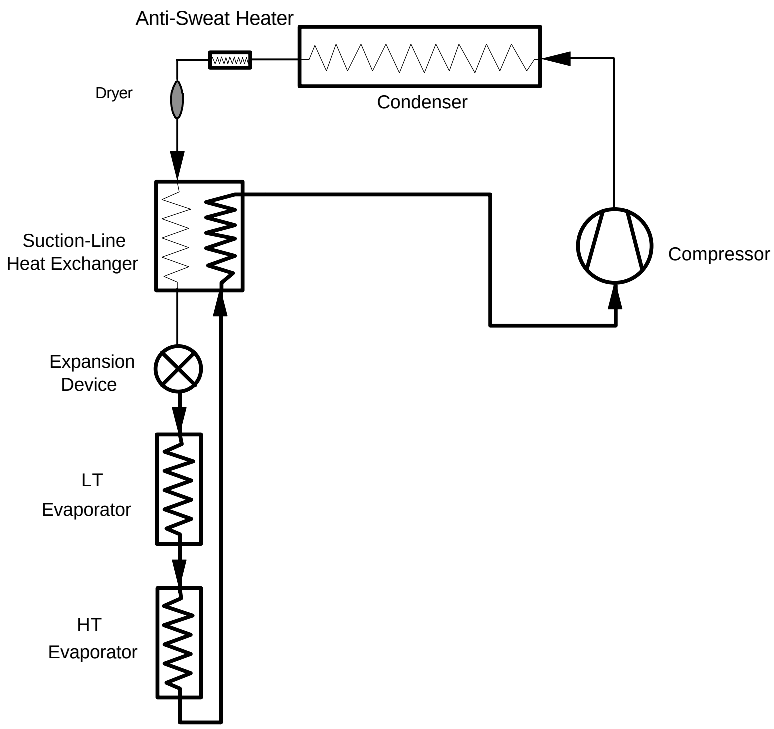


Figure 6. Lorenz Cycle

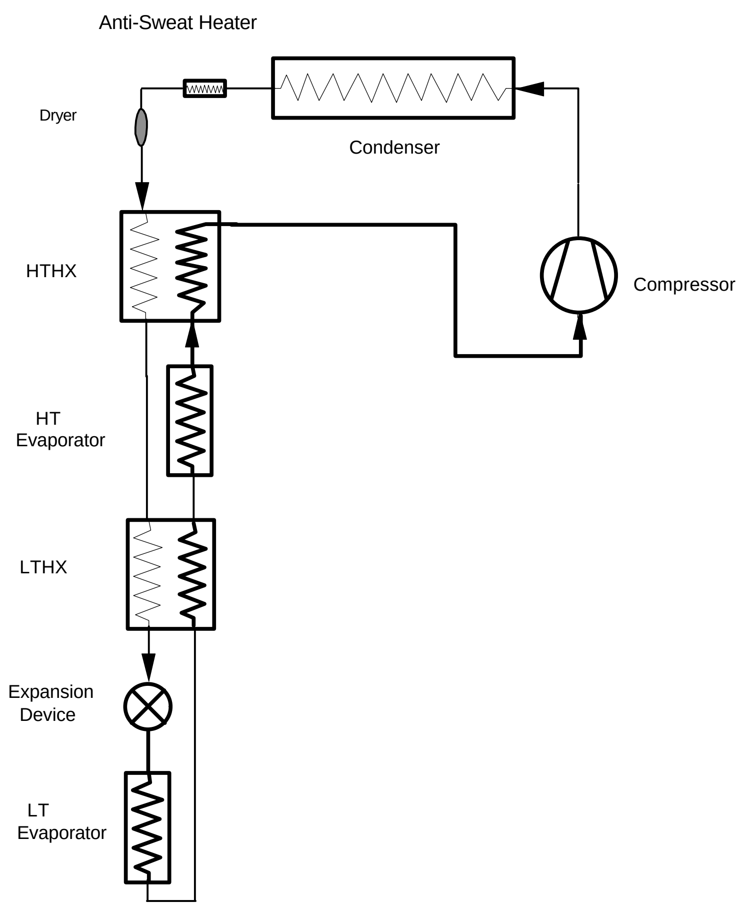


Figure 7. Lorenz-Meutzner Cycle

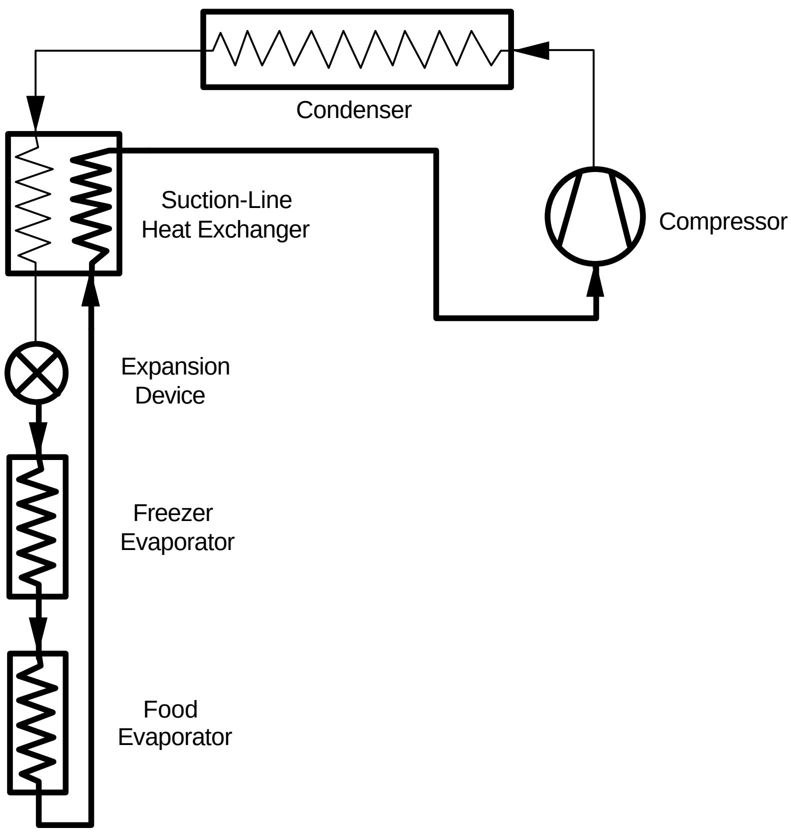


Figure 8. Lorenz-Meutzner Cycle with Bistable Solenoid Valve

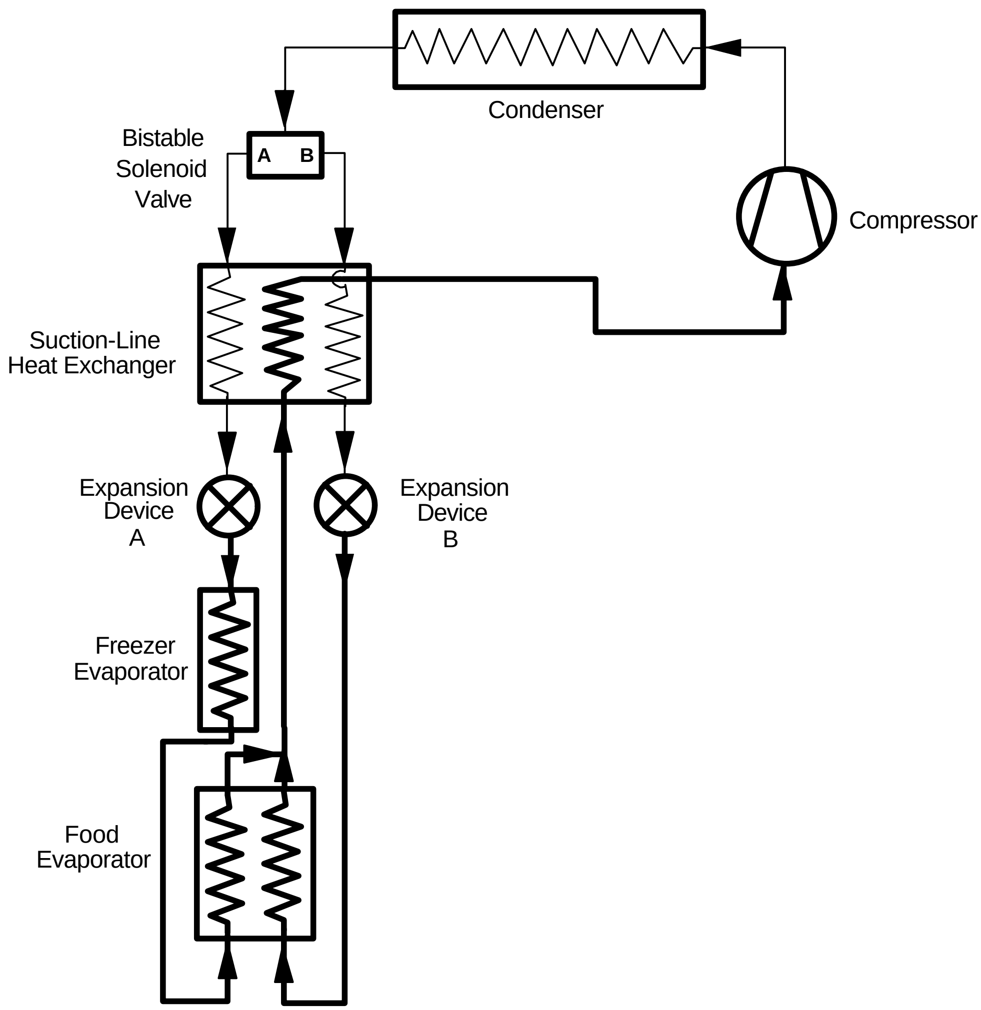


Figure 9. Modified Lorenz-Meutzner Cycle

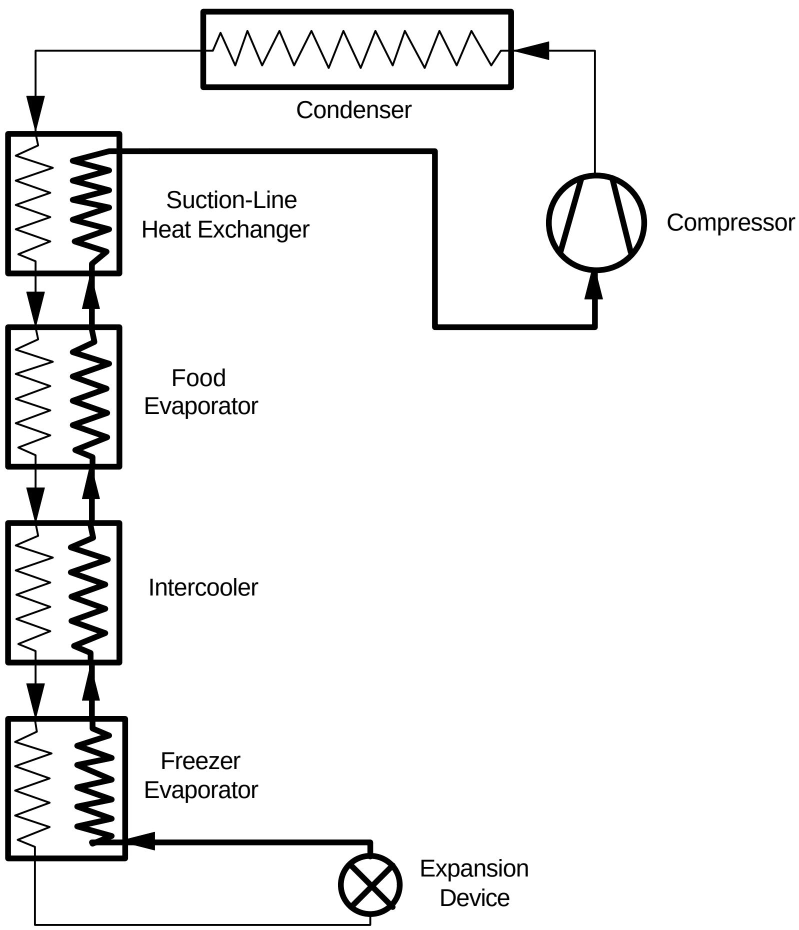


Figure 10. Modified Lorenz-Meutzner Cycle with Bistable Solenoid Valve

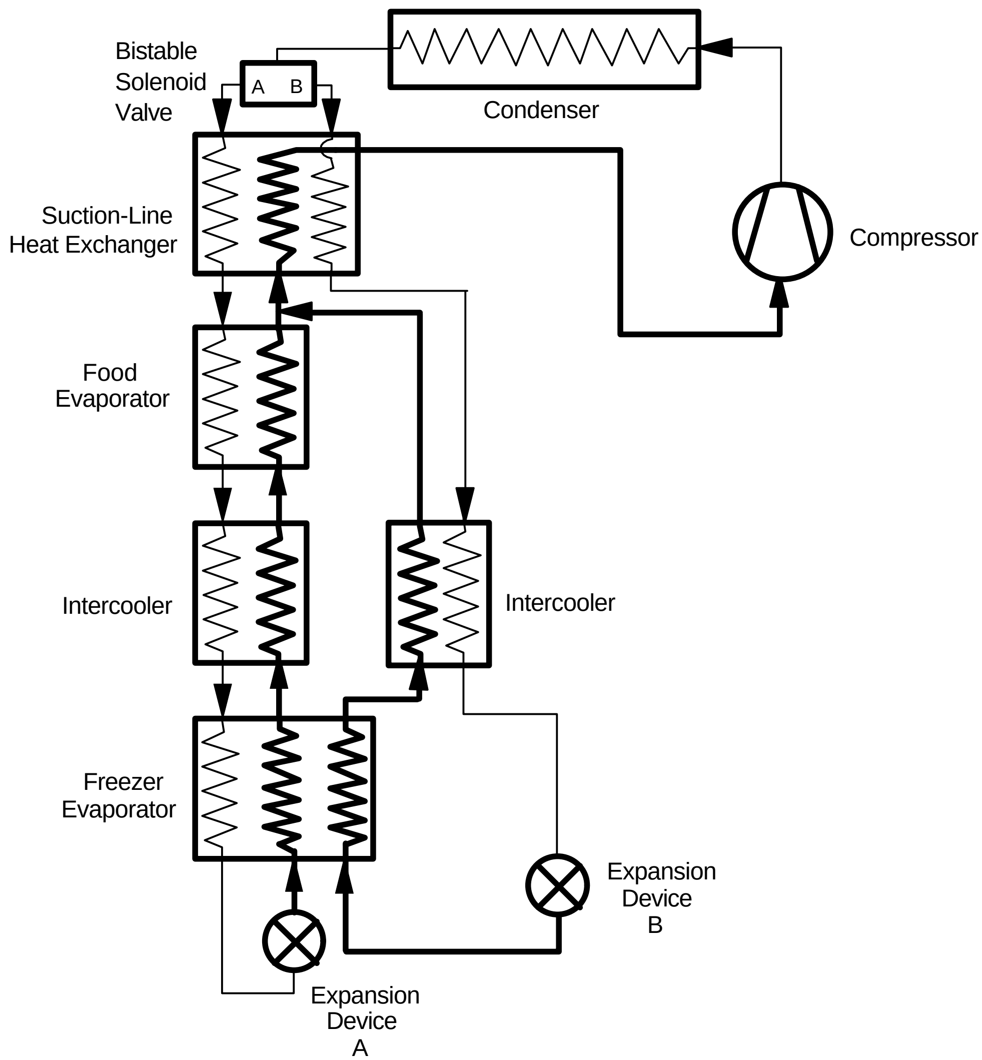


Figure 11. Haier Cycle

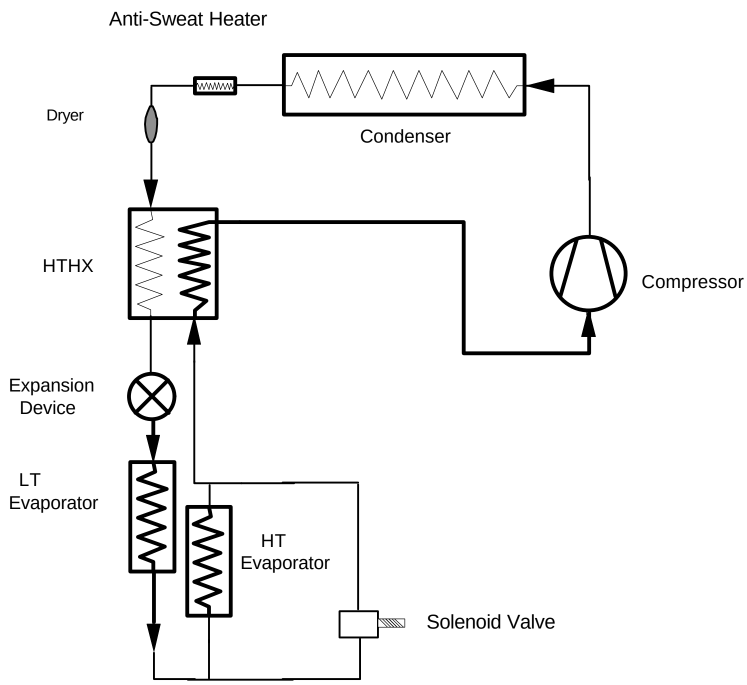


Table 9. Compressor Data

Refrigerant	Model Number	Manufacturer	COP	Capacity* (W)	Availability
R-12	B2116B	ASPERA	1.14	186	Production
	PW7.5K14	EMBRACO	1.08	164	Production
	BK1112A	ASPERA	1.32	156	Production
	JB1112A	JIAXIPERA	1.29	156	Production
R-134a	GL60A	ZANUSSI	1.13	164	Production
	GL80AH	ZANUSSI	1.30	180	Production
R-152a	TG105-12	AMERICOLD	1.36	152	Prototype
	TG205-12	AMERICOLD	1.42	152	Prototype
R-600a	HL80AH	ZANUSSI	1.28	119	Production
	HL90AH	ZANUSSI	1.30	128	Production
	HL99AH	ZANUSSI	1.31	137	Production
	HC70-12	AMERICOLD	1.40	119	Prototype
	HC77-12	AMERICOLD	1.43	133	Prototype
	HC82-12	AMERICOLD	1.48	144	Prototype

* Data provided by manufacturers.

Table 10. Refrigeration System Descriptions

System Identifier	Illustration	Condenser	Anti-Sweat Heater	Fresh Food Evaporator	Freezer Evaporator	Inter-Cooler	Valve
ORIGINAL[1]	FIG- 4	SHUTTER	BEFORE CONDENSER	TUBE BEHIND LINER	EXPOSED TUBE PLATE	SUCTION LINE ONLY	YES
CONVENTIONAL[1]	FIG-5	WIRE TUBE	BEFORE CONDENSER	TUBE BEHIND LINER	EXPOSED TUBE PLATE	SUCTION LINE ONLY	NO
LORENZ I[1]	FIG-6	WIRE TUBE	NONE	TUBE PLATE IN FRONT OF LINER	EXPOSED TUBE PLATE	TWO STAGES OUTSIDE LINER	NO
LORENZ II[1]		WIRE TUBE	NONE	EXPOSED WIRE TUBE	EXPOSED WIRE TUBE	TWO STAGES OUTSIDE LINER	NO
LORENZ III[1]		WIRE TUBE	AFTER CONDENSER	EXPOSED WIRE TUBE	EXPOSED WIRE TUBE	TWO STAGES INSIDE LINER	NO
LORENZ IV[1]		WIRE TUBE	AFTER CONDENSER	TUBE BEHIND LINER	EXPOSED WIRE TUBE	TWO STAGES BEHIND LINER	NO
LORENZ V[1]		WIRE TUBE	AFTER CONDENSER	EXPOSED ROLL-BOND	EXPOSED WIRE TUBE	TWO STAGES BEHIND LINER	NO
L-M[2]	FIG-7	WIRE-TUBE	NONE	EXPOSED TUBE PLATE	EXPOSED TUBE PLATE	SUCTION LINE ONLY	NO
L-M WITH VALVE[2]	FIG-8	WIRE-TUBE	NONE	EXPOSED TUBE PLATE	EXPOSED TUBE PLATE	SUCTION LINE ONLY	YES
ML-M[2]	FIG-9	WIRE-TUBE	NONE	EXPOSED PLATE-TUBE-IN-TUBE	EXPOSED TUBE PLATE	SEE FIGURE 9	NO
ML-M WITH VALVE [2]	FIG-10	WIRE-TUBE	NONE	EXPOSED PLATE-TUBE-IN-TUBE	EXPOSED TUBE PLATE	SEE FIGURE 10	YES
HAIER[3]	FIG-11	SHUTTER	AFTER CONDENSER	BEHIND LINER	EXPOSED TUBE PLATE	SUCTION LINE ONLY	YES

[1] Built at CHEARI
[2] Built at U. Md.
[3] Built at Haier Group.

Table 11. Refrigeration System Component Descriptions[1]

System Identifier	Condenser	Anti-Sweat Heater	Fresh Food Evaporator	Freezer Evaporator	Inter-Cooler	Capillary Tube for the Optimum Configuration	Valve Type
ORIGINAL	NA	NA	NA	NA	NA	NA	NA
CONVENTIONAL	NA	NA	NA	NA	NA	NA	None
LORENZ I	NA	None	NA	NA	NA	NA	None
LORENZ II	NA	None	NA	NA	NA	NA	None
LORENZ III	NA	NA	NA	NA	NA	NA	None
LORENZ IV	NA	NA	NA	NA	NA	NA	None
LORENZ V	NA	NA	NA	NA	NA	NA	None
L-M[2]	Same as Original	None	Area=0.49 m^2 Tubing=5.08 m O.D.=0.79 cm	Same as Original Tubing=1.95 m O.D.=0.79 cm	None	I.D.=0.66 mm Length=10.85 m	None
L-M WITH VALVE[2]	Same as Original	None	Area=0.49 m^2 Tubing=5.08 m O.D.=0.79 cm	Same as Original Tubing=1.95 m O.D.=0.79 cm	None	I.D.=0.66 mm Length=10.24 m	ELBI BISTABLE
ML-M[2]	Same as Original	None	Area=0.35 m^2 Tubing=4.06 m O.D.=0.95 cm	Area=0.49 m^2 Tubing=6.86 m O.D.=0.95 cm	Length=0.61m	I.D.=0.66.mm Length=10.69 m	None
ML-M WITH VALVE[2]	Same as Original	None	Area=0.35 m^2 Tubing=4.06 m O.D.=0.95 cm	Area=0.49 m^2 Tubing=6.86 m O.D.=0.95 cm	Length=0.61m	I.D.=0.66 mm Length=11.15	ELBI BISTABLE
HAIER	NA	NA	NA	NA	NA	NA	NA

[1] NA indicates that information is not available or proprietary.

2. Cabinet Descriptions

The Haier BCD-220, a 220-liter manual-defrost bottom-freezer refrigerator (145 liters in the fresh food section and 75 liters in the freezer) popular in the Chinese market, was chosen as the baseline unit. The incremental cost of conversion was lowered by minimizing changes to the interior components and modifying the exterior of the cabinet instead. These changes included:

- September 1993 prototype cabinets (identified as THICKER I throughout this report) — addition of 23 mm of micro-cell HCFC-141b-blown foam insulation to sides and back of the cabinet and 10 mm to doors

- December 1993 prototype cabinets (THICKER II) — THICKER I plus an additional 5 mm of insulation added to both doors

- December 1994 prototype cabinets (THICKER III) — THICKER II with cyclopentane-blown foam insulation and 23 mm of insulation added to the cabinet bottom.

The dimensions of the baseline model and the three prototype models, along with foam thermal conductivities, are shown in Table 12.

3. System Descriptions

Many different combinations of cabinet designs, components, and cycles were constructed and tested. The test models are categorized for future discussion as follows:

- cabinet — involving cabinet modifications

- cycle — involving component and cycle modifications

- system — involving cabinet, component, and cycle modifications.

4. Procedures

Energy consumption tests were performed at CHEARI and Haier in China and at the University of Maryland in the United States. Most Chinese test procedures and conditions followed Chinese standards GB8059.1 and GB8059.2 (SBTS, no date), with the exception of a few tests done at an ambient temperature of 32ºC (90ºF) to facilitate comparison with the US results. Similarly, most tests done at the University of Maryland were performed according to the AHAM standard (AHAM 1988), with the exception of a few tests at 25ºC (77ºF) to facilitate comparison with the Chinese results.

Test conditions and procedures at the three test facilities are summarized in Tables 13, 14, and 15. Temperature measurement locations are shown in Figure 12.

The results of several other tests, such as pull-down and electrical safety, performed to certify units in China are given along with the energy consumption test results in Appendix A.

Table 12. Cabinet Data

Model		Baseline	September-1993 Prototype	December-1993 Prototype	December-1994 Prototype
Identifier		Original	THICKER I	THICKER II	THICKER III
Freezer Insulation (mm)	Door	55	65 (+10)	70 (+5)	70
	Sides	50	73 (+23)	73	73
	Back	60	83 (+23)	83	83
	Top*	75	75	75	75
	Bottom	60	60	60	83 (+23)
Fresh Food Insulation (mm)	Door	25	35 (+10)	40 (+5)	40
	Sides	30	53 (+23)	53	53
	Back	45	68 (+23)	68	68
	Top	53	53	53	53
	Bottom*	75	75	75	75
Foam Properties	Blowing Agent	CFC-11	HCFC-141B	HCFC-141B	CYCLOPENTANE
	Thermal Conductivity mW/(m*K) (24°C)	18.4	17.0	17.0	20.4
Cabinet Dimensions (cm)	Height	1485	NA	NA	1500
	Width	550			600
	Depth	600			640

* Mullion

NA: not available

Table 13. CHEARI Test Conditions, Specifications, and Procedures

Test Room	*Ambient Temperature* : Tests are carried out at two ambient temperature conditions: 25ºC for the typical Chinese energy consumption test and 32ºC. *Humidity* : Relative humidity is kept between 45% and 75%. *Air Circulation* : Refrigerators are shielded from air currents of velocity above 0.25m/s.
Power Supply	*Rated Voltage* : 220 V ± 0.5% *Rated Frequency* : 50HZ ± 1%
Instrumentation	*Temperature* : Type T thermocouples positioned in the center of tinned solid brass cylinders with a mass of 25g measure temperature. Measurements are accurate within ± 0.3ºC. *Pressure* : AK-4 pressure transducers are equipped with HP 3852A Data Acquisition / Control Unit to measure refrigerant pressure in the circuit during the test. Transducer accuracy is 0.3%. *Energy Consumption* : ER-1-22222 watt transducers are equipped with HP 3852A Data Acquisition / Control Unit to measure energy consumption continuously during the test. Transducer accuracy is 0.2%.
Load	Freezer and fresh food compartments are not filled with test packages.
Temperature Control	A computer, not the thermostat, accurately controls the fresh food compartment average temperature, T_m , at 5ºC. The fresh food compartment temperature is controlled, and the refrigeration system is adjusted to maintain the freezer compartment temperature, T_{cm} ,between -19 ºC and -20 ºC. When the value of $\frac{T1+T2+T3}{3}$ equals 5.5ºC, the compressor starts. When the value of $\frac{T1+T2+T3}{3}$ equals 4.5ºC, the compressor stops. *Fresh Food Compartment* : T_m = 5ºC *Freezer Compartment* : -19ºC $\geq T_{cm} \geq$ -20ºC
Procedure	After stable operating conditions have been achieved, energy consumption is determined for a 24 hour period.

NOTE: $T_m = \dfrac{\frac{T1on+T2on+T3on}{3}+\frac{T1off+T2off+T3off}{3}}{2}$ and $T_{cm} = \dfrac{\frac{T4on+T5on+T6on}{3}+\frac{T4off+T5off+T6off}{3}}{2}$

Table 14. Haier Test Conditions, Specifications, and Procedures

Test Room	*Ambient Temperature* : Tests are carried out at 25ºC. *Humidity* : Relative humidity is kept between 45% and 75%. *Air Circulation* : The refrigerators are shielded from air currents of velocity above 0.25m/s.
Power Supply	*Rated Voltage* : 220 V ± 0.5% *Rated Frequency* : 50HZ ± 1%
Instrumentation	*Temperature* : Type T thermocouples positioned in the center of tinned solid brass cylinders with a mass of 25g are used to measure temperature. Measurements are accurate within ± 0.3ºC. *Energy Consumption* : A kWh meter measures energy consumption.
Load	Freezer compartment is filled with test packages.
Temperature Control	Thermostats accurately control both compartment temperatures. *Fresh Food Compartment* : T_m = 5ºC ± 0.5ºC *Freezer compartment* : T_{cm}= -18ºC ± 0.5ºC
Procedure	After stable operating conditions have been achieved, energy consumption is determined for a 24 hour period.

Table 15. U. Md. Test Conditions, Specifications, and Procedures

Test Room	*Ambient Temperature* : Tests are carried out at two ambient temperature conditions: 32.2ºC for the typical US energy consumption test (AHAM 1985) and 25ºC. *Humidity* : Relative humidity is not controlled. *Air Circulation* : The refrigerators are shielded from any air currents of velocity above 0.25m/s.
Power Supply	*Rated Voltage* : 220 V ± 1.5% *Rated Frequency* : 50HZ ± 0.05%
Instrumentation	*Temperature* : Type T thermocouples, positioned in the center of brass cylinders with a diameter and height of 2.54cm, measure temperature. Measurements are accurate within ± 0.3ºC. *Pressure* : Setra 280E pressure transducers monitor the refrigerant pressure at various points in the circuit. *Energy Consumption* : An Ohio Semitronics GW5-002x5-51 watt transducer monitors energy consumption continuously during test. 24 hour average energy consumption is then determined. Transducer accuracy is within ±0.2%.
Load	Freezer and fresh food compartments are not filled with test packages.
Temperature Control	Resistance temperature detectors and a separate OMEGA temperature controller, not the thermostats, accurately control fresh food and/or freezer compartment temperature(s). The other compartment temperature is controlled by adjusting the refrigeration system. *Fresh Food Compartment* : T = 3.3ºC ± 1.1ºC *Freezer Compartment* : -15ºC ± 1.1ºC
Procedure	After stable operating conditions have been achieved, energy consumption is determined from the first compressor-on-time to the last compressor-on-time during an approximately 12 hour period. The 24 hour energy consumption is then calculated.

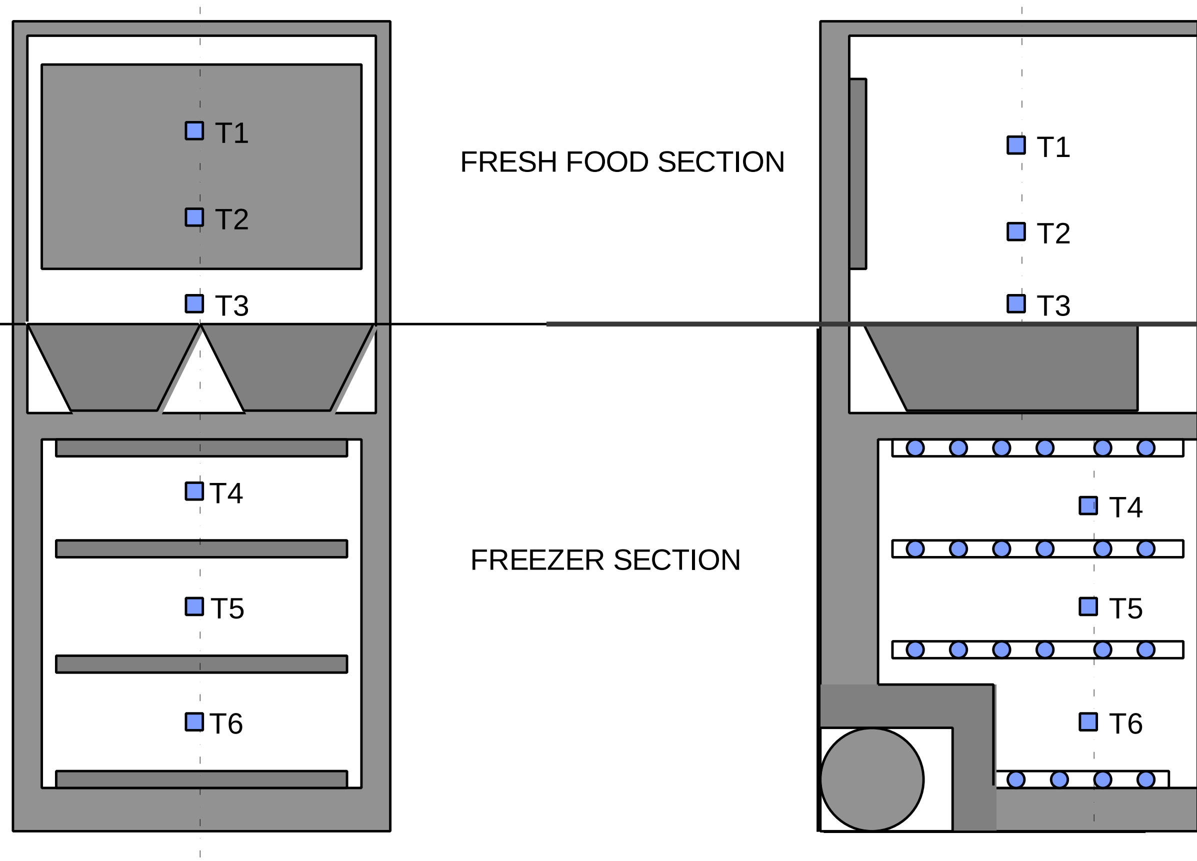


Fig. 12: Temperature Sensor Layout

B. Laboratory Test Results and Analysis

A large number of closed-door, energy-consumption tests have been completed at the three test facilities. A summary of the results of these tests, including details on the modifications, compressors and their coefficients of performance (COP), refrigerant, ambient test temperature, and energy consumption, is shown in Table 17. Additional test results can be found in Appendix A and in references Radermacher et al. 1995a and USEPA 1994.

1. Baseline

Baseline tests were done on model BCD-220 refrigerators taken off the production line at the Haier factory. Tests were performed under Chinese and US test conditions at CHEARI and the University of Maryland. As Table 16 shows, the U. Md. results were about 2 percent higher than the CHEARI results under Chinese test conditions and 7 percent lower than CHEARI results under US test conditions.

Table 16. Baseline Test Results

Test Conditions	Energy Usage (kWh/24h)	
	CHEARI	U. Md.
Chinese	1.37	1.40
US	1.83	1.70

Tests done in support of a similar project for US refrigerators showed that results differed between laboratories by as much as 6 percent under US test conditions (USEPA 1994). Considering the differences in temperature control strategies—tests performed at CHEARI control fresh food temperature while those done at U. Md. control freezer temperature—and the fact that these tests were done on different production samples and at different laboratories (Tables 13 and 15), the results are in very good agreement.

The CHEARI results show a 34 percent increase in energy usage from Chinese to US test conditions, while the U. Md. results show a 21 percent increase. CHEARI results are very close to those predicted by ERA.

Table 17. Summary of Test Results

Test Series	Cabinet Identifier	System Identifier	Compressor Manufacturer Model (COP)	Refrigerant	Ambient Temperature (^{o}C)	Energy Consumption (kWh/24h) and Test Site[2]		Energy Savings Compared to Baseline (%)
BASELINE	ORIGINAL	ORIGINAL	Aspera B2116B (1.14)[1]	R12	25	1.37[1]	C	-
						1.40	M	-
					32	1.83[1]	C	-
						1.70	M	-
CYCLE	ORIGINAL	CONVENTIONAL	Aspera B2116B (1.14)	R12	25	1.37	C	0
					32	1.78	C	3
		LORENZ II	Aspera B2116B(1.14)	R32/R134a	25	1.20	C	12
				R32/R152a		1.19	C	13
				R143a/R134a/ R123		1.12	C	18
				R143a/R152a/ R123		1.11	C	19
				RC270/R152a/ R123		1.09	C	20
				R22/R152a/ R123		1.09	C	20
				R32/R152a/ R123		1.07	C	22
				RC270/R123		1.05	C	23
CABINET	THICKER I	ORIGINAL	Aspera B2116B(1.14)	R12	25	1.14	C	17
					32	1.42	C	22

[1] Selected as baseline for energy savings calculations.

[2] Test site: CHEARI - C, U. Md. - M or Haier - H.

Table 17. Summary of Test Results (cont.)

Test Series	Cabinet Identifier	System Identifier	Compressor Manufacturer Model (COP)	Refrigerant	Ambient Temperature (°C)	Energy Consumption (kWh/24h) and Test Site[2]	Energy Savings Compared to Baseline (%)
CABINET and COMPONENTS	THICKER I	ORIGINAL	Jiaxipera PW7.5K14 (1.08)	R12	25	1.17 C	15
CABINET and COMPONENTS	THICKER I	ORIGINAL	Jiaxipera PW7.5K14 (1.08)	R12	32	1.48 C	19
CABINET and COMPONENTS	THICKER II	ORIGINAL	Aspera BK1112A (1.32)	R22/R152a	25	0.86 C	37
CABINET and COMPONENTS	THICKER II	ORIGINAL	Aspera BK1112A (1.32)	R22/R152a	25	0.77 H	44
CABINET and COMPONENTS	THICKER II	ORIGINAL	Aspera BK1112A (1.32)	R22/R152a	25	0.88 M	36
CABINET and COMPONENTS	THICKER II	ORIGINAL	Aspera BK1112A (1.32)	R22/R152a	32	1.22 M	33
CABINET and COMPONENTS	THICKER II	ORIGINAL	Zanussi HL90AH (1.30)	R600a	25	0.99 M	28
CABINET and COMPONENTS	THICKER II	ORIGINAL	Zanussi HL90AH (1.30)	R600a	32	1.22 M	33
CABINET and COMPONENTS	THICKER II	ORIGINAL	Americold HC77-12 (1.43)	R600a	32	0.95 M	48
CABINET and COMPONENTS	THICKER III	ORIGINAL	Zanussi HL90AH (1.30)	R600a	25	0.84 H	39
CABINET and COMPONENTS	THICKER III	ORIGINAL	Zanussi HL99AH (1.31)	R600a	25	0.82 H	40
CABINET and COMPONENTS	THICKER III	ORIGINAL	Americold HC77-12 (1.43)	R600a	25	0.84 C	39
CABINET and COMPONENTS	THICKER III	ORIGINAL	Americold HC77-12 (1.43)	R600a	25	0.88 M	36
CABINET and COMPONENTS	THICKER III	ORIGINAL	Americold HC77-12 (1.43)	R600a	25	0.76 H	45
CABINET and COMPONENTS	THICKER III	ORIGINAL	Americold HC77-12 (1.43)	R600a	32	1.1 M	40
CABINET and COMPONENTS	THICKER III	ORIGINAL	Americold HC82-12 (1.48)	R600a	25	0.70 H	49
SYSTEM	THICKER I	L-M	Americold TG205-12 (1.42)	R152a	32	0.96 M	48
SYSTEM	THICKER I	L-M	Americold TG205-12 (1.42)	R290/R600a	32	0.83 M	55
SYSTEM	THICKER I	L-M	Americold TG205-12 (1.42)	R290/R600	25	0.47 M	66
SYSTEM	THICKER I	L-M	Americold TG205-12 (1.42)	R290/R600	32	0.73 M	60
SYSTEM	THICKER I	L-M WITH VALVE	Americold TG205-12 (1.42)	R290/R600	25	0.67 M	51
SYSTEM	THICKER I	L-M WITH VALVE	Americold TG205-12 (1.42)	R290/R600	32	0.87 M	52
SYSTEM	THICKER I	ML-M	Americold TG205-12 (1.42)	R290/R600	32	0.82 M	55
SYSTEM	THICKER I	ML-M WITH VALVE	Americold TG205-12 (1.42)	R290/R600	32	0.87 M	52
SYSTEM	THICKER I	ML-M WITH VALVE	Americold TG205-12 (1.42)	R290/R600	32	1.06 M	42
SYSTEM	THICKER I	ML-M WITH VALVE	Americold TG205-12 (1.42)	R290/R600	25	0.70 M	49

[1] Selected as baseline for energy savings calculations.
[2] Test site: CHEARI - C, U. Md. - M or Haier - H.

Table 17. Summary of Test Results (cont.)

Test Series	Cabinet Identifier	System Identifier	Compressor Manufacturer Model (COP)	Refrigerant	Ambient Temperature (°C)	Energy Consumption (kWh/24h) and Test Site[2]	Energy Savings Compared to Baseline (%)
SYSTEM	THICKER II	CONVEN-TIONAL	Zanussi GL80AH (1.30)	R134a	25	0.76 C	45
			Americold TG105-12 (1.36)	R152a	25	0.76 C	45
					32	0.97 C	47
				DME	25	0.74 C	46
					32	0.95 C	48
				R290/R600a	25	0.69 C	50
		LORENZ III	Zanussi HL90AH (1.30)	R600a	25	0.80 C	42
					32	1.00 C	45
			Zanussi HL99AH (1.31)		25	0.79 C	42
					32	1.00 C	45
			Americold HC82-12 (1.48)		25	0.68 C	50
					32	0.84 C	54
		LORENZ IV	Americold HC77-12 (1.43)		25	0.70 C	49
					32	0.83 C	55
		LORENZ III	Americold TG105-12 (1.36)	R290/R600a	25	0.67 C	51
				R290/R600		0.60 C	56
		LORENZ IV				0.62 C	55
		LORENZ III		R290/R600a/ nC5		0.58 C	58
		LORENZ IV				0.66 C	52
		LORENZ IV	Aspera BK1112A (1.32)	R22/R152a/ R123	25	0.72 C	47
						0.76 M	45
					32	1.03 M	44
		HAIER	Aspera BK1112A (1.32)	R290/R600a	25	0.69 H	50
						0.79 M	42
					32	1.09 M	40

[1] Selected as baseline for energy savings calculations.

[2] Test site: CHEARI - C, U. Md. - M or Haier - H.

2. Alternate Refrigeration Cycles

Energy savings are calculated as the difference between baseline model energy use and altered design energy use divided by the baseline energy use:

$$\text{Energy Savings(\%)} = \frac{E_b - E_a}{E_b} \quad ,$$

where E_b = baseline energy use, and E_a = alternate design energy use. CHEARI energy consumption results were used as the baseline values for all energy savings calculations.

The difference in energy use between the conventional and original cycles is presented in Table 18 for tests done at CHEARI for various conditions and temperatures. This table indicates an average 2 $\pm$ 2 percent savings were found when the original cycle was replaced with the conventional cycle; unmeasurable energy savings were achieved at 25^{o}C and 3 percent energy savings were achieved at 32^{o}C. These small changes may result from the removal of the valve, but the level of uncertainty in the tests ($\pm$ 2 to 3 percent) makes this determination difficult. The results are, however, consistent with the ERA prediction of 5 percent.

Table 18. Energy Savings with Conventional Refrigeration Cycle

Test Conditions	**Energy Usage**	
	kWh/24h	**% Savings**
25^{o}C	1.37	0
32^{o}C	1.78	3

Lorenz II cycle models built and tested at CHEARI yielded 12-23 percent energy savings with binary refrigerant blends and 18-22 percent savings with ternary blends. The most energy efficient blends are shown in Table 19.

Two of the four most efficient blends contained cyclopropane (RC270), a relatively unstable compound that could decompose over the normal life of a refrigerator. The two HCFC/HFC blends, although not zero ODP substitutes, had the best performance of those blends consisting of stable chemicals. The blends are, however, flammable according to tests performed in accordance with ASTM E681-85, Standard Test Method for Concentration Limits of Flammability of Chemicals. ERA also predicted 16 percent energy savings with this cycle and R22/R152a/R123 refrigerant blend.

Table 19. Energy Usage with Most Efficient Refrigerant Blends

Refrigerant Blend	Energy Usage	
	kWh/24h	% Savings
40% - RC270 40% - R152a 20% - R123	1.09	20
30% - R22 40% - R152a 30% - R123	1.09	20
24% - R32 51% - R152a 25% - R123	1.07	22
50% - RC270 50% - R123	1.05	23

3. Cabinet Improvements

This section and the following sections evaluate the energy savings associated with a variety of cabinet improvements labeled as THICKER I, THICKER II, and THICKER III, each representing an incremental increase in cabinet insulation thickness, as shown in Table 12.

The THICKER I cabinet, incorporating additional foam insulation (23 mm to cabinet sides and back and 10 mm to both doors and a micro-cell HCFC-141b foam formulation), resulted in 20 $\pm$ 3 percent energy savings for tests performed at CHEARI (Table 20).

Table 20. Energy Savings with THICKER I

Test Conditions	Energy Usage	
	kWh/24h	% Savings
25^{o}C	1.14	17
32^{o}C	1.42	22

These modifications did not require changes to the interior of the refrigerator, and this result is in very good agreement with ERA predictions.

4. Cabinet and Component Improvements

This section evaluates the energy savings associated with a combination of cabinet and component improvements.

The THICKER I cabinets in combination with a slightly less efficient compressor (1.08-COP as compared to 1.14 for the original unit) resulted in 17 ± 2 percent energy savings in tests performed at CHEARI (Table 21). This loss in efficiency is slightly less than the 4-5 percent decrease in efficiency expected from the 5 percent lower compressor COP. It is, however, well within the range of measurement uncertainty.

Table 21. Energy Savings with THICKER I and 1.08 COP Compressor

Test Conditions	Energy Usage	
	kWh/24h	% Savings
25°C	1.17	15
32°C	1.48	19

The THICKER II cabinets include all the modifications to THICKER I plus an additional 5 mm of insulation added to the doors. THICKER II, with a 1.32-COP (16 percent higher efficiency) R12 compressor and a 30 percent R22/70 percent R152a refrigerant blend substituted for R12 in the original cycle, achieved 35 ± 2 percent energy savings compared to the baseline model based on the CHEARI and U. Md. results (Table 22).

Table 22. Energy Savings with THICKER II

Test Conditions	Energy Usage	
	kWh/24h	% Savings
25°C	0.77 @ HAIER 0.86 @ CHEARI 0.88 @ U. Md.	44 37 36
32°C	1.22 @ U. Md.	33

The CHEARI and U. Md. results are in excellent agreement. Minor differences in the test procedures probably result in the higher energy savings shown in the Haier result. As Tables 13 and 14 show, the freezer temperature at Haier is maintained at ≤−18°C as compared to −19 °C to −20°C at CHEARI. This difference could result in lower energy consumption and hence, higher savings.

Isobutane (R600a) refrigerant and compressors were installed into the THICKER II cabinets with the original cycle at U. Md. Energy savings of 31 $\pm$ 3 percent were achieved with 1.30-COP compressors and 48 percent savings were achieved with 1.43-COP units (Table 23).

Table 23. Energy Savings with THICKER II and R600a Refrigerant

Compressor COP	Energy Usage	
	kWh/24h	% Savings
1.30 (+14%)	0.99 @ 25ºC 1.22 @ 32ºC	28 33
1.43 (+25%)	0.95 @ 32ºC	48

The results with the 1.30-COP compressors and isobutane refrigerant were somewhat less than those obtained with 1.32-COP R12 compressors and the R22/R152a blend. The refrigeration systems in these tests were optimized for the R22/R152a blend, and with the exception of switching compressors and charging an optimal quantity of refrigerant, the refrigeration systems were not re-optimized. The high-temperature results do suggest that similar performance can be achieved when the system is optimized for isobutane.

THICKER III cabinets, which included all of the modifications made to the THICKER II units plus an additional 23 mm of insulation added to the bottom, but with cyclopentane blown foam, were built, optimized, and tested with isobutane refrigerant and compressors and the original cycle. These units showed an average 38 $\pm$ 2 percent reduction in energy consumption with 1.43 COP compressors at CHEARI and U. Md., and slightly higher savings with 1.30 to 1.48-COP compressors at Haier (Table 24).

Table 24. Energy Savings with THICKER III with R600a Refrigerant

Compressor COP	Energy Usage	
	kWh/24h	% Savings
1.30 (+14%)	0.84 @ Haier	39
1.31 (+15%)	0.82 @ Haier	40
1.43 (+25%)	0.76 @ Haier 0.84 @ CHEARI 0.88 @ U. Md. 1.1* @ U. Md.	45 39 36 40
1.48 (+30%)	0.70 @ Haier	49

*test done and energy savings calculated on 32°C basis.

For a visual comparison of the baseline and increased insulation thickness models, see Figure 13 below. The baseline unit, the BCD-220, is shown on the left. The increased insulation prototype BCD-222 is pictured on the right.

Figure 13. Production BCD-220 and Prototype BCD-222 Refrigerators

5. System Improvements

This section evaluates the impact on energy efficiency of system improvements, including alternate cycles and cabinet and component changes.

THICKER II cabinets built with Lorenz cycles but charged with a pure refrigerant (isobutane) were tested at CHEARI. With the pure refrigerant, the Lorenz cycle should yield efficiency improvements similar to those of the conventional cycle, i.e. about 3 percent. Energy savings ranged from 44 percent with 1.30-COP compressors to 54 percent with 1.48-COP units in the THICKER II cabinets (Table 25). These savings were five percent more than for the THICKER III cabinet owing to the higher thermal conductivity of the cyclopentane blown foam.

Table 25. Energy Savings with Different Cabinets and Compressors

Compressor COP	% Savings	
	THICKER II & Lorenz Cycle	THICKER III & Original Cycle
1.30 (+14%)	44	39
1.31 (+15%)	44	40
1.43 (+25%)	50	45
1.48 (+30%)	54	49

Unlike the U. Md. refrigerators (see Table 23), these models were optimized for R600a. The 44 percent savings with the THICKER II cabinets, 1.30 or 1.31-COP compressors, and isobutane refrigerant are slightly better than would be expected from the results of the R22/R152a blend. When a 3 percent improvement due to the cycle change is included, the results are within the limits of experimental uncertainty. The 5 percent lower energy savings obtained with THICKER III cabinets made with cyclopentane blown foam is consistent with the ERA predictions and other experimental results available in the literature (UNEP 1994).

Other refrigerants tested with the conventional or Lorenz cycles and with pure refrigerants showed virtually no change in efficiency from systems with isobutane. A R290/R600a blend in the conventional cycle showed about a 4 percent improvement in efficiency over the pure refrigerants (Table 26).

THICKER II cabinets with Lorenz or Haier cycles and 1.32-COP compressors showed virtually the same energy savings as the systems with pure refrigerants (Table 27). Haier reported a higher savings for the Haier cycle, but as previously noted, this may partially be due to different measurement techniques. An average 7 percent additional energy savings was achieved with a variety of blends in Lorenz cycles using 1.36-COP compressors (Table 28). Similar results were also found at U. Md. with L-M and ML-M cycles, THICKER I cabinets, and 1.42-COP compressors (Table 29).

Table 26. Energy Savings with Refrigerants in Conventional and Lorenz Cycles

COP	Cycle	Refrigerant	% Savings
1.30	Conventional	R134a	45
1.31	Conventional	R134a	45
1.30	Lorenz III	R600a	44
1.31	Lorenz III	R600a	44
1.36	Conventional	R152a	46
1.36	Conventional	DME	47
1.36	Conventional	R290/R600a	50
1.43	Lorenz IV	R600a	52
1.48	Lorenz III	R600a	52

Table 27. Energy Savings with Refrigerants in Lorenz and Haier Cycles

Cycle	Refrigerant	% Savings
Lorenz IV	R22/R152a/R123	45
Haier	R290/R600a	46

Table 28. Energy Savings with Refrigerant Blends in Lorenz Cycle

Cycle	Refrigerant	% Savings
Lorenz III	R290/R600a	51
Lorenz III	R290/R600	56
Lorenz IV	R290/R600	55
Lorenz III	R290/R600a/nC5	58
Lorenz IV	R290/R600a/nC5	52

Table 29. Energy Savings for Refrigerant Blends in L-M and ML-M Cycles

Cycle	Refrigerant	% Savings
L-M	R152a	48
L-M	R290/R600a	55
L-M	R290/R600	63
ML-M	R290/R600	55

A final series of tests was undertaken at U. Md. to determine energy savings with the L-M and ML-M cycles and independent temperature control in both refrigerator compartments (Table 30). In the original cycle, this type of control is achieved with the addition of a control valve and a freezer-only refrigerant loop (Figure 4). Similar additions to the L-M and ML-M cycles (Figures 9 and 11) resulted in lower energy savings as compared to L-M and ML-M cycles without independent temperature control (Radermacher et al. 1995a).

Table 30. Energy Savings with Independent Temperature Control

Cycle	Valve	% Savings
L-M	NO	63
L-M	YES	52
ML-M	NO	55
ML-M	YES	52 - 42

IV. FIELD TEST PROGRAM

After analysis of the laboratory test results, a production line at the Haier Group factory was temporarily modified to manufacture approximately 200 field test units using THICKER III cabinets and the following zero-ODP energy-efficiency measures:

- original cycle
- isobutane refrigerant
- Americold HC77-12 compressors
- wire-tube type freezer evaporator
- 10 percent larger fresh food evaporator
- wire-tube type condenser.

These units were produced during the first quarter of 1995. Demonstration of the safe and reliable operation of these CFC-free, energy-efficient refrigerators in consumers' homes was essential to the successful completion of the project. Assessment of the prototype units' performance included the following steps:

- determination of the number of sites to be included in the program to ensure that all the major climatic zones in China were represented
- determination of the number of units to be placed in each region to ensure that a sample size with reasonable statistical significance was employed
- selection of locations for test units within each city
- identification of data to be collected on household characteristics and energy consumption patterns
- identification of data to be collected to assess actual energy consumption by refrigerators in houses and customer satisfaction with the new refrigerators
- determination of the monitoring period needed to represent temperature extremes (winter and summer) and at least one season in-between
- development of a tracking system for the tests, including data recording forms (see sample in Appendix B) and a computer database to store data for subsequent analysis
- purchase of simple monitoring equipment (kWh meters, thermometers, and several kVA

meters to estimate average power factor), and setup of the new refrigerators and monitoring equipment

- initial post-setup check to see if refrigerator and monitoring equipment were functioning properly
- administration of pre-study questionnaire (included in Appendix B)
- monthly reading of the monitoring instruments to collect energy consumption data
- analysis of the data, including analysis of refrigerator energy consumption, changes in energy consumption relative to the baseline refrigerator, household reactions to the new refrigerator, and other relevant issues.

A. Field Test Results

1. Introduction

Field testing of the prototypes was crucial to demonstrating the safety and reliability of the CFC-free, energy-efficient prototype design. Moreover, it was important to determine how the energy savings of the prototype in daily home use compared to the results of laboratory testing. Given multiple door openings throughout the day, food loads in the freezer and fresh-food compartments, and widely varying indoor temperatures throughout the year, energy consumption in actual household use would normally increase for both baseline and prototype units, reducing the relative savings. What is important to the future growth of electricity demand in China, however, is the potential for absolute savings relative to the baseline model.

The field testing program was designed initially to include all 200 of the manufactured prototypes, but a number of the models "leaked" into the local market in Qingdao and other places before shipment to the three cities for testing. The field test period was set at one year, in order to capture the effect of all four seasons on refrigerator performance. Field testing took place in Beijing, Shanghai, and Guangzhou (Figure 14). The selected cities are large urban centers, with a substantial base of "middle class" consumers and about 100 percent refrigerator penetration in the urban market.

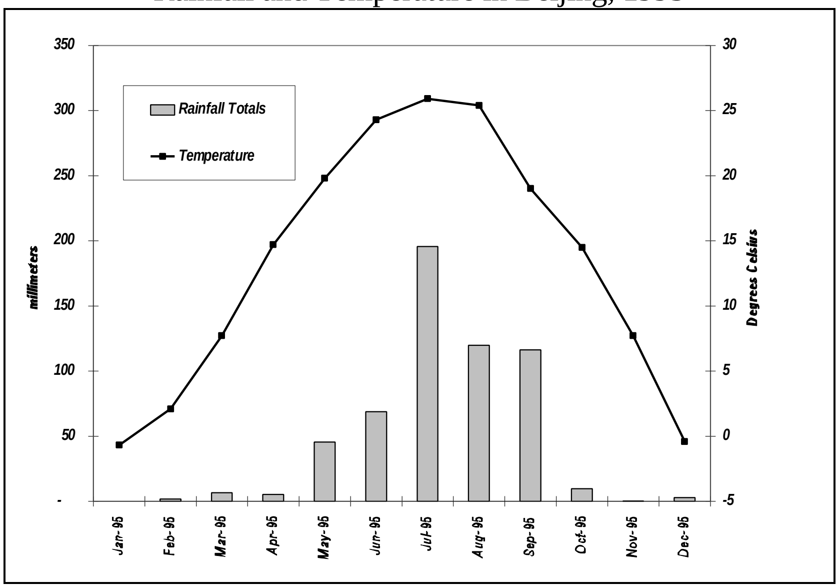
Beijing, in North China, has a temperate climate characterized by hot wet summers and cold, dry winters. The annual average temperature is 12.9◦C, with wide annual variations. The permanent population (i.e., excluding migrant workers) was 10.7 million at the end of 1995 (SSB 1996).

Shanghai, at the mouth of the Yangzi River on the East China Sea, has a temperate climate characterized by hot wet summers and mild winters. The annual average temperature is 16.5◦C, and the temperature usually remains above freezing during the winter. Shanghai is China's largest city, with population of 13.01 million at the end of 1995.

Guangzhou, capital of the southern province of Guangdong, has a sub-tropical climate averaging 22.5◦C in temperature annually. The summers are hot and wet, and winter warm. Guangzhou had 6.47 million inhabitants at the end of 1995.

Figure 14. Climate in the Field Test Cities

Rainfall and Temperature in Beijing, 1995



Rainfall and Temperature in Shanghai, 1995

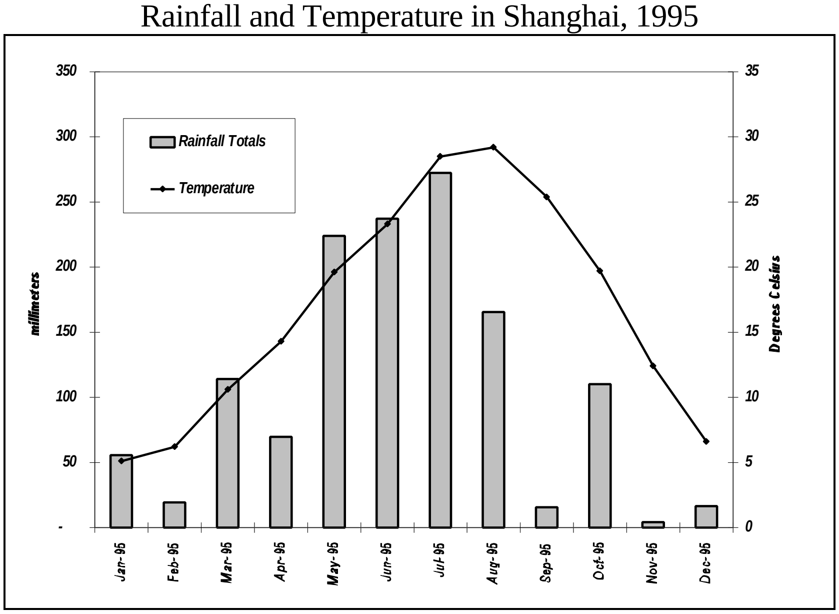
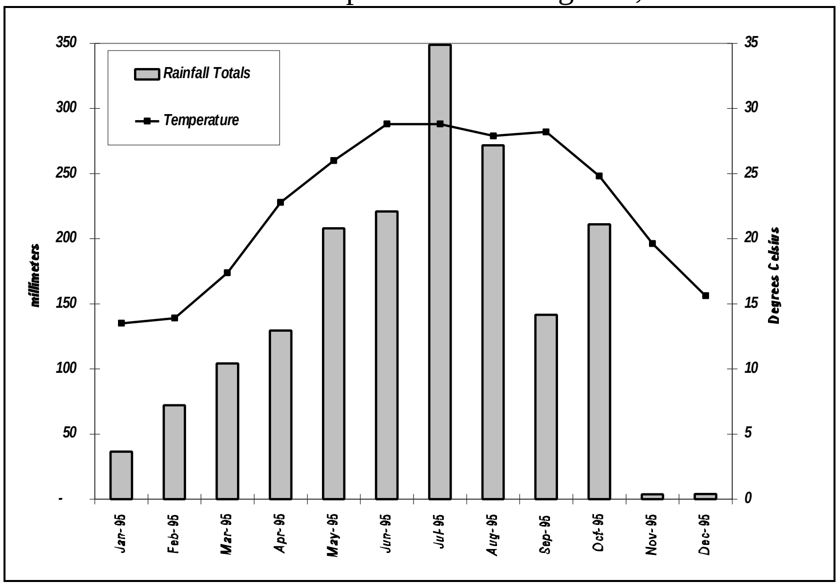


Figure 14. Climate in the Field Test Cities (cont.)

Rainfall and Temperature in Guangzhou, 1995



Source: SSB 1996

2. Methodology

About 30 typical households were selected in each city to participate in the field test program out of a pool of about 60 households per city identified as possible participants. Participants were offered a prototype or baseline model refrigerator at a substantial discount to the market price. In addition, the households were offered regular payments during each stage of the program. All field test units were placed in the same part of each city to facilitate data collection.

In May and June of 1995, a total of 85 CFC-free, energy-efficient prototype units—model BCD-222B—and 19 baseline units—model BCD-225—were installed in the participating households. Incomplete energy consumption data were collected for four prototypes and five baseline units in Guangzhou. In addition, one prototype refrigerator failed and was dropped from the field test in Shanghai. Table 31 shows the locations of the remaining 94 field test units and the dates over which energy consumption readings were made.

Table 31. Locations and Dates of Field Tests

City	Number of Units in Test	Test Dates
Beijing		
Prototype units	27	7/2/95 to 6/29/96
Baseline units	7	7/2/95 to 6/29/96
Guangzhou		
Prototype units	18	7/5/95 to 1/22/96
Baseline units	2	7/5/95 to 1/22/96
Shanghai		
Prototype units	35	6/25/95 to 6/20/96
Baseline units	5	6/25/95 to 6/20/96

At the time of the refrigerator installation, a watt-hour meter was also installed on all units to monitor energy usage. Readings of cumulative power consumption were then made approximately weekly for two months, and then approximately monthly for the remainder of the roughly year-long field test program. A questionnaire designed to gather relevant socio-economic data such as household size, income, ownership of other appliances and usage patterns was administered one month into the test period. In addition, a second questionnaire concerning the customer's opinion about the prototype refrigerator was given at the end of the test period. An English translation of the complete set of forms used to collect these data is attached in Appendix B.

3. Characterization of Study Households

As part of the study, data were collected on the demography of study households, old refrigerators, ownership and use of other appliances, and how households used their new refrigerators. These data were collected through questionnaires administered near the beginning and end of the study period, and provided the basis for better understanding household characteristics and how variations in household characteristics may affect refrigerator energy use.

a. Study Households

Households in the study had an average size of 3.1 people, with the average slightly higher in Beijing and slightly lower in Shanghai and Guangzhou. For China's urban areas as a whole, the average household size was 3.23 in 1995, down slightly from 3.28 in 1994 (SSB 1996). In 1994, the average household in Beijing had 3.23 persons, and in Shanghai 2.99 persons (SSB 1995).

At the time of the survey in mid-1995, nearly half the households in our study had a monthly income between RMB 1001-1500 (approximately US$120-180), with about one-quarter having lower incomes and one-quarter having larger incomes. This income level of half of the respondents placed them within the range of "medium" and "medium-to-high" income levels in urban areas (third and fourth quintiles, as defined by the China State Statistical Bureau). In 1995, the average monthly income per household in China's largest cities reached RMB 1407 (about US$170). Further details are provided in Table 32.

Table 32. Information on Study Households

Item	Beijing	Shanghai	Guangzhou	All	Number of Responses
Average household size	3.55	2.75	2.92	3.1	100
Monthly household income					102
<500 RMB	3%	5%	14%	7%	
500-1000	6	21	32	19	
1001-1500	44	59	32	47	
1501-2000	18	8	11	12	
2001-3000	18	8	7	11	
3001-4000	12	0	4	5	
>4000	0	0	0	0	

b. Old Refrigerators

All of the households in the study already owned refrigerators. Nearly all of these refrigerators were smaller than the new 222-liter prototype model, averaging 165 liters. According to verbal reports by a member of each household, the original units ranged in age from 2 to 20 years old, with the average unit being approximately eight years old. On average, the old refrigerators consumed 1.14 kWh/day, according to standardized testing information on the refrigerator nameplate. This is 36 percent more than the laboratory-tested consumption of the prototype. Thus, assuming these label measurements accurately portray consumption in the field, the average household could expect their new refrigerator to use 26 percent less energy than their previous unit. Old refrigerators were produced by more than a dozen manufacturers, with the largest number (nearly 30%) produced by Beijing-based Snowflake, formerly China's largest refrigerator manufacturer. Additional information on the old refrigerators that were replaced is contained in Table 33.

Table 33. Information on Old Refrigerators

Old Refrigerator Brand	Percentage*
Snowflake	29
Haier	12
Wanbao	9
Yiyou	9
Xiangxueha	9
11 other brands	32

* Based on information from 34 responses

Item	Average	Range	Number of Responses
Old refrigerator size	165 liters	100-220	41
Old refrigerator energy use	1.14 kWh/day	0.5-1.6	35
Year old refrigerator purchased	1987	1975-1993	40

c. Ownership and Use of Other Appliances

Each of the households surveyed owned many types of appliances. Nearly all households had televisions and fans, and many had more than one. Approximately 70 percent of the households also owned clothes washers and microwave ovens. For the most part, ownership patterns are broadly consistent between cities, with the exception of space conditioning equipment. One-third of study households in Shanghai and Guangzhou owned air conditioners, while only 6 percent did in Beijing. Likewise, more than half of Shanghai households owned electric space heaters, because many apartments lack central heat despite average winter temperatures of approximately 6 °C (43 °F). In Guangzhou the climate is too warm generally to need space heating, while in Beijing all apartments have central heating.

As part of the survey, data were also collected on appliance nameplate power use and resident estimates of annual operating hours (broken down into days used per year and hours per day). Nameplate power use is typically a maximum load—average use is often substantially lower. Household estimates of operating hours are probably not very accurate. Also, for some of the appliances and cities, sample sizes were small and thus averages are biased by outliers. Still, these data do provide order of magnitude approximations. These data are summarized in Table 34.

Particularly notable is the fact that residents report that on average televisions are operated 1235 hours per year, or over 3 hours per day on average.

Table 34. Information on Appliance Ownership and Operations in Study Households

Equipment Type	% of Households Possessing	Average Power (Watts)	Average Hours Used Per Year
Air conditioner	B: 6% S: 34% G: 33% Total: 24%	B: 800 S: 1172 G: 901 Total: 1040	B: 315 S: 328 G: 183 Total: 286
Electric shower or water heater	B: 0% S: 9% G: 0% Total: 3%	S: 635	S: 226
Washing machine	B: 73% S: 70% G: 63% Total: 69%	Total: 346	B: 123 S: 152 G: 199 Total: 159
Electric clothes dryer	B: 9% S: 3% G: 7% Total: 6%	Total: 399	Total: 107
Electric space heater	B: 3% S: 56% G: 0% Total: 22%	Total: 929	B: NA S: 259
Fan	B: 153% S: 143% G: 131% Total: 143%	Total: 103	B: 209 S: 426 G: 519 Total: 402
Rice cooker	B: 39% S: 52% G: 44% Total: 45%	Total: 659	Total: 343

Table 34. Information on Appliance Ownership and Operations (cont.)

Equipment Type	% of Households Possessing	Average Power (Watts)	Average Hours Used Per Year
Electric stove	B: 0% S: 9% G: 0: 0% Total: 3%	S: 750	S: 234
Electric oven	B: 0% S: 3% G: 4% Total: 2%	Total: 647	Total: 30
Microwave oven	B: 70% S: 69% G: 56% Total: 65%	Total: 105	Total: 520
Kitchen exhaust fan	B: 12% S: 31% G: 0% Total: 16%	Total: 737	Total: 580
Television	B: 138% S: 124% G: 81% Total: 117%	Total: 103	Total: 1235
Personal computer	Total: 4%	Total: 50	Total: 307
Iron	B: 6% S: 53% G: 19% Total: 27%	Total: 751	B: 17 S: 137 G: 137 Total: 96

Note: B= Beijing; S=Shanghai; G=Guangzhou; Total = total of all three cities. Where individual values are not provided, values for individual cities were very similar to each other or sample sizes for individual cities were too small to be meaningful. Values greater than 100% indicate ownership of multiple units in households. Guangzhou data is derived from a small sample and may be biased. Guangzhou TV ownership may be biased downward, since no Guangzhou respondent answered the survey question about ownership of a second television.

d. Use of New Refrigerators

Approximately one month after the new refrigerator was installed, field staff visited each apartment and measured temperatures in the fresh food and freezer compartments using a mercury bulb thermometer. On average, they found that freezers were -17 °C (+1 °F) and fresh food compartments were 9 °C (48 degrees F). While Beijing temperatures were lower, temperature measurements were only made in a few Beijing homes, and thus these differences may not be significant. On average, both the fresh food and freezer compartments were approximately half full with food at the time of the field visit. Additional data on these issues are summarized in Table 35.

Table 35. Data on Use of New Refrigerator (After One Month)

	Beijing	**Shanghai**	**Guangzhou**	**All**
Interior temperature (°C):				
Freezer	-20.3	-16.4	NA	-16.9
Fresh food	7.7	9.7	NA	9.4
How full on average?				
Fresh food	39%	54%	41% (44%)	48%
Freezer	72%	44%	60% (58%)	53%

Note: Data in parentheses were gathered at the end of the study period.

4. Field Test Energy Consumption Results

On completion of the field tests in June 1996, energy consumption results were compiled and combined with socio-economic data into one large data set, and a series of analyses of variance were performed. The results of these analyses are described below. The analyses were based on 85 observations of energy consumption with associated socio-economic information, since nine more observations—one prototype in Beijing, one baseline in Guangzhou, and seven prototypes in Shanghai—contained more than 90 percent missing values and had to be deleted from the analyses. All analyses were performed with the aid of the Statistical Analysis System (SAS) procedures PROC TTEST and PROC GLM. A description of these procedures complete with references can be found in the *SAS/STAT User's Guide*, Version 6, Vol. 2, 1989 (Cary, NC: SAS Institute).

a. Overall Energy Consumption

The two-sample t-test revealed that prototype refrigerators consumed on average 26.8 percent less energy than baseline refrigerators. This difference is significant, with the p-value less than .0001. This p-value indicates that there is only a .01 percent chance that the average energy consumption of the prototype refrigerators is the same as that of the baseline refrigerators. The 95 percent confidence interval for the energy savings of the prototypes is 21.5 to 32 percent.

Laboratory tests of the prototype model BCD-222B showed an average 39 percent reduction in energy use compared to the baseline BCD-220 model. Based on Chinese testing procedures (performed at an ambient temperature of 25°C), the BCD-222B consumed 0.84 kWh per day, compared to 1.37 kWh per day for the BCD-220 model. The BCD-220 was, however, replaced by a new BCD-225 model at the time of the field testing program. About 5 percent more efficient than the 220, the 225 consumed 1.3 kWh per day (based on Chinese testing standards). With the BCD-225 as the baseline model, the prototype thus consumed 35 percent less energy in standard tests and 26.8 percent less energy on average in the field tests.

Tables 36, 37, and 38 contain the means for the models and cities and the pair-wise comparisons between the cities produced by the F-test (all the other analyses below have also been done using the F-test):

Table 36. Mean Energy Consumption, kWh/day

Model	City	Mean•	Sample Size
Prototype	Beijing	0.78	26
Prototype	Guangzhou	0.79	18
Prototype	Shanghai	0.84	28
Baseline	Beijing	1.00	7
Baseline	Guangzhou	1.10	1
Baseline	Shanghai	1.29	5

Table 37. Comparisons of Prototype Refrigerator Means

Cities	p-value	Conclusion
Beijing and Guangzhou	.5057	Not different
Guangzhou and Shanghai	.0027	Different
Shanghai and Beijing	.0001	Different

Table 38. Comparisons of Baseline Refrigerator Means

Cities	p-value	Conclusion
Beijing and Guangzhou	.0235	Different
Guangzhou and Shanghai	.0001	Different
Shanghai and Beijing	.0001	Different

Means for the prototype units are similar for Beijing and Guangzhou ($p= 0.5057>0.05$), but different for Shanghai. The means for the baselines are all different, although the relatively large p-value for Beijing and Guangzhou in comparison to the others implies that the means for these two cities are much more likely to be the same than those for the other city pairs. However, having only a single baseline unit in Guangzhou calls into question any conclusions based on this small sample size.

b. Relationship of Energy Consumption to Socio-Economic Factors

This analysis seeks to determine if the observed difference between the energy consumption of the prototypes and baselines can be explained by any of the socio-economic factors collected in the questionnaire. For example, if all prototype refrigerators happened to be installed in Beijing and all baseline models in Guangzhou, the difference in energy consumption could simply be due to the difference in temperature between the cities. Hence it is reasonable to examine the differences between models by city, income group, and other factors. Such pair-wise comparisons of prototypes and baselines are summarized in Tables 39 through 46.

Table 39. Energy Savings Versus Location
n=85

City	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
Beijing	22%	.0001	Significant	(18.5%, 25.5%)
Guangzhou	28%	.0003	Significant	(20.8%, 35.3%)
Shanghai	34.7%	.0001	Significant	(32.1%, 37.2%)

Table 40. Energy Savings Versus Number of People in Apartment
n=36

Number of People	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
2	22.1%	.1289	Non-significant	
3	22.4%	.0008	Significant	(14.7%, 30.2%)
4	20.1%	.0028	Significant	(14.3%,25.8%)

Table 41. Energy Savings Versus Family Income
n=84

Income Group	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
2	28.5%	.1203	Non-significant	
3	32.6%	.0009	Significant	(26.8%, 38.4%)
4	18.1%	.0001	Significant	(12.1%, 24.1%)
5	36.5%	.0001	Significant	

Table 42. Energy Savings Versus Air Conditioning
n=84

A/C	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
No	24.7%	.0006	Significant	(17.7%, 31.7%)
Yes	30.6%	.0001	Significant	(24.7%, 36.5%)

Table 43. Energy Savings Versus Electric Space Heater
n=84

Heater	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
No	25.5%	.0001	Significant	(19.8%, 31.3%)
Yes	34.0%	.0001	Significant	(29.7%, 38.3%)

Table 44. Energy Savings Versus One Fan
n=80

One Fan	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
No	21.4%	.0009	Significant	
Yes	27.1%	.0001	Significant	(21.4%, 32.7%)

Table 45. Energy Savings Versus Two Fans
n=80

Two Fans	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
No	30.4%	.0003	Significant	(23.7%, 37.1%)
Yes	19.9%	.0001	Significant	(16.4%, 23.5%)

Table 46. Energy Savings Versus Kitchen Exhaust Fan
n=83

Kitchen Fan	Energy Savings	p-value	Conclusion	95% Confidence Interval for Energy Savings
No	25.2%	.0002	Significant	(18.9%, 31.5%)
Yes	31.2%	.0001	Significant	(23.4%, 38.9%)

Table 39 indicates that geographical location is a significant indicator of prototype energy savings, while Table 40 shows that these savings are significant only in apartments of three or four inhabitants. Only one baseline refrigerator was installed in an apartment with 2 residents, so this p-value is not very reliable. Data were also insufficient to test these cases for apartments with five or six inhabitants and for families in income group 6 (RMB 3001-4000/month). The results shown in Tables 41 through 46 indicate that the prototype's energy savings is significant for all of the other variables in the data set. This implies that the observed difference in energy consumption can be explained by no single variable, other than that the prototype is more energy efficient than the baseline. (An insufficient number of complete data sets was available to do a step-wise analysis to determine if the energy consumption difference between the two models could be explained by a combination of two or more of the socio-economic factors.)

Tables 39 to 46 compare the energy consumption of the two models as a function of one of the socio-economic factors (e.g. city, family income, etc). The energy consumption of the baseline and prototype models in these comparisons was in most cases significantly different. It is also possible to look at one model and determine if its energy consumption is significantly affected by socio-economic factors. For example, looking separately at apartments with and without air conditioning, it can be ascertained if energy consumption of the prototypes and baseline models is significantly influenced by the presence of air conditioning. The p-values for these tests are given in Table 47, with a p-value greater than 0.05 indicative of non-significance or no sensitivity to a given socio-economic factor, and a p-value less than 0.05 indicative of significance or sensitivity to a given factor.

Table 47. Changes in Energy Consumption

Socio-Economic Factor	Prototype p-value	Baseline p-value
City temperature	.0001	.0001
Family income	.3891	.7540
No. of people	.8164	.7000
Air conditioning	.3821	.0001
Space heater	.1514	.0018
One fan	.5684	Not enough data
Two fans	.7846	.0009
Kitchen exhaust fan	.4468	.0156

This table shows that prototype energy consumption was most sensitive to city temperature and independent of other socio-economic factors. In contrast, baseline model energy consumption was significantly influenced by city temperature as well as the presence of air-conditioning, space heating, and fans. In both cases, family income and the number of people in the apartment had no significant influence on energy consumption. The reasons for this difference between baseline and prototype models are unclear.

Finally, an analysis for “important variables” affecting the energy consumption of all of the refrigerators indicates that the factors given in Table 48 have a significant effect on energy consumption:

Table 48. Categorical Factors Associated with Significant Effects on Refrigerator Energy Consumption

Factor	p-value	Number of Observations Used in Analysis
Model type	.0001	85
City	.0001	85
Income	.0014	84
Kitchen fan	.0019	83
Air conditioning	.0035	84
Number of people	.0105	36
Two fans	.0480	80

It must however be noted that the significance of the effect of number of people in household on energy consumption is not as reliable as the other conclusions because the analysis is based on too few (i.e., 36) observations. Also, the p-value for “Two Fans” is close to .05, so this factor is close to being significant.

The previous analysis was based on the categorical or indicator variables (i.e., the variables that divided households into categories, such as households with and without air conditioning). A further analysis of the continuous variables (shown in Table 49) which underlie these categorical variables (such as power, number of days per year and hours per day) shows that only the following continuous characteristics have a significant effect on energy consumption of the refrigerators.

Table 49. Continuous Factors Associated with Significant Effects on Refrigerator Energy Consumption

Factor	Characteristics and their p-values
Air conditioning	Power (p=.0030) Days/year (p=.0045) Hours/day (p=.0004)
Kitchen fan	Days/year (p=.0171) Hours/day (p=.0430)

c. Summary of Findings

Despite the limited size of the data set collected by the end of the field test period, several conclusions can be drawn about the operation of the prototype refrigerator in households. Clearly, the prototype refrigerator demonstrated substantial energy savings over the baseline model, averaging a reduction of 27 percent in power consumption. This compares to a 35 percent reduction in laboratory testing.

Greater savings were enjoyed in the warmer cities, with the lowest savings found in Beijing (22%) and the highest in Shanghai (35%). The lower savings in Beijing and Guangzhou were in part due to the unexpectedly low electricity use of the baseline refrigerators, which consumed on average 19 percent less power than in laboratory tests. Power use by the prototype refrigerators in these two cities also was about seven percent less than in laboratory tests. In both cases, relative and absolute savings were lower than what was achieved in the laboratory . Interestingly, the consumption figures for Shanghai almost exactly matched laboratory tests for both the prototype and the baseline, resulting in comparable savings.

Households with space heaters showed higher energy savings than those without space heaters, as would be expected from refrigerators with thicker insulation. Some results, however, were counterintuitive, as higher savings were also demonstrated in households with air conditioners and kitchen exhaust fans. Households with air conditioners achieved an average 34 percent reduction in refrigerator energy consumption compared to 26 percent for non air-conditioned households. Kitchen exhaust fans, which would also presumably reduce kitchen temperatures, also affected savings: in those households equipped with kitchen exhaust fans, savings increased by 6 percent.

Shanghai had the highest level of space heater ownership. The heaviest use of air conditioners was also in Shanghai, where both the power rating and number of hours of annual use were higher than in Beijing and Guangzhou (see Table 34). Shanghai led in terms of the number of households with kitchen exhaust fans, and the higher ownership of all three types of appliances may in some way explain the greater savings achieved there.

Further analysis and explanation of the savings in the prototype refrigerator is not possible owing to the absence of data on such potential causative factors as door opening and room temperatures.

5. Consumer Reaction Analysis

By examining factors that consumers like and dislike, manufacturers can improve product design and make the product more appealing. This information is also useful to discover how to best promote a new product, or to promote existing products in new markets. These were the reasons underlying the development of a consumer opinion portion of the household survey questionnaire.

This section of the report summarizes consumer reactions to the 85 prototype units that were placed in the three cities for field testing. Household responses to individual questions are presented and analyzed. A copy of the complete household response survey is included in Appendix B (Form E).

a. Satisfaction Ratings

Participating households were asked to list their top two likes and dislikes about the prototype. Households were given a list of ten features from which to choose, and an opportunity to add features of their own selection to the list.

When participating households were asked what they liked most about their new prototype, 62 percent of responses listed storage capacity. The new model, at 222 liters, provides 35 percent more space than the average of the refrigerators replaced (the increase ranged from 0% to 122%). Additional factors rated as highly desirable include the prototype's styling and temperature reliability. While few households listed the prototype's beneficial environmental impact as one of the primary desirable features, a significant number of households listed this feature as their second (29 out of a total of 98 second-choice responses) choice, making this the second most highly ranked feature overall. Relatively few households listed the prototype's energy efficiency as a desirable feature, even though over two-thirds of the households reported lower energy consumption after installation of the prototype. These responses are presented in Figure 15. The original tabulation can be found in Appendix D, Table E1.

Three features were highlighted by households as unsatisfactory. The most disliked feature (39 of 86 responses, or 45%) was noisy operation. Notably, 38 of a total of 65 respondees (58%) listed this as their first selection regarding the prototype's most unsatisfactory feature. The feature listed next most often as unsatisfactory was the lack of an automatic defrost system (23% of responses), followed by unattractive styling (16% of responses). Also notable is that more respondees listed unattractive styling as their first most unattractive feature than listed lack of an automatic defrost system (11 versus 7 respectively). However, none of the households that responded to this question found the new model a poor value for the money. It is also interesting to note that there were significantly more "likes" than "dislikes" listed in the evaluation of the prototype (218 versus 86). These responses are summarized in Figure 16, and the original tabulation appears in Appendix D Table D2. (Note that the number of responses in some cases exceeds the number of responding households because some households entered more than the required two responses.)

Figure 15. Classification of Features that Households Found Most Satisfactory
(ranked by total number of households selecting the indicated feature)

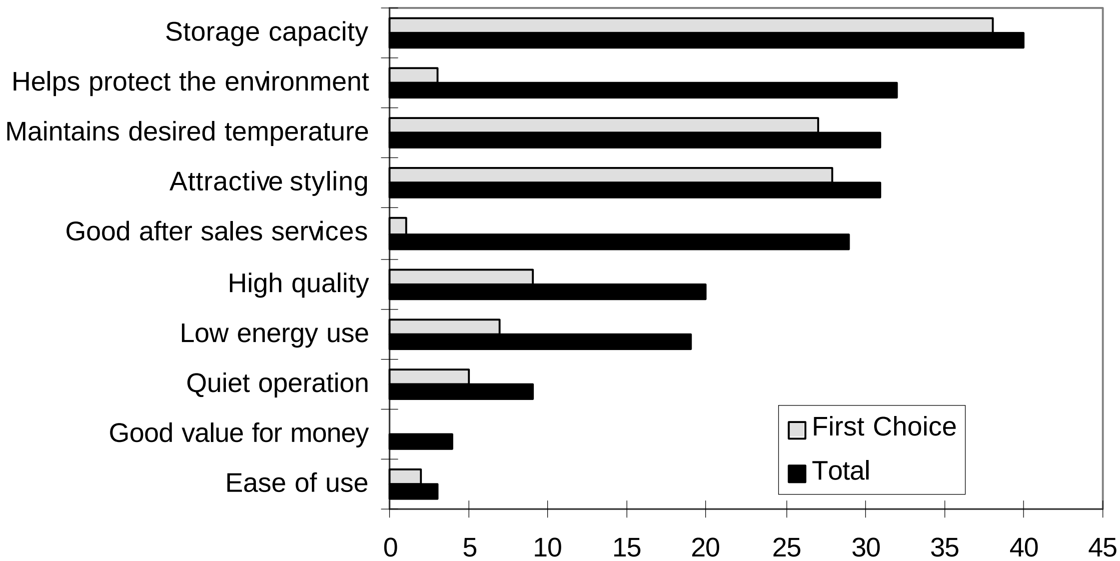
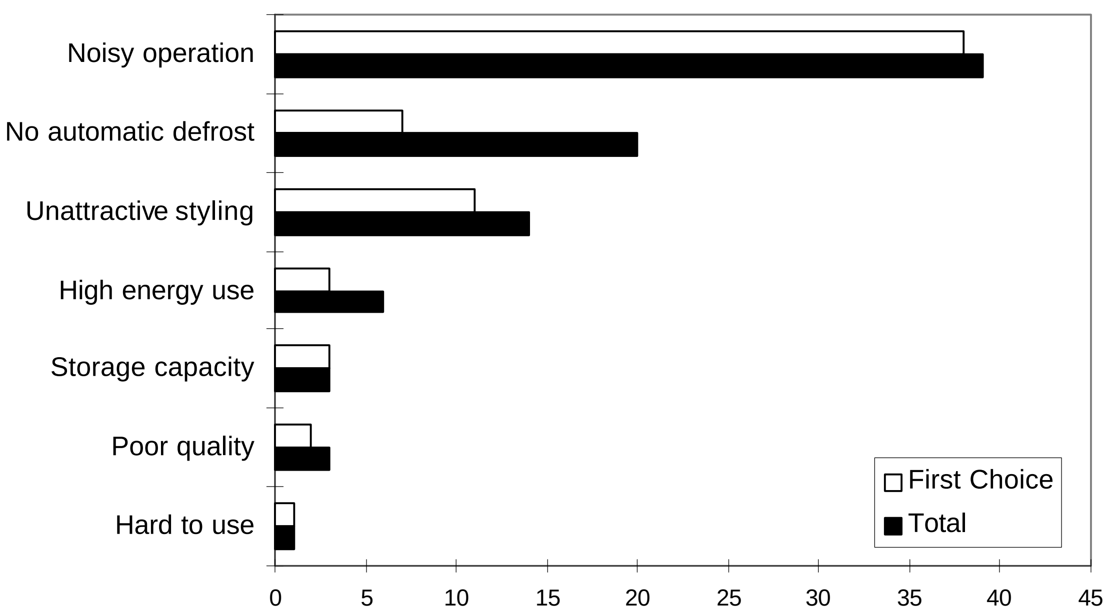


Figure 16. Classification of Features That Households Found Least Satisfactory
(ranked by total number of households selecting the indicated feature)



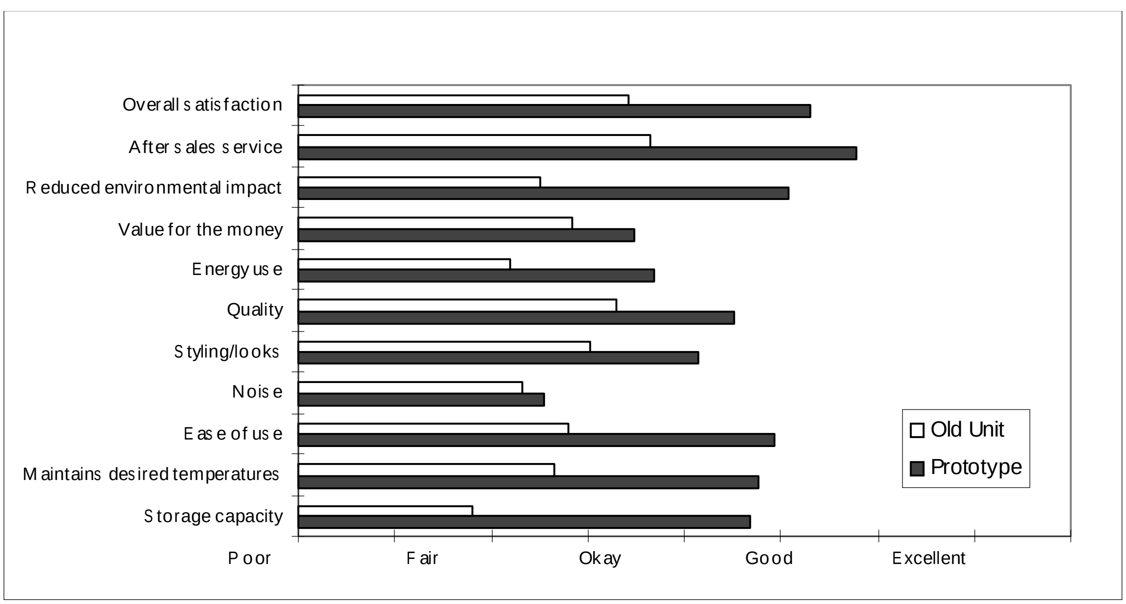
b. Comparison of New and Old Model Ratings

Households were also asked to rate both the prototype and their previously owned model as poor to excellent, based on the following characteristics:

- Storage capacity
- Maintaining desired temperatures
- Ease of use
- Noise
- Styling/appearance
- Quality
- Energy use
- Value for the money
- Reducing impacts on the environment
- After sales service
- Overall satisfaction

The weighted averages of these ratings are presented in Figure 17, calculated by assigning numerical rankings (Poor = 1, Excellent = 5) to the survey results, multiplying each ranking by the number of responses it received, and dividing by the total number of responses. Separate response data for the new and old models can be found in Appendix D, Tables D3 and D4. Appendix D, Table D5 compares the responses for both models, using only responses that rated both new and old refrigerators.

Figure 17. Weighted Average Rating of Prototype vs. Old Unit



More than half of the responding households rated the prototype as “okay” to “excellent” for ten of the eleven categories (all characteristics except for noise), 69 percent of responding households felt “good” with their purchase, and 28 percent of responding households felt “okay” about their purchase. Note, however, that there is some ambiguity in comparing this result to the 43 percent of households that rate “Value for the money” of the new refrigerator as “fair”, and that for two of the characteristics (energy consumption and value for the money), ratings in the “okay” to “excellent” were only slightly above 50 percent. Also, as noted above, interpretation of this response is affected by the fact that households purchased the prototype refrigerator at a significant discount in order to encourage and reward participation in the survey. This overall response and the reasons for it are consistent with consumer responses on likes and dislikes discussed above. More notable, however, is that a significant number of respondents (28 out of 58, or 48%) rated the prototype as “fair” or “poor” (mostly the former) in energy use, indicating that these households’ expectations of energy savings were not, or only partially, met. This rating was however superior to the 74 percent of respondees who rated energy use of their original refrigerator as “fair” or “poor”. See also further discussion on energy use later in this section.

Identical categories and rating systems were also adopted for the old refrigerators. As detailed in Appendix D, Table D4, none of the households surveyed gave their original units a rating of “excellent” in any of the categories except noise, and more than half of the households rated their old units as “poor” to “fair” for seven of the eleven categories. For the four categories in which at least half of responding households rated their original units as “okay” to “excellent” (styling, quality, after sales service, and overall satisfaction), households are nearly evenly divided between a “poor” to “fair” and “okay” to “excellent” rating.

c. Energy Use

Participating households were asked if they noticed a difference in their electricity usage since installation of the prototype. Of those that reported seeing a difference, 68 percent reported that they used less electricity after installation of the Prototype model. For those households which made information available on the rated power consumption of their previous unit, the decrease in average rated refrigerator electricity use for households reporting less energy use was 0.62 kWh/day, in comparison to 0.41 kWh/day for households which reported an increase in energy use. Households which reported a decrease in energy use had average prototype energy consumption of 0.72 kWh/day, as opposed to 0.85 kWh/day (18% higher) for households which reported noticing an increase in energy use. Those households that reported noticing an increase in their energy use originally had, on average, relatively smaller models of the old refrigerators that consumed less electricity (the average of all old models was 1.14 kWh/day). The savings from the prototype, therefore, were correspondingly less, and may have been compensated for by an increase in other electricity use.

d. Summary of Findings

According to the information provided, households were generally satisfied with the new prototype units. Over two-thirds reported a decline in electricity usage, and its reduced impact on the environment was strongly endorsed. In all, 86 percent of responding households said they would recommend purchase of the prototype model to friends and relatives. The main drawback of the prototype was found to be its noise level (an issue often raised in connection with isobutane compressors), which has in part been dealt with by the design team during revisions for the final product. Consumers were highly satisfied with the larger storage area of the refrigerator, but a general dissatisfaction with the lack of automatic defrost reflected Chinese consumers' growing preference for this more "modern" yet higher energy-consuming feature. In addition, the design team has addressed the styling issue (also listed as one of the prototype's drawbacks by a number of households), and has worked to upgrade the final product's styling by adding external design features now popular in China (e.g., beveled doors).

An additional issue that will affect the market for energy efficient CFC-free refrigerators in China is stated consumer preference for automatic defrost models, which was second highest on the list of what households disliked about the prototype (a manual-defrost model). As the Chinese household refrigerator market has developed and household income has increased, refrigerator purchasers have increasingly demanded bigger refrigerators with such "modern" features as automatic defrost. Though automatic defrost models inherently consume more electricity, manufacturers and promoters of energy efficient refrigerator design may need to take this factor into consideration in future product design plans by also including auto-defrost units in their energy-efficient product lines.

6. Conclusions

The field testing of the prototype refrigerator demonstrated the technical feasibility of manufacturing a CFC-free energy-efficient refrigerator for household use. The results of the year-long field test showed that the prototype saves energy—from 22 percent to 35 percent depending on location. The savings were, however, slightly less than expected. It is unclear if the lower savings were due to the small number of baseline units in the field or if other factors were present for which data are lacking for analysis.

Among the factors found to have a significant impact on energy consumption of the models were the model type (baseline vs. prototype), location (city), family income, and the presence or absence of air conditioning and a kitchen fan. The limited sample size made it difficult to determine which factors, or combination of factors, played a significant role in influencing energy consumption.

Consumers in general liked the prototype refrigerator and indicated that they would recommend it to their friends. The storage capacity of the refrigerator—in many cases larger than the refrigerator it replaced—was considered its most desirable feature, and consumers felt that the refrigerator performed well in maintaining food at the desired temperature. Significantly, environmental protection was an important factor contributing to consumer satisfaction with the refrigerator. A number of users had concerns about the noise level of the new refrigerator, the lack of an automatic defrost feature, and some felt that the styling was not adequate.

About one-third of households felt that energy consumption increased after installation of the prototype. This response is attributed at least in part to the increase in absolute refrigerator size for most consumers, and may also have been influenced by climate, indoor conditions, and other operating factors. It could also reflect that refrigerator savings were swamped by increased electricity use by other appliances or lighting at the same time.

V. CONSUMER PREFERENCE RESEARCH PROGRAM

Focus groups were used to identify consumer preferences for a future marketing/education program to promote CFC-free, energy-efficient products. ACEEE sponsored and directed this effort, which consisted of the following activities:

- selection of an internationally recognized market research firm (Ogilvy & Mather) with an office in China and extensive experience in the Chinese market
- selection of the research approach — a series of focus groups in three major Chinese cities (Beijing, Shanghai, and Guangzhou)
- identification of issues to be explored in the research, including consumer decision criteria, relative importance of energy and environmental concerns in consumer decisions, reaction to potential marketing messages, and suggestions on setting up a labeling program
- selection of a target audience consisting of recent and prospective purchasers of new refrigerators
- development, refinement, testing, and finalization of a script for the focus groups
- conducting of focus groups and revision of the script based on focus group results
- data analysis — comparing findings from different focus groups and identifying trends
- completion of a report on focus group findings.

A. Method

Focus group participants were selected based on the following characteristics:

- monthly family income over 2000 RMB, below which households would be less likely to own a refrigerator
- 25-45 years old
- planning to purchase a refrigerator in the next six months or have purchased a refrigerator in the past six months.

Eight sessions with eight to ten people per session were conducted as follows:

- Beijing: all male, planning to purchase in the next six months
- Beijing: all male, had purchased in the last six months

- Beijing: all female, planning to purchase in the next six months
- Beijing: all female, had purchased in the last six months
- Shanghai: all male, planning to purchase or had purchased in the last six months
- Shanghai: all female, planning to purchase or had purchased in the last six months
- Guangzhou: all male, planning to purchase or had purchased in the last six months
- Guangzhou: all female, planning to purchase or had purchased in the last six months.

B. Results

The focus group studies showed:

- Quality is *the* most important criterion in refrigerator selection.
- Appearance and price are the next most important selection criteria.
- Chinese consumers consider brand name to be a key indicator of quality.
- Quality is an overall index. Chinese consumers considered the following factors to be important and desirable in determining the quality of a refrigerator:
  - Fast and efficient cooling
  - Durability and reliability
  - Quiet operation
  - Savings in electric power consumption.
- The most highly rated advertising concepts were:
  - This refrigerator is one of the few Chinese refrigerators certified to meet the international quality standard International Standards Organization (ISO) 9000.
  - This refrigerator uses 40 percent less energy.
- These consumers were willing to pay 20 percent more (300-500 RMB) for a product which offered 40 percent energy savings and was certified by a highly regarded third party.
- The focus group members indicated that a label is a good way to identify CFC-free products, but quality is more important than environmental protection.

Products from high-awareness brand producers were considered to be of good quality and reliability. Chinese consumers generally obtain information about brands and product features from TV and newspaper advertisements and by soliciting opinions from relatives and friends. After deciding on a specific brand, capacity, features, and price range, consumers go to several department stores to compare prices, check external appearance, examine internal structure (drawers, shelves, etc.), and check for quiet operation and good cooling ability.

While consumers were most interested in international quality certification, certification by a well-respected Chinese organization, such as the China State Bureau of Technical Supervision (SBTS), was seen as a reasonable alternative. Similarly, consumers were attracted to the claim of 40 percent energy savings, provided that these claims were backed by a reputable, independent organization. Interestingly, when consumers were asked whether 50 percent energy savings would be more appealing than 40 percent, many said no because they did not find 50 percent energy savings believable.

Since Chinese consumers generally felt that quality was more important than environmental protection, it was concluded that all CFC-free refrigerators should pass a quality standard before being awarded labels designating them as “super-efficient, CFC-free” models.

The complete consumer focus group report is presented in Appendix C.

VI. CONCLUSIONS

- Good agreement was found between energy consumption tests performed at CHEARI and U. Md., while energy consumption measured at Haier was generally lower due to minor differences in testing procedures.

- Small energy savings (≤3 percent) were obtained with the conventional cycle as compared to the original cycle.

- The Lorenz cycle yielded over 20 percent savings when HCFC/HFC blends were used.

- Addition of insulation (23 mm to cabinet sides and back and 10 mm to both doors) and improvement in insulation thermal conductivity from 18.4 to 17.0 mW/(m*K) resulted in 20 percent energy savings.

- Addition of insulation (23 mm to cabinet sides and back and 15 mm to both doors) and improvement in insulation thermal conductivity from 18.4 to 17.0 mW/(m*K) produced:
  - 35 percent savings with a 1.32-COP compressor and a R22/R152a refrigerant blend
  - 44 percent savings with a 1.30 or 1.31-COP compressor and isobutane refrigerant in a conventional cycle
  - 54 percent savings with a 1.48-COP compressor and isobutane
  - 5 percent reduction in savings after conversion to cyclopentane blown foam with a thermal conductivity of 0.020 W/(m*K)
  - no change in savings with other pure refrigerants
  - 4 percent additional savings with a R290/R600a blend
  - no change in savings with the Haier or Lorenz IV cycle with a R22/R152a/R123 blend
  - 7 percent more savings with Lorenz, L-M, or ML-M cycles and hydrocarbon blends
  - loss in additional savings when independent temperature control of the two refrigerator compartments was initiated.

- The zero-ODP units with the highest energy efficiency resulted in approximately 40 percent energy savings relative to the baseline. These units incorporate the original cycle, isobutane refrigerant, an additional 15 mm of cyclopentane blown foam insulation added to cabinet doors, and an additional 23mm of cyclopentane blown foam insulation added to cabinet sides, back, and bottom.

- Field tests of the project prototype show that the new unit is significantly more energy efficient than the baseline unit under actual household use conditions, though proportional savings are lower than in the laboratory.

- Consumer opinion research found that quality is the most important criterion in deciding on a refrigerator purchase, and consumers would pay 20 percent more for a quality product that consumed 40 percent less energy.

- For other manufacturers in China and elsewhere who wish to adopt CFC-free energy-efficient refrigerator technology, the Sino-US Refrigerator Project demonstrates that it is technologically feasible to do so.

- A substantial increase in energy efficiency can be obtained through the adoption of technically proven measures, each of which has been put into use by manufacturers. The prototype developed in this project demonstrates that the combination of measures can result in significant energy savings. In the case of consumers in Beijing, Shanghai, and Guangzhou, where electricity prices have risen to ¥0.75-1.00/kWh, savings from the prototype could equal up to 1 percent of total household income annually.

VII. REFERENCES

AHAM (Association of Home Appliance Manufacturers). 1988. *Standard for Household Refrigerators and Household Freezers*. American Home Appliance Manufacturers. Chicago. 1988.

ASHRAE (American Society for Heating, Refrigeration, and Air Conditioning Engineers) 1992. ANSI/ASHRAE Standard 34-1992, *Number Designation and Safety Classification of Refrigerants*. Atlanta, GA. 1992.

China Daily. “Industrial Output hit $532b.” *China Daily Business Weekly*. February 2, 1996.

China Leading Group for Ozone Layer Protection. *ODS Phase-out Strategy for Domestic Refrigeration*. International Symposium on Sectoral Strategies for ODS Phase-out in China. Xian. June 1995.

EPA 1997. Fine, Alan, et al., *The Sino-US CFC-Free Super-Efficient Refrigerator Project Progress Report: Prototype Development and Design*. Washington DC: USEPA, 1997. (in progress)

IPCC (Intergovernmental Panel on Climate Change). 1995. *Climate Change 1995: The Science of Climate Change*. Cambridge University Press. 1995.

Nadel et al. 1997. Nadel, Steven, Guan Fu Min, Yu Cong, and Hu Dexia, “Lighting Energy Efficiency in China: Current Status, Future Directions,” American Council for an Energy-Efficient Economy, Washington, DC, 1997.

Radermacher, R., Z. Liu, S.I. Haider and B.Y. Liu. 1994. “Test Results of Hydrocarbon Mixtures in Domestic Refrigerators/Freezers.” *1994 International CFC and Halon Alternatives Conference: Conference Proceedings*. October 1994.

Radermacher, R., Z. Lu, S.I. Haider, and B.Y. Liu. 1995a. “Independent Compartment Temperature Control of a Modified Lorenz-Meutzner-cycle Refrigerator with a Hydrocarbon Mixture.” *1995 International CFC and Halon Alternatives Conference: Conference Proceedings*. October 1995.

Radermacher, R., Z. Liu, and S.I. Haider. 1995b. "Simulation and Test Results of Hydrocarbon Mixtures in a Modified-Lorenz-Meutzner Cycle Domestic Refrigerators." *International Journal of HVAC&R Research*. Volume 1, Number 2. April 95. Pp. 127-142.

SBTS. no date. China State Bureau of Technical Supervision. *China National Household Refrigerator Standard GB8059.1*. People’s Republic of China State Bureau of Technical Supervision.

SBTS. no date. China State Bureau of Technical Supervision. *China National Household Refrigerator Standard GB8059.2*. People's Republic of China State Bureau of Technical Supervision.

SSB 1994. *China Statistical Yearbook 1994*. Beijing. 1994.

SSB 1995. State Statistical Bureau, *Zhongguo Renkou Tongji Nianjian (China Population Statistics Yearbook) 1995*. Beijing: Statistical Publishing House, 1995.

SSB 1996. State Statistical Bureau, *Zhongguo Tongji Nianjian (China Statistical Yearbook) 1996.* Beijing: Statistical Publishing House, 1996.

UNEP (United National Environment Programme). 1994. *1994 Report of the Flexible and Rigid Foam Technical Options Committee*. UNEP Available from US Environmental Protection Agency. Washington, DC. EPA 430/K94/028. November 1994.

USEPA (US Environmental Protection Agency). 1993a. *EPA Refrigerator Analysis (ERA) Program: Users Manual*. US Environmental Protection Agency. Washington, DC. EPA-430-R-93-007. June 1993.

USEPA (US Environmental Protection Agency). 1993b. Fine, H. Alan, Jean Lupinacci. *Multiple Pathways to Super-Efficient Refrigerators*. US Environmental Protection Agency. Washington, DC. EPA-430-R-93-008. July 1993.

USEPA (US Environmental Protection Agency). 1994. Fine, H. Alan, Jean Lupinacci, Reinhard Radermacher. *Energy-Efficient Refrigerator Prototype Test Results*. US Environmental Protection Agency. Washington, DC.EPA-430-R-94-011. June 1994.

WMO (World Meteorological Organization). 1994. *Scientific Assessment of Ozone Depletion: 1994*. WMO Global Ozone Research and Monitoring Project Report No. 37. Geneva. 1995.

Yang. 1995. Yang Mianmian, et al. "Latest Developments on CFC Substitution in China: Application of HCs on the Refrigerators made by Haier Group, Qingdao, China". *1995 International CFC and Halon Alternatives Conference: Conference Proceedings.* October 1995.

APPENDIX A. Laboratory Test Results

Table A1. CHEARI Test Results - Baseline

Ambient Temp.	25°C					
Prototype ID	BASELINE					
Cabinet ID	ORIGINAL					
System ID	ORIGINAL					
Compressor	B2116B					
Refrigerant	R12					
Purity	99.95%					
Input (W)	142.2	139	137.2	137.1	136.43	133.69
EC (kWh/day)	1.262	1.271	1.312	1.374	1.411	1.461
T ff (°C)	4.8	4.7	4.7	4.9	4.7	4.8
T fz (°C)	-18.2	-18.6	-19.1	-19.8	-20.2	-22.8
On-time (min.)*	30	30	30	32	32	33
Off-time (min.)*	50	50	46	46	44	36
Duty-cycle (%)	37.5	37.5	39.5	41.0	42.1	47.8

* There are several cycles in a long cycle.

Table A2. CHEARI Test Results - Cycle Modifications

Ambient Temp.	25 °C					
Cabinet ID	ORIGINAL					
System ID	LORENZ II					
Compressor	B2116B					
Refrigerant	R22/R142b	R22/R152a/R123	R32/R152a	R32/R134a	R32/R134a/123	R32/R152a/R123
Mass Fraction	55/45	30/40/30	21/79	12/88	10/70/20	24/51/25
Input (W)	137.2	128.91	148.41	139.31	132.11	126.18
EC (kWh/day)	1.112	1.091	1.191	1.201	1.086	1.066
T ff (°C)	4.8	4.7	4.7	4.7	4.8	5
T fz (°C)	-19.3	-19.8	-19.4	-19.3	-19.7	-19.7
On-time (min)	15	13	14	18	13	12
Off-time (min)	28	25	30	31	24	24
Duty-cycle (%)	35	34	32	36	35.1	33.3

Table A2. CHEARI Test Results -- Cycle Modifications (Continued)

Ambient Temp.			25 °C		
Cabinet ID			ORIGINAL		
System ID			LORENZ II		
Compressor			B2116B		
Refrigerant	RC270/R123	RC270/R152a/12	R143a/R134a/R1	R143a/R152a/R1	R143a/R134a/R14
Mass Fraction	50/50	40/40/20	35/50/15	33/52/15	25/55/20
Input (W)				133.25	
EC (kWh/day)	1.051	1.092	1.120	1.107	1.101
T ff (°C)	4.8	4.7	4.7	5	5
T fz (°C)	-20.1	-20.3	-20.1	-19.7	-19.8
On-time (min.)				17	16
Off-time (min.)				33	34
Duty-cycle (%)				34	32

Table A3. CHEARI Test Results - Cabinet Modifications

Ambient Temp.	25°C					
Prototype ID						
Cabinet ID	THICKER I					
System ID	ORIGINAL					
Compressor	B2116B			PW7.5K14		
Refrigerant	R12					
Purity	99.95%					
Input (W)	153.6	151.8	151.3	148.6	147.1	145.2
EC (kWh/day)	1.026	1.08	1.141	1.07	1.104	1.170
T ff (°C)	4.8	4.7	4.7	4.9	4.7	4.8
T fz (°C)	-18.5	-19.2	-20.1	-18.7	-19.2	-20.4
On-time (min.)	10	11	12	12	12	13
Off-time (min.)	24	24	24	24	23	22
Duty-cycle (%)	29.4	31.4	33.3	33.3	34.3	37.1

Table A4. CHEARI Test Results - Cabinet and Component Modifications

Ambient Temp.	25 °C			
Prototype ID				DEC 02
Cabinet ID	THICKER I			THICKER II
System ID	ORIGINAL			
Compressor	PW7.5K14			BK1112A
Refrigerant	R12			R22/R152a
Purity	99.95%			30/70
Input (W)	148.6	147.1	145.2	98.71
EC (kWh/day)	1.07	1.104	1.170	0.861
T ff (°C)	4.9	4.7	4.8	4.8
T fz (°C)	-18.7	-19.2	-20.4	-20.1
On-time (min.)	12	12	13	20
Off-time (min.)	24	23	22	37
Duty-cycle (%)	33.3	34.3	37.1	35.1

Table A5. CHEARI Test Results - System Modifications

Ambient Temp.	25 °C					
Prototype ID	DEC 01		DEC 04	DEC 03	DEC 05	DEC 04
Cabinet ID	THICKER II					
System ID	CONVENTIONAL		LORENZ III	LORENZ III	LORENZ IV	LORENZ III
Compressor	TG105		HL90AH	HL99AH	HC77	HC82
Refrigerant	R152a	DME	R600a			
Purity	99.95%	99.8%	93%			
Input (W)	98.51	96.6	109.08	98.4	78.01	83.72
EC (kWh/day)	0.762	0.744	0.804	0.789	0.696	0.675
T ff (°C)	4.8	4.7	4.8	4.8	5	5
T fz (°C)	-20.1	-20.3	-19.8	-20.1	-20.1	-19.9
On-time (min.)	11	19	14	13	21	12
Off-time (min.)	23	37	27	29	39	26
Duty-cycle (%)	32.4	33.9	34.2	31	35	31.6

Table A5. CHEARI Test Results - System Modifications (Continued)

Ambient Temp.	25°C				
Prototype ID	DEC 01	DEC 04	DEC 03	DEC 03	DEC 05
Cabinet ID	THICKER II	THICKER II	THICKER II	THICKER II	THICKER II
System ID	CONVENTIONAL	LORENZ III	LORENZ III	LORENZ III	LORENZ IV
Compressor	JB1112	BK1112A	BK1112A	TG105	TG105
Refrigerant	R22/R152a/R123			RC270/R152a/R123	R143a/R152a/R123
Mass Fraction	30/40/30			40/40/20	33/52/15
Input (W)	120.11	110.52	94.37	89.8	93.2
EC (kWh/day)	0.822	0.743	0.721	0.601	0.641
T ff (°C)	5	4.7	4.7	5	5
T fz (°C)	-19.8	-20.1	-20.1	-19.8	-19.8
On-time (min.)	8	5	11	8	14
Off-time (min.)	18	14	27	26	42
Duty-cycle (%)	30.8	26.3	29	23.5	25

Table A5. CHEARI Test Results - System Modifications (Continued)

Ambient Temp.	25°C					
Prototype ID	DEC 04	DEC 01	DEC 03	DEC 05	DEC 03	DEC 05
Cabinet ID	THICKER II	THICKER II	THICKER II	THICKER II	THICKER II	THICKER II
System ID	LORENZ III	CONVENTIONAL	LORENZ III	LORENZ IV	LORENZ III	LORENZ IV
Compressor	TG105					
Refrigerant	R290/R600a		R290/R600		R290/R600a/nC5	
Mass Fraction	60/40		58/42		60/20/20	
Input (W)	97.89	106.71	99.93	100.24	115.27	104.58
EC (kWh/day)	0.666	0.693	0.603	0.624	0.582	0.661
T ff (°C)	4.8	4.7	4.7	5	4.6	4.6
T fz (°C)	-20.2	-20.8	-20.6	-19.8	-19.4	-20.4
On-time (min.)	8	16	8	13	7	14
Off-time (min.)	21	42	25	40	27	42
Duty-cycle (%)	28	28	24.2	24.5	20.6	25

Table A5. CHEARI Test Results - System Modifications (Continued)

Ambient Temp	25 °C						
Prototype ID	HAIER 01	HAIER 02	HAIER 03	HAIER 05	HAIER 06	HAIER 07	HAIER 08
Cabinet ID	THICKER II			THICKER III			
System ID	HAIER SYS	ORIGINAL		ORIGINAL			
Compressor	BK1112A			HL90AH	HL99AH	HC77	HC82
Refrigerant	R290/R600a	R22/R152a	R22/R152a	R600a			
Mass Fraction	55/45	30/70	30/70	90%		99.9%	
Input (W)							
EC (kWh/day)	0.69	0.75	0.78	0.84	0.82	0.78	0.70
T ff (°C)	5	5	5	5	5	5	5
T fz (°C)	-18	-18	-18	-18	-18	-18	-18
On-time (min)							
Off-time (min)							
Duty-cycle(%)							

*Data provided by Haier

Table A6. Haier Test Report 1

BRAND	HAIER	MODEL	BCD-222B
STANDARD	GB8059.2-87	EQUIVALENT	ISO 8187
CABINET ID	OPTION III	FOAMING SYS	ICI cyclopentane
SYSTEM ID	ORIGINAL	REFRIGERANT	R600a
COMPRESSOR	HL 77	CHARGE SIZE	62g
PRODUCTION DATE	MARCH 1995	TEST DATE	APRIL 1995

Table A6. Haier Test Report 1 (Continued)

No	Item	Technical Specification	Test Results: 2 Runs		Comment
1	Pull Down	32°C Ambient Temperature Temperature shall be reached as follows in 3 hours Fresh Food: Tm ≤ 7°C °C ≤ T1, T2, T3 ≤ 10°C Freezer: Tm ≤ -18°C	4.2 hours	4.1 hours	did not meet standard
2	Storage Temperature	32°C and 16°C Ambient Temperature Temperature shall be kept as follows, after stable operating conditions have been attained. Fresh Food: Tm ≤ 5°C 0°C ≤ T1, T2, T3 ≤ 10°C Freezer: Tf ≤ -18°C	32°C Tm=3.7°C Tf=-20.0°C 16°C Tm=4.0°C Tf=-19.3°C	32°C Tm=4.4°C Tf=-18.9°C 16°C Tm=2.9°C Tf=-19.0°C	Good
3	Energy Consumption	25°C Ambient Temperature Fresh Food: Tm = 5°C 0°C ≤ T1, T2, T3 ≤ 10°C Freezer: Tf ≤ -18°C Measured energy consumption shall not exceed 115% of rated values.	0.75 kWh/day	0.74 kWh/day	Good

Table A6. Haier Test Report 1 (Continued)

4	Freezing Test	25°C Ambient Temperature Light Load (M Package) shall be frozen from 25°C to -18C in 24 hrs. The maximum temperature of any packages in the ballast load should remain equal to or colder than -15°C. At end of test, maximum temperature of the warmest M Package shall be equal to or colder than -18°C. During the test: $T_m \le 7°C$ $0°C \le T1, T2, T3 \le 10°C$	12.0 kg takes 18.7 hr from 25°C to -18°C	12.0 kg takes 19.8 hr from 25°C to -18°C	Good
5	Heating	32°C Ambient Temperature Hermetic compressor motor winding shall not exceed 140°C Compressor shell shall not exceed 150°C	Winding: 74.9°C Shell: 57.8°C	Winding: 76.2°C Shell: 54.0°C	Good
6	Current Leakage	Current leakage shall not exceed 1.5mA.	0.092mA	0.101mA	Good
7	Insulation Resistance and Electrical Strength	Under moist conditions, insulation resistance shall not be less than 2MΩ. Unit must withstand a voltage of 1250V for 1 minute	> 500MΩ No flashover or breakdown	> 500MΩ No flashover or breakdown	Good
8	Grounding		0.065Ω	0.060Ω	Good
9	Temperature Rise Test	25°C Ambient Temperature Length of time from when the temperature of warmest M Package in freezer reaches -18°C until moment when any one of the M Packages first reaches -9°C.	880 minutes	840 minutes	Good
10	Start	Starting refrigerator at 0.85 rated voltage should not cause fuses to blow.	Failed	Pass	Failed
11	Noise		/	/	
12	Ice-Making		/	/	

Table A6. Haier Test Report 1 (Continued)

13	Input Power and Current		Main Loop: P=80.1W I=0.488A Freezer Loop: P=82.8W I=0.501A	Main Loop: P=80.1W I=0.488A Freezer Loop: P=82.8W I=0.501A	Good

Table A7. Haier Test Report 2

BRAND	HAIER	MODEL	BCD-222B
STANDARD	GB8059.2-87	EQUIVALENT	ISO8187
CABINET ID	OPTION III	FOAMING SYS	ICI cyclopentane
SYSTEM ID	ORIGINAL	REFRIGERANT	R600a
COMPRESSOR	HL 77	CHARGE SIZE	
PRODUCTION DATE	APRIL 1995	TEST DATE	MAY 1995

Table A7. Haier Test Report 2 (Continued)

No	Item	Technical Specification	Test Results			Comment
1	Pull Down	32°C Ambient Temperature Temperature shall be reached as follows in 3 hours Fresh Food: $Tm \leq 7°C$ $°C \leq T1, T2, T3 \leq 10°C$ Freezer: $Tm \leq -18°C$	3.8 hrs	4.1 hrs	3.8 hrs	can not meet standard
2	Storage Temperature	32°C and 16°C Ambient Temperature Temperature shall be kept as follows, after stable operating conditions have been attained. Fresh Food: $Tm \leq 5°C$ $0°C \leq T1, T2, T3 \leq 10°C$ Freezer: $Tf \leq -18°C$				
3	Energy Consumption	25°C Ambient Temperature Fresh Food: $Tm = 5°C$ $0°C \leq T1, T2, T3 \leq 10°C$ Freezer: $Tf \leq -18°C$ Measured energy consumption shall not exceed 115% of rated values.	0.71 kWh/day	0.82 kWh/day	0.73 kWh/day	

Table A8. Haier Test Report 3

BRAND	**HAIER**	**MODEL**	BCD-222B
STANDARD	**GB8059.2-87**	**EQUIVALENT**	ISO 8187
CABINET ID	**OPTION III**	**FOAMING SYS**	ICI cyclopentane
SYSTEM ID	**ORIGINAL**	**REFRIGERANT**	R600a
COMPRESSOR	**HL 77**	**CHARGE SIZE**	60g
PRODUCTION DATE	**APRIL, 1995**	**TEST DATE**	MAY 5, 1995

Table A8. Haier Test Report 3 (Continued)

No	Item	Technical Specification	Test Results		Comment
1	Pull Down	32°C Ambient Temperature Temperature shall be reached as follows in 3 hours Fresh Food: $Tm \le 7°C$ $°C \le T1, T2, T3 \le 10°C$ Freezer: $Tm \le -18°C$			
2	Storage Temperature	32°C and 16°C Ambient Temperature Temperature shall be kept as follows, after stable operating conditions have been attained. Fresh Food: $Tm \le 5°C$ $0°C \le T1, T2, T3 \le 10°C$ Freezer: $Tf \le -18°C$	32°C Tm= 4.6°C Tf= -21.7°C 16°C Tm= 4.5°C Tf= -20.5°C		Good
3	Energy Consumption	25°C Ambient Temperature Fresh Food: $Tm = 5°C$ $0°C \le T1, T2, T3 \le 10°C$ Freezer: $Tf \le -18°C$ Measured energy consumption shall not exceed 115% of rated values.	0.76 kWh/day		

Table A9. U. Md. Test Results - Cabinet and Component Modifications

Ambient Temp.	25°C		32°C		25°C	32°C	
Prototype ID							
Cabinet ID	THICKER II						
System ID	ORIGINAL						
Compressor	BK1112A				HL90AH		HC77-12
Refrigerant	R22/R152a				R600a		
Mass Fraction	30/70						
Input (W)							
EC (kWh/day)	0.873	0.878	1.231	1.217	0.987	1.223	0.947
T ff (°C)	5.2	5.2	3.2	3.2	3.2	3.2	3.6
T fz (°C)	-19.2	-19.1	-19.2	-19.2	-19.6	-19.3	-18.8
On-time (min.)							
Off-time							
Duty-cycle(%)	33	34	47	476	40	60	60

Table A10. U. Md. Test Results - System Modifications

Ambient Temp.	32°C						
Prototype ID							
Cabinet ID	THICKER I						
System ID	LORENZ VI						
Compressor	TG205-12						
Refrigerant	R152a			R600a/R290	R600/R290		
Mass Fraction				36/64	32/68		
Input (W)							
EC (kWh/day)	0.984	0.95	0.970	0.827	0.78	0.772	0.745
T ff (°C)	0.2	4.5	3.2	3.4	2.4	2.7	4.2
T fz (°C)	-15.0	-14.9	-15.0	-15.0	-15.1	-15.1	-15.1
On-time (min)	26	25.5	26	40	18	17	17.5
Off-time (min)	45.5	46	46	108	50	52.5	52
Duty-cycle(%)	36.4	35.6	36	27	24.5	25.2	24.1

Table A10. U. Md. Test Results - System Modifications (Continued)

Ambient	25°C	32°C	32°C	25°C		32°C
Prototype ID						
Cabinet ID	THICKER I					
System ID	LORENZ VI					
Compressor	TG205-12					
Valve*	No		Yes			
Refrigerant	R600/R290					
Mass Fraction	30/70					
Input (W)						
EC (kWh/day)	0.503	0.729	0.847	0.661	0.671	0.868
T ff (°C)	3.3	2.4	3.3	3.1	3.1	3.2
T fz (°C)	-15.0	-15.0	-15.5	-15.2	-15.1	-15.0
On-time (min)	4	4	7	13	15	13
Off-time (min)						
Duty-cycle(%)	19	21	25	21	21	26

*See reference Radermacher et. al. 1995a for additional information.

Table A10. U. Md. Test Results - System Modifications (Continued)

Ambient Temp.	32°C	32°C	25°C		32°C
Prototype ID					
Cabinet ID					
System ID					
Compressor					
Valve*	No	Yes			
Refrigerant					
Mass Fraction					
Input (W)					
EC (kWh/day)	0.820	1.055	0.675	0.698	0.866
T ff (°C)	2.4	2.3	3.2	2.2	3.1
T fz (°C)	-14.9	-15.0	-15.1	-15.2	-15.1
On-time (min.)	19	23	17	15	12
Off-time (min.)					
Duty-cycle (%)	27	30	21	21	26

*See reference Radermacher et. al. 1995a for additional information.

Table A10. U. Md. Test Results - System Modifications (Continued)

Ambient Temp.	25°C		32°C		25°C		32°C	
Prototype ID								
Cabinet ID	THICKER II							
System ID	LORENZ IV				TG205-12	HAIER		
Compressor	BK1112A							
Refrigerant	R22/R152a/R123				R20-/R600a			
Mass Frac.	30/40/30							
Input (W)								
EC (kWh/d)	0.764	0.764	1.032	1.051	0.873	0.870	1.092	1.091
T ff (°C)	3.0	2.9	3.8	3.9	1.8	1.8	4.6	4.6
T fz (°C)	-16.9	-17.0	-16.6	-16.4	-20.8	-20.8	-18.8	-18.7
On-time (min.)								
Off-time(min.)								
Duty-cycle(%)	31	33	43	43	26	26	32	31

APPENDIX B. Field Test Forms

NCLI/EPA/Haier Refrigerator Monitoring Project
Form A

List of Participating Apartments

City ___________________

Building & Apt. #	Names	Best times to read meter	Refrig. Forms completed B C D E F G	meter Install Date	Meter readings completed (Y = yes)	(enter date) 2wk	4wk	2mo	kVA 3mo	4mo	5mo	6o	7mo
1.													
2.													
3.													
4.													
5.													
6.													
7.													
8.													
9.													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													

NCLI/EPA/Haier Refrigerator Monitoring Project
Form B

Data on Old and New Refrigerator

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number (e.g.: 3-1406 or M-912) 2 __________

3. Information about old refrigerator:

   Brand 3a ___________
   Model number 3b ___________
   Size (liters) 3c _______
   Energy rating (kWh/day) 3d _______
   Year purchased 3e _______

4. New refrigerator installed:

   Model (A=BCD-222, B=BCD-220) 4a ____
   Serial number 4b ___________

5. Meters installed:

   kWh meter (Y=yes, N=no) 5a ____
   kVA meter (Y=yes, N=no) 5b ____

NCLI/EPA/Haier Refrigerator Monitoring Project
Form C

Initial Questionaire

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number 2 __________
(e.g.: 3-1406 or M-912)

3. Number of people living in apartment 3 _____
(exclude visitors and short-term residents -- people living there less than three months per year)

4. Approximate monthly family income: 4 _____
   - A= Less than 500 RMB
   - B= 500-1000 RMB
   - C= 1001-1500 RMB
   - D= 1501-2000 RMB
   - E= 2001-3000 RMB
   - F= 3001-4000 RMB
   - G= More than 4000 RMB

5. Information about other electric equipment in the apartment:

Equipment type	Have? (1=yes, 0=no)	Power (Watts)	# days used/ year	Avg. hrs/ working day
Air conditioner	5a1_____	5a2_____	5a3_____	5a4_____
Electric shower or water heater (if gas, enter 0)	5b1_____	5b2_____	5b3_____	5b4_____
Washing machine	5c1_____	5c2_____	5c3_____	5c4_____
Electric clothes dryer	5d1_____	5d2_____	5d3_____	5d4_____
Electric space heater	5e1_____	5e2_____	5e3_____	5e4_____
Fan #1	5f1_____	5f2_____	5f3_____	5f4_____
Fan #2	5g1_____	5g2_____	5g3_____	5g4_____
Rice cooker	5h1_____	5h2_____	5h3_____	5h4_____
Electric stove	5ii_____	5i2_____	5i3_____	5i4_____
Electric oven	5j1_____	5j2_____	5j3_____	5j4_____
Microwave oven	5k1_____	5k2_____	5k3_____	5k4_____
Kitchen exhaust fan	5l1_____	5l2_____	5l3_____	5l4_____
Television #1	5m1_____	5m2_____	5m3_____	5m4_____
Television #2	5n1_____	5n2_____	5n3_____	5n4_____
Personal computer	5o1_____	5o2_____	5o3_____	5o4_____
Iron	5p1_____	5p2_____	5p3_____	5p4_____
Other major electric appliances -- specify: (include second and third units of appliances listed above)				
5q0__________________	5q1_____	5q2_____	5q3_____	5q4_____

5r0____________________ 5r1______ 5r2______ 5r3______ 5r4______
5s0____________________ 5s1______ 5s2______ 5s3______ 5s4______
5t0____________________ 5t1______ 5t2______ 5t3______ 5t4______

Notes:

(2) Power (Watts): Enter input power, not output power. This can usually be found on a plate on the back of the unit. If you cannot find the power use on the unit, do not estimate, but instead enter -99.

(3) Number days used/year: Approximate number of days appliance is used in a year. For example, if an air conditioner is used 80% of the days during the four summer months, then the number of days it is used is 96 (4 months * 30 days * 80% of the days).

(4) Number of hours used/working day: For those days appliance is used, how many hours is it used on average.

6. Information about electric lights:

Room	Fix- ture Num.	Lamp type (I=incandescent, F=fluorescent tube, C= of lamps compact in fluorescent	Number of all lamps in fixture	Total Watts hours used per day fixture	Number of on average
Room 1	1	6a1___________	6a2_____	6a3______	6a4_______
Room 1	2	6b1___________	6b2_____	6b3______	6b4_______
Room 1	3	6c1___________	6c2_____	6c3______	6c4_______
Room 2	1	6d1___________	6d2_____	6d3______	6d4_______
Room 2	2	6e1___________	6e2_____	6e3______	6e4_______
Room 2	3	6f1___________	6f2_____	6f3______	6f4_______
Room 3	1	6g1___________	6g2_____	6g3______	6g4_______
Room 3	2	6h1___________	6h2_____	6h3______	6h4_______
Room 3	3	6i1___________	6i2_____	6i3______	6i4_______
Kitchen	1	6j1___________	6j2_____	6j3______	6j4_______
Kitchen	2	6k1___________	6k2_____	6k3______	6k4_______
Hall	1	6l1___________	6l2_____	6l3______	6l4_______
Hall	2	6m1___________	6m2_____	6m3______	6m4_______
Toilet	1	6n1___________	6n2_____	6n3______	6n4_______

Other (use these rows for additional rooms or additional fixtures in the rooms listed above)

__________	___	6o1___________	6o2_____	6o3______	6o4_______
__________	___	6p1___________	6p2_____	6p3______	6p4_______
__________	___	6q1___________	6q2_____	6q3______	6q4_______

Note: If lights are used more hours in the winter than the summer, provide the average of the summer and winter figures.

7. Temperatures at time of visit

Freezer (middle compartment, halfway back) 7a_____ C
Refrigerator (2nd shelf from top, halfway back) 7b_____ C

8. Contents of refrigerator and freezer at time of visit

Which statement best describes how full the fresh food and freezer compartments are at the time of the visit?

0 = empty
25 = 25% full
50 = half full
75 = 75% full
100 = completely full

Fresh food compartment 8a_____
Freezer compartment 8b_____

NCLI/EPA/Haier Refrigerator Monitoring Project
Form D

Apartment Electricity Use Data -- 1994

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number (e.g.: 3-1406 or M-912) 2 __________

3. Electricity use data:

Date		kWh used since previous reading
94-1-___	(3a)	
94-2-___	(3b1)	3b2__________
94-3-___	(3c1)	3c2__________
94-4-___	(3d1)	3d2__________
94-5-___	(3e1)	3e2__________
94-6-___	(3f1)	3f2__________
94-7-___	(3g1)	3g2__________
94-8-___	(3h1)	3h2__________
94-9-___	(3i1)	3i2__________
94-10-___	(3j1)	3j2__________
94-11-___	(3k1)	3k2__________
94-12-___	(3l1)	3l2__________
95-1-___	(3m1)	3m2__________
95-2-___	(3n1)	3n2__________
95-3-___	(3o1)	3o2__________
95-4-___	(3n1)	3p2__________
95-5-___	(3o1)	3q2__________

Notes on Forms A, B, C, and D:

Form & question	Note
Form A	This form will be used as a master tracking form for each city, in order to track which information has been collected for each household.
Forms B,C & D Q 1&2	These will be used to keep track of the questionaires and make sure all of the questionaires have been received.
Form B:	
3	This form will be filled out when the old refrigerator is taken from the home. This information will be used to characterize the degree to which the new Haier refrigerator is an upgrade from the old refrigerator.
4	This question separates that homes with standard from super-efficient refrigerators and will be used to make comparisons between these two groups.
Form C:	
3	This will be used in the conditional demand model of apartment energy use that will be used to help determine energy savings from the new refrigerator. It may also be used as a factor to explain variations in refrigerator energy use between apartments.
4	This will be used to compare the households participating in the study to the population at large in the three cities. Data on the population at large will be obtained from the State Statistical Bureau and/or analogous Municipal bureaus.
5	This information will be used in the conditional demand model of apartment energy use. It will also be used to provide limited information on Chinese air conditioners for another possible EPA project. This question is very comprehensive -- if it proves too complicated in a field trial of the questionaire, we will simplify it.
6	This information will be used in the conditional demand model of apartment energy use. It will also be used to provide limited information on Chinese residential lighting for another possible EPA project.
7	When the interviewer enters each apartment, his first task will be to place thermometers in the refrigerator and freezer compartments. These thermometers will be read just before he leaves the apartment.
8	From the choices given, enter the answer that is closest. For example, if the refrigerator is 90% full, enter "100".
Form D:	
3	These data will be obtained from the building management. They will be used for the conditional demand model of apartment energy use.

NCLI/EPA/Haier Refrigerator Monitoring Project
Form E

Final Questionaire

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number 2 ___________
(e.g.: 3-1406 or M-912)

3. a. What two things have you most liked about your new refrigerator?

3a1_____
3a2_____

1= Storage capacity
2= Maintains desired temperature
3= Easy to organize food
4= Quiet operation
5= Attractive styling
6= High quality
7= Low energy use
8= Good value for money
9= Helps protect the environment
10= Good after purchase service
11= Other -- specify:
____
____

b. What things have you not liked about your new refrigerator?

3b1_____
3b2_____

1= Storage capacity
2= Does not maintain desired temperature
3= Difficult to organize food
4= Noisy operation
5= Styling unattractive
6= Poor quality
7= High energy use
8= Poor value for money
9= Does not defrost automatically
10= Bad after purchase service
11= Other -- specify:
____
____

4a. Has your new refrigerator needed any repairs (Y=yes, N=no)? 4a_____
b. If yes, how many times has has it been repaired? 4b_____

5. Please rate your new refrigerator and your old refrigerator on the following attributes:
(1=poor, 2= fair, 3=okay, 4=good, 5=excellent)

New Old

Attribute	refrigerator	refrigerator
a. Storage capacity	5a1_____	5a2_____
b. Maintains desired temperatures	5b1_____	5b2_____
c. Convenience of finding foods in refrigerator	5c1_____	5c2_____
d. Noise	5d1_____	5c2_____
e. Styling/looks	5e1_____	5d2_____
f. Quality	5f1_____	5e2_____
g. Energy use	5g1_____	5f2_____
h. Value for the money	5h1_____	5g2_____
i. Attention to reducing impacts on the environment	5i1_____	5h2_____
j. After purchase service	5j1_____	5j2_____
k. Your overall satisfaction	5k1_____	5k2_____

6. Since obtaining your new refrigerator, have you noticed any change in the amount of electricity you use? 6 _____

A= Now use more electricity
B= Now use less electricity
C= Electricity use has not changed
D= Don't know

7a. Would you recommend to your friends and relatives that they purchase this model of refrigerator? (Y=yes, N=no) 7a_____

b. Briefly explain your answer -- why would you recommend or not recommend this refrigerator?

8. Number of people living in apartment (exclude visitors and short-term residents -- people living there less than 3 months per year) 8_____

9. Has any of the following electrical equipment been purchased in 1995?

Equipment type	Purchased in 1995? (Y=yes, N=no)	Month purchased (1=Jan., 2=Feb., etc.)	Power (Watts)	Was it a new or replacement unit (N=new, (R=replacement)
Air conditioner	9a1_____	9a2_____	9a3_____	9a4_____
Electric shower or water heater	9b1_____	9b2_____	9b3_____	9b4_____
Washing machine	9c1_____	9c2_____	9c3_____	9c4_____
Electric clothes				

dryer	9d1_____	9d2_____	9d3_____	9d4_____
Electric space heater	9e1_____	9e2_____	9e3_____	9e4_____
Fan #1	9f1_____	9f2_____	9f3_____	9f4_____
Fan #2	9g1_____	9g2_____	9g3_____	9g4_____
Rice cooker	9h1_____	9h2_____	9h3_____	9h4_____
Electric stove	9ii_____	9i2_____	9i3_____	9i4_____
Electric oven	9j1_____	9j2_____	9j3_____	9j4_____
Microwave oven	9k1_____	9k2_____	9k3_____	9k4_____
Kitchen exhaust fan	9l1_____	9l2_____	9l3_____	9l4_____
Television #1	9m1_____	9m2_____	9m3_____	9m4_____
Television #2	9n1_____	9n2_____	9n3_____	9n4_____
Personal computer	9o1_____	9o2_____	9o3_____	9o4_____
Iron	9p1_____	9p2_____	9p3_____	9p4_____
Other major electric appliances -- specify: (include second and third units of appliances listed above)				
9q0_________________	9q1_____	9q2_____	9q3_____	9q4_____
9r0_________________	9r1_____	9r2_____	9r3_____	9r4_____
9s0_________________	9s1_____	9s2_____	9s3_____	9s4_____

10. Temperatures at time of visit

Freezer (middle compartment, halfway back) 10a_____ C
Refrigerator (2nd shelf from top, halfway back) 10b_____ C

11. Contents of refrigerator and freezer at time of visit

Which statement best describes how full the fresh food and freezer compartments are at the time of the visit?

0 = empty
25 = 25% full
50 = half full
75 = 75% full
100 = completely full

Fresh food compartment 11a_____
Freezer compartment 11b_____

12. Who answered the questions in this questionaire?

Primary respondent 12a____
Secondary respondents 12b____,____,____

1= Husband
2= Wife
3= Grandmother
4= Grandfather
5= Children
6= Other

NCLI/EPA/Haier Refrigerator Monitoring Project
Form F

Data on Refrigerator Meter Readings

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number 2 __________
(e.g.: 3-1406 or M-912)

3. Meter type (W=kWh, V=kVA) 3 ___
[Note: For apartments with both kWh and kVA meters, two Form F need to be filled out -- one for each meter]

4. Refrigerator electricity use data:

Reading	Date	Meter reading	Temperature in room with refrigerator (degrees C)
Initial	95-6-___ (4a1)	4a2_______	4a3_____
2 weeks	95-6-___ (4b1)	4b2_______	4b3_____
4 weeks	95-7-___ (4c1)	4c2_______	4c3_____
2 months	95-8-___ (4d1)	4d2_______	4d3_____
3 months	95-9-___ (4e1)	4e2_______	4e3_____
4 months	95-10-___ (4f1)	4f2_______	4f3_____
5 months	95-11-___ (4g1)	4g2_______	4g3_____
6 months	95-12-___ (4h1)	4h2_______	4h3_____
7 months	96-1-___ (4i1)	4i2_______	4i3_____

NCLI/EPA/Haier Refrigerator Monitoring Project
Form G

Apartment Electricity Use Data -- 1995

1. City (B=Beijing, S=Shanghai, G=Guangzhou) 1 ___

2. Building and apartment number 2 __________
(e.g.: 3-1406 or M-912)

3. Electricity use data:

<u>Date</u>		<u>kWh used since previous reading</u>
95-5- ___	(3a1)	3a2__________
95-6- ___	(3b1)	3b2__________
95-7- ___	(3c1)	3c2__________
95-8- ___	(3d1)	3d2__________
95-9- ___	(3e1)	3e2__________
95-10-___	(3f1)	3f2__________
95-11-___	(3g1)	3g2__________
95-12-___	(3h1)	3h2__________
96-1- ___	(3i1)	3i2__________

NCLI/EPA/Haier Refrigerator Monitoring Project
Form H

Refrigerator Repair Record

Date	Bldg & Apt. #	Refrigerator model (A=BCD-222, B=BCD-220)	Describe problem	Describe repairs made
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

Notes on Forms E, F, G and H:

Form & Question	Note
1&2	These will be used to keep track of the questionaires and make sure all of the questionaires have been received.

Form E:

3 This is an open-ended question, to find out what people most like and dislike about the new refrigerator, before we start asking about specific attributes we consider important.

4 This question will help determine the answer to the most basic question -- did the new refrigerator work. Answers to this question will be used to help make sure full repair records are kept.

5 This question determines overall consumer satisfaction with the new refrigerator relative to their old unit, as well as their evaluation of major refrigerator attributes. We will also use this question to try to compare the super-efficient and standard efficiency new refrigerators.

6 This question is to see whether the new refrigerator causes a noticeable change in energy use. This will be compared to test ratings (kWh/day) of the new and old refrigerators.

7 This question helps determine how well consumers like their new refrigerator and will be used in conjunction with questions 2 and 4 to determine overall consumer satisfaction.

8 Answers to this question will be compared to answers to the same question on the initial questionaire to determine if the number of occupants has changed. Changes in occupancy will be noted in the conditional demand model of apartment energy use that will be used to help determine energy savings from the new refrigerator. Answers to this question may also be used as a factor to explain variations in refrigerator energy use between apartments.

9 This question, along with answers to question 5 on the initial questionaire (Form C) will be used in the conditional demand model of apartment energy use that will be used to help determine energy savings from the new refrigerator.

10 When the interviewer enters each apartment, his first task will be to place thermometers in the refrigerator and freezer compartments. These thermometers will be read just before he leaves the apartment.

11 From the choices given, enter the answer that is closest. For example, if the refrigerator is 90% full, enter "100".

12 This question will be used to see if there are any age or sex biases in the sample. Primary respondent is the person who answers most of the questions. Secondard respondents are people who help the primary respondent. "Husband" and "wife" are the adults who rent the apartment. "Grandmother" and "Grandfather" are their parents. "Children" are their children, some of whom may now be adults. "Other includes friends and other relatives.

Form F This form will be used to record data from each meter reading including the date of the reading, the number registering on the kWh meter, and the temperature in the room where the refrigerator is located. Room temperatures will be measured with an electronic thermometer at a point one meter in front of where the freezer and refrigerator compartments meet. Kwh readings will be compared between the standard and efficient refrigerators. The room temperature data will be used to help explain variations in refrigerator energy use between different households.

Form G This is nearly identical to Form D and is used to compile whole-apartment electricity use for the period after the new refrigerator is installed. This data will be used to conduct a conditional demand analysis on energy savings (or an increase in energy use) attributable to the new refrigerator relative to the old refrigerator.

Form H This form will be used to keep track of any repairs that are made to refrigerators during the monitoring period. Answers will be used to help answer the question "how well did the new refrigerators work?"

APPENDIX C. Olgilvy & Mather Consumer Opinion Research Report

Research Report for

Product Promise Test of

CFC-Free and High-efficiency Refrigerator

Prepared By: O&M Beijing
May 11, 1995

CONTENTS

I. BACKGROUND

- ACEEE, NEPA, NCLI, and USEPA are planning to extend the CFC-FREE high efficiency techniques to refrigerator-manufactures within China for the purpose of environmental protection.

- ACEEE, NEPA, NCLI, and USEPA are planning to stimulate consumers' interests in CFC-FREE high efficiency refrigerators through mass media and other effective ways in order to encourage refrigerator-manufactures to produce these refrigerators.

Therefore, ACEEE, NEPA, NCLI, and USEPA commissioned O&M to conduct a product promise test in order to understand consumers' perceptions and attitudes towards CFC-FREE and high-efficiency refrigerators and receive guidance that will help the development of the promotion program.

II. OBJECTIVES

The major purpose of this project is as following:

A. To understand consumers' demand, criteria and priority towards refrigerators.

B. To understand consumers' perceptions, attitudes and priorities towards product promise of CFC-FREE high-efficiency refrigerators.

C. To find out consumers' perceptions and attitudes towards how to identify CFC-FREE high-efficiency refrigerators and how to promote them.

D. To understand consumers' perceptions and attitudes towards CFC's and energy efficiency.

III. METHODOLOGY

A. Approach: Use focus groups -- a qualitative approach for understanding consumers' perceptions and attitudes towards CFC-FREE high-efficiency refrigerators.

B. Sample criteria, each participant:

(a) comes from a family with a monthly family income over 2000 RMB;

(b) is in the 25 - 45 age range; and,

(c) is planning to purchase a refrigerator in the next 6 months or has already purchased a refrigerator in the past 6 months.

The reasons for selecting these criteria are:

1. Those who are going to purchase, or have purchased refrigerators, pay more attention to the product than others.

2. CFC-FREE refrigerators are a new product, so we focused on young people with higher incomes who tend to show more curiosity about new things.

C. Group Composition:

Variables: sex and purchasing status

We originally included two variables based on the assumptions that:

1. Men tend to have quite different attitudes towards a technical product from women, and in their family, both of men and women are decision-makers in selecting refrigerators.
2. Recent purchasers and prospective purchasers have different knowledge, concerns and shopping experiences about refrigerators.

Group composition:

Group	Sex	Age	Purchasing status
1.	male	25 - 45	plan to purchase refrigerator in the next 6 months

2.	male	25 - 45	had purchased refrigerator in the past 6 months.
3.	female	25 - 45	plan to purchase refrigerator in the next 6 months
4.	female	25 - 45	had purchased refrigerator in the past 6 months.

Sample size: 8 - 10 participants in each group

D. Sample recruitment:

We recruit samples by Central Location Test around 3-4 of the biggest department stores in different districts of each city. Every participant passed a screening questionnaire which is attached as appendix I.

E. Region:

Since consumers in different parts of China have different attitudes and habits, we plan to carry out the product promise test in the following three large cities: Beijing , Shanghai, and Guangzhou.

We carried out the test in Beijing first, running 4 focus groups. Because we found little difference between the recent purchasers and prospective purchasers, we merged them together and conducted only two groups each in Shanghai and Guangzhou (one of men, one of women).

F. Management:

One researcher from O&M managed the whole project, including field work, outline of the findings, and the final report.

G. Facilities: One-way mirror, promise boards

IV. DISCUSSION FLOW

Introduce each other to understand participants' background

Discuss the process of selecting and purchasing refrigerators to understand consumers' demand, criteria, and priority towards refrigerators.

Discuss the promise of the CFC-FREE, high-efficiency refrigerators to understand the consumers' attitudes, preferences, and priorities towards the product promises, which will help to create a suitable product concept for CFC-FREE high-efficiency refrigerators.

Discuss how to identify CFC-FREE, high-efficiency refrigerators to understand consumers' perceptions and attitudes towards the label.

Discuss freon and environmental protection to understand consumers' perceptions and attitudes towards freon and environmental protection.

V. KEY FINDINGS

1. Consumers' demands and priorities in a refrigerator

In consumer's perception of an ideal refrigerator, quality is the first factor. All of our groups consider quality first above all other factors.

In their minds, "quality" is an overall index, which includes qualities such as "durable and reliable", "noiseless", "fast and efficient cooling," and " keeping food fresh".

After quality, consumers will think about the appearance and the price. Consumers in our groups are willing to pay additional money for extra benefits, such as quality.

2. Selection procedure

During consumers' purchasing procedure, they consider brand a key criteria of quality.

In their minds, products of high awareness brands mean good quality and reliability.

Consumers get information about brands and features mostly from ads (on TV and in newspaper) and from soliciting opinions from their relatives and friends.

Once they decide on a specific brand, capacity, features and price range, consumers go to several department stores, to compare prices, check for a good appearance, examine the internal structure (drawers, shelves, etc.), and check for quiet operation and good cooling ability.

3. Preferred combination of promises

The most two important and impressive promises are F and A:

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.

A. This refrigerator can save 40% electric power.

If such a product with the two above mentioned promises was on the market, consumers in our focus groups think it is attractive and worth buying.

These consumers are willing to pay 20% higher price for such a product.

4. The symbol of CFC-FREE refrigerators

All consumers think a label is a good symbol to identify a CFC-FREE product.

Consumers think that quality is more important than environmental protection. So among the list of agencies provided, they consider "State Bureau of Technology Supervision" as the best one to identify best products.

"US Environmental Protection Agency" is another acceptable agency and is generally regarded as the best for identifying CFC-FREE products.

It is essential that all the CFC-FREE products should pass a quality standard before they get the label.

VI. DATA MANAGEMENT

1. Consumers' demands, criteria and priorities

1.1 Consumers' demands and preferred criteria in a refrigerator

All consumers in our groups consider quality first above all other factors.

Many consumers point out that the most important characteristics are:
- fast and efficient cooling to keep the food fresh
- sufficiently large capacity

Furthermore, they consider an ideal refrigerator should have the following characteristics:
- it should be durable and reliable
- it should be quiet
- it should have compartmentalized shelves to keep the food separate and fresh
- it should have good after-sales service
- it should be efficient and economical in order to save electric power

Quality is an overall index, the above mentioned characteristics are all aspects of quality and practicality in consumers' eyes.

After quality, the two things that the consumers find important are (in descending order):
- good appearance
- moderate price

A moderate price range in their minds is 2000 - 3000 RMB for local or JV products, 4000 - 6000 RMB for imported products.

Consumers tend to choose local or JV brands which are priced 2000 - 3000 yuan. Consumers think that local or JV products not only have similar quality as imported products, but also can be cheaper and can provide more convenient after-sale service.

Only a few people in the groups tested in Beijing listed CFC-FREE as being an additional benefit. None of the people in Guangzhou or Shanghai did so. Those that did list CFC-FREE as a benefit did not consider it of great value comparing with quality and price.

1.2 Consumers' demands, criteria essential in a refrigerator by group

The group composition is as the follows:

Beijing

Group 1.	male	25 - 45	plan to purchase refrigerator in the next 6 months
Group 2.	male	25 - 45	had purchased refrigerator in the past 6 months
Group 3.	female	25 - 45	plan to purchase refrigerator in the next 6 months
Group 4.	female	25 - 45	had purchased refrigerator in the past 6 months

Shanghai

Group 5.	male	25 - 45	had purchased refrigerator in the past 6 months
Group 6.	female	25 - 45	had purchased refrigerator in the past 6 months

Guangzhou

Group 7.	male	25 - 45	had purchased refrigerator in the past 6 months
Group 8.	female	25 - 45	had purchased refrigerator in the past 6 months

The important characteristics pointed out in our groups:

Note: Description is very brief here. Please refer to detailed group analysis.

The most important characteristics

	1	2	3	4	5	6	7	8	Total
Durable and reliable	*	*	*	*	*	*	*	*	8
Fast and efficient cooling	*	*	*	*	*	*	*	*	8
Quiet	*	*	*	*	*	*	*	*	8
Excellent after-sales service		*	*	*					3
In-home after-sales service								*	1
A quality certificate						*			1
Save electric power	*		*	*	*	*	*	*	7
Large capacity, bigger freezer						*			1
Large capacity to store vegetables					*				1
Large capacity fridge							*		1
Good appearance			*	*		*			3
Good appearance and well painted								*	1
Moderate price at 2500 - 3000 RMB			*	*			*		3
Famous brand			*						1

Other important characteristics pointed out in our groups:

Other important characteristics	1	2	3	4	5	6	7	8	Total
Excellent after-sales service					*				1
In-home after-sales service							*		1
A quality certificate	*	*							2
Save electric power		*		*					2
Large capacity, bigger freezer	*	*		*					3
Freezer on the bottom			*						1
Large capacity fridge								*	1
Compartmentalized shelves	*	*	*	*	*		*	*	7
Compartmentalized with thermometers						*			1
Good appearance	*	*			*				3
Good appearance and style, design							*		1
Moderate price at 2500 - 3000 RMB	*							*	2
Moderate price less than 3000 RMB		*							1
Price should match the quality					*				1
CFC-FREE	*	*	*						3
Famous brand		*							1
Automatic defrost function			*	*	*	*	*	*	6
Light			*						1
Easily adjusted door				*	*				2
Revolving inner - shelving				*	*				2
Smooth back (covered coils)								*	1

In group 1, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- quiet
- efficient and economical in order to save electric power

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- a quality certificate and convenient after-sales service
- large capacity to store food, especially have a bigger freezer to freeze raw meat and fish.
- compartmentalized shelves to keep the food separate and fresh
- good appearance
- moderate price at 2500 - 3000 RMB
- CFC-FREE in consideration of environmental protection

In group 2, consumers think that the most important characteristics in a refrigerator are:

- durable and reliable
- fast and efficient cooling to keep the food fresh
- excellent after-sales service
- quiet

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- large capacity to store food, especially have a bigger freezer to freeze raw meat or fresh fish
- compartmentalized shelves to keep the food separate and fresh.
- efficient and economical in order to save electric power
- good appearance
- moderate price less than 3000 RMB
- famous brand
- a quality certificate
- CFC-FREE in consideration of environmental protection

In group 3, consumers think that the most important characteristics in a refrigerator are:

- durable and reliable
- fast and efficient cooling to keep the food fresh
- excellent after-sales service
- efficient and economical in order to save electric power
- quiet
- good appearance
- famous brand with a moderate price (2000-3000RMB)

Furthermore, they think that an ideal refrigerator should have the following characteristics:

- large capacity to store food, especially have a bigger freezer to freeze raw meat food or fresh fish. They would prefer the freezer to be at the bottom of the refrigerator
- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh
- light weight and greater permissible incline angle to make transport and installation easier without damage
- CFC-FREE in consideration of environmental protection

In group 4, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- excellent after-sales service
- efficient and economical in order to save electric power
- quiet
- good appearance
- moderate price

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- large capacity to store food, especially have a bigger freezer to freeze raw meat or fresh fish
- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh.
- efficient and economical in order to save electric power

In group 5, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- quiet
- large capacity to store vegetables and fruit in summer
- efficient and economical in order to save electric power

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- good appearance
- good after-sales service
- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh
- door can be easily adjusted to open from either the left or right side
- inner-shelving should be circular and revolving for easy access
- price should match the quality

In group 6, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- a quality certificate and convenient after-sales service
- quiet
- large capacity freezer to store surplus festival food
- efficient and economical in order to save electric power
- good appearance

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh, and have a thermometer in each shelf
- door can be easily adjusted to open from either the left or right side
- inner-shelving should be circular and revolving for easy access
- price should match the quality

In group 7, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- quiet
- large capacity fridge to store dried food, such as dried mushrooms to prevent them from becoming damp or attracting worms
- efficient and economical in order to save electric power
- moderate price (2500-3000 RMB)

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- good appearance and style, such as rounded edges, concealed handle, smokey
- pattern design
- in-home after-sales service
- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh

In group 8, consumers think that the most important characteristics in a refrigerator are:

- durability and reliability
- fast and efficient cooling to keep the food fresh
- quiet
- efficient and economical in order to save electric power
- in-home after-sales service
- good appearance and be well painted

Furthermore, they consider that an ideal refrigerator should have the following characteristics:

- large capacity to store dried food, such as dried mushrooms to prevent them from becoming damp or attracting worms
- automatic defrost function
- compartmentalized shelves to keep the food separate and fresh
- a moderate price (2000 - 3000 RMB)
- smooth back (covered coils)

1.3 Priority

"If the quality is questionable, even if it is very cheap, I would not buy it"

Consumers purchase refrigerators for daily-use. So, they care about whether it has efficient cooling and whether it is durable or not.

Once quality has been established, consumers will pay attention to whether the appearance is good or not. It is useless if it looks beautiful but it cannot cool efficiently.

After these conditions, consumers will take "moderate price" into consideration.

Because a refrigerator is a long-term durable product, consumers think that the purchasing price range can be extended if it is good quality.

Consumers in Shanghai and Guangzhou go further to consider cost as a combination of the following:

a. the basic purchasing price
b. the cost of maintenance (including the transport involved)
c. the monthly cost of electricity (Consumers in Beijing don't mention price in this way.)

All in our groups consider that if it is good quality with low maintenance and low energy consumption, the purchasing price can be raised further.

In conclusion, consumers are willing to pay additional money for extra benefits, such as quality.

All of our groups think that 20% or 300-500 RMB higher is acceptable for a good quality product.

They do not consider a 50% or 1000 RMB higher price worth paying. There is little difference among consumers, female or male, in Shanghai, Beijing or Guangzhou, about acceptable prices.

2 Selection procedure

2.1 Selection procedure

In consumer's perception of an ideal product, quality is the first factor. But in their purchasing selection procedure, what are they thinking about? How do they decide what is a good quality product? How important is branding?

When consumers plan to buy a new refrigerator, they will concentrate on advertisements on TV and in newspapers. Besides this, they will ask their relatives and friends about their knowledge and experience using various brands. After receiving this information, they tend to choose high awareness local brands first, then they think about a suitable capacity and additional features, such as compartmentalized shelves and the position of the ice box.

In fact, before they step into a department store, they have a pretty good idea in mind about the brand, features, and price range of the refrigerator to be purchased.

They usually go around to several department stores and check to see what is available on the market. At this stage, the major purpose is to find a competitive price with a good appearance, and to check on the internal structure (e.g. capacity, storage drawers, and temperature indicators), and to check for quiet operation and good cooling ability.

2.2 Criteria of Quality

From their answers about purchasing procedure, we find that consumers generally consider brand name as the main criteria of quality.

Because quality is a major factor to establish a brand, in consumers' mind, the brand is their guarantee of quality.

With after sales service in mind, consumers often tend to choose local brands such as:

In Beijing:	Xuehua, Xiling, Xinfei, Xindaohaier, Changling;
In Shanghai:	Shangling, Shuanglu;
In Guangzhou:	Hualing, Sanling, Rongsheng.

2.3 Other factors influencing the selection procedure
-The decision maker

Consumers in Beijing, Shanghai and Guangzhou all generally go to department stores in pairs when making the selection. Compared with men, women are more concerned about good appearance and convenient function. Both men and women are equal decision makers.

-Sources of information

First, consumers use mass media such as TV and newspapers to get external new information.

Families , relatives, friends, and colleagues also influence the selection by personal contact and opinion. When consumers make a plan to purchase a refrigerator, they always ask their relatives and friends for information.

-Selection of purchasing store

Consumers usually choose a large store when purchasing a refrigerator because these generally provide good after sales service:

In Beijing:	Xidanshangchang, Baihuodalou;
In Shanghai:	Hualian, Zhongbai, Dongfang;
In Guangzhou:	Huashabaihuo, Nanfangdasha, Guangzhoubaihuo.

3 Priorities of the product's promises

3.1 Preferred combination of promises

After discussing all promises, consumers in Beijing consider that the most important and impressive promises are F , A and B (in descending order):

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.
A. This refrigerator can save 40% electric power.
B. This refrigerator uses CFC-FREE material for the purpose of environmental protection.

Note: This is a change from the previous discussion on important characteristics in which consumers said CFC-FREE is not important. The reason for the change is that the groups discussed CFC's concepts and benefits in between the important characteristics and product promise sections of the focus group.

Consumers in Shanghai consider that the most important and impressive promises are F and A:

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.
A. This refrigerator can save 40% electric power.

In Guangzhou, men and women appear to have different opinions.

Our male group thought that the most important and impressive promises are F and I:

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.

I. This refrigerator has 3 years free post-buying guarantee.

Our female group thought that the most important and impressive promises are A and D:

A. This refrigerator can save 40% electric power.

D. This refrigerator is a high-quality product using the latest techniques from the US and Germany.

They consider that the promise F is too technical a term to comprehend and to remember, but the promise D is more popular and clear.

But a point to note is that after moderator's explanation, the puzzle word to them "ISO 9000" begins to make sense and they pick promise F as the most important and impressive promise.

If such a product with all the above mentioned promises was on the market, consumers in our groups think it attractive and worth buying.

But consumers still pay attention to the price, the appearance and the brand of the new product before they finally pay for it.

"Is it too expensive? I would not buy it if its price is 1000 RMB higher than others.

I would be willing to pay 200 - 300 RMB more at least for such a good quality product.."

-a 25- 45 aged woman in Shanghai

And they have also pointed out that the use of advertising is very important.

"If nobody recognized it, I would not buy it."

-a 25 - 45 aged woman in Shanghai

Consumers are willing to pay more for such a product. In all of our groups, 20% higher price would be accepted.

3.2 Consumers' attitude towards promises by group

After discussion, consumers are requested to fill in a questionnaire, serving as an additional reference. They are given the freehand to answer as they like. We do not confine that they must respond to every question or must pick one promise only. Therefore, the total number collected for each group may exceed the base number or may be less.

The questionnaire asks consumers to judge the promises in terms of :

1.	Importance	--	Whether the promise is critical and indispensable. For example, quality is more important than money in consumers' perception.
2.	Attractiveness/Preference	--	Whether the promise is appealing. For example, saving 40% electricity is preferred, but this is not the most important point as quality.
3.	Impressiveness	--	Whether the promise engraves on consumers' mind. What is impressive can be negative or positive.
4.	Originality	--	Whether the promise is a copy-cat of what is already available on the market or whether it is something unique which consumers do not find in other brands.

Actually, the above four descriptions have no drastic difference. But since CFC-FREE is a rather new concept to consumers, we dig deeper to see if we can find out where CFC-FREE is standing.

Listed below are the consumers' choices in detail:

The most important promises

Groups	1.	2.	3.	4.	5.	6.	7.	8.
Promises:								
Base=	7	8	6	6	8	8	8	8
A	4	2		1	1	2		
F	1	3	4	5	5	1	6	7
I	2		1		1			1
B		1	1			3		1
E		1	1			1		
H		1						
D					1	2	1	
G						1		1
C							1	

The most attractive promises

Groups	1.	2.	3.	4.	5.	6.	7.	8.
Promises:								
Base=	7	8	6	6	8	8	8	8
A	2	4	2		2	5	2	1
F	2	1	2	5	2		2	4
B		1	5		1			1
E	2							
C	1					1	1	
I			1		2		3	2
G				1		1		
D					1	1		1
H						1		1

The most impressive promises

Groups	1.	2.	3.	4.	5.	6.	7.	8.
Promises:								
Base=	7	8	6	6	8	8	8	8
A	3	5	2	1	3	7		
B		2	3				1	2
F	3	1	2	5	5	1	7	6
E	1							
I	1		2		1			1
G								1

The most original promises

Groups	1.	2.	3.	4.	5.	6.	7.	8.
Promises:								
Base=	7	8	6	6	8	8	8	8
A		3		M	6	2	1	M
B		4	2	M	1		5	M
F	1	1	2	M				M
G	3			M		2	1	M
H	2			M			1	M
I			1	M				M
D	1			M				M

The most unimportant promises

Groups	1.	2.	3.	4.	5.	6.	7.	8.
Promises:								
Base=	7	8	6	6	8	8	8	8
G		4	1	M				
H	1	2		M	3	2	3	
D		2		M		1	1	
C	5		1	M			1	1
E			1	M		5	1	
A				M			1	2
B				M	4			
I				M	1			

From the above listed consumers' choices of product promises, we can see 2 things:

First, CFC-FREE scores well in terms of impressiveness and originality. This is a consistent finding in both discussion and questionnaire section.

Second, there are no significant differences between the different areas and sexes in consumers attitude of product promises.

In different areas:

The most important promises

In Beijing F, A, I and B;

In Shanghai F, A and B;

In Guangzhou F, I and D.

The most attractive promises

In Beijing F, B, A and I;

In Shanghai F, A and I;

In Guangzhou F, I and A.

The most impressive promises

In Beijing	A, F, B and I;
In Shanghai	F, A;
In Guangzhou	F, B.

The most original promises

In Beijing,	B, A, F and G;
In Shanghai	A and G;
In Guangzhou	B.

The most unimportant promises

In Beijing,	G, C, H, D;

In Shanghai	H, B and E;
In Guangzhou,	H, C and A.

Different sexes:

The most important promises

In male	F, A, E and I;
In female	F, B, A and G.

The most attractive promises

In male	A, F, and I;
In female	F, A and B.

The most impressive promises

In male	F, A and B;
In female	F, A and B.

The most original promises

In male	F, A, I and B;
In female	F, A, G and B.

The most unimportant promises

In male	H, G, B and D;
In female	E, H, C and A.

3.3 Attitude toward each promise

A. This refrigerator can save 40% electric power. (saving approximately 125 RMB/year)

"This product has more tangible benefits than others available on the market."

- a 25-45 aged woman in Guangzhou

This is the most attractive point. Consumers in our groups found it amazing that 40% of electric power may be saved. But they wonder whether energy efficiency will lead to poor freezing ability and whether the price will be too high. This benefit is very important and clear. If it is true, many consumers said they will definitely buy this refrigerator because it is economical.

They care more about how much energy may be saved. As for how much money, they can calculate themselves. Each refrigerator consumes a different amount of energy and energy cost is different in different regions. Thus, 40% is more accurate than 125 Yuan and it also sounds like more.

40% is more believable than 50%. Participants in all the three cities believe 50% is too much to be true. They suggest that 40% is good enough.

Almost all consumers consider that this is the most attractive promise, except men in our Guangzhou groups because they think that 40% is too high to be believable.

B. This refrigerator applies CFC-FREE material as refrigerant for the purpose of environmental protection.

" There is only one earth. We should take care about our future descendants."

- a 25-45 aged man in Shanghai

Consumers like this idea. They think it is the future of refrigerators and is good for society. Female respondents like it very much. They believe that this new product will replace the old one. This new technology is very important to the human health.

Consumers consider this promise is good for the refrigerator manufacturers because they believe the manufacturers that pay attention to environmental protection and adopt CFC-FREE technology have high social ethics, foresight, and better technology than others.

But for themselves, CFC-FREE isn't as important as quality. They believe an individual can contribute very little. It doesn't count much whether one family uses a CFC-FREE refrigerator. Consumers will not purchase a refrigerator only because it is CFC-FREE.

CFC-FREE is a new type of refrigerator and it will attract great attention. Many consumers will consider buying it if other conditions are similar (quality, price). Female respondents in the 3 cities pay more attention to purchasing a new type of refrigerator because it will not be replaced by newer technology too soon. But they are worried about the soundness of the new technology. It may lead to a less reliable product.

In Beijing, consumers accept this promise most eagerly.

Some consumers in Guangzhou think this product is most original, but not important.

Consumers in Shanghai neither think it is original nor impressive. A few of them even think it the most unimportant promise.

C. This refrigerator can use energy efficiently, thereby making additional energy available to help with China's economic development.

"China's economic development is a big issue. I can do nothing to help it."

- a 25-45 year-old man in Beijing

Almost all consumers in the 3 cities consider it as the most unimportant promise.

"Saving energy" is a good benefit for saving money. But "energy" is such a big concept and it is not clear how much energy may be saved.

"Help with China's economic development" sounds like a slogan. They do not like the connection of slogans with politics.

Saving energy is attractive. But it's not a decisive factor. Every refrigerator claims this benefit.

D. This refrigerator is a high-quality product using the latest techniques from the U.S.A and Germany.

"I do not know what benefits I would get from it, because I do not know which of the latest techniques will be used."

- a 25-45 aged woman in Shanghai

It is too vague.

Good technology doesn't stand for good quality. There is no clear statement about what kind of technology it is.

They will not buy this type of refrigerator until their friends or relatives recommend it.

Our groups in Beijing and Shanghai think it is the most unimportant promise.

Only a few female respondents in Guangzhou accept it because they believe products using imported technique must have good quality.

E. This refrigerator is certified by the Beijing Household Electrical Appliance Research Institute as meeting the highest Chinese quality standards for refrigerators.

"I do not think that the regional level "Beijing" is suitable as an accreditation agency for the highest Chinese quality standards."

- a 25-45 aged man in Shanghai

All consumers in our groups think it is important to pass a quality requirement. But they know nothing about the requirements. BHEARI is not convincing enough because it sounds like a regional criteria.

However, compared with the same type of refrigerator without any kind of certificate, they would prefer this type of refrigerator.

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.

"I think that international standards are more believable than those in China. But I have never heard of ISO 9000 before, I want to know more detailed information about it."

- a 25-45 aged man in Beijing

All of our groups in all three cities think this is the most important and impressive promise.

They like this promise because it is difficult to pass an international standard. This quality standard is clearly defined and authoritative. But they know little about ISO 9000. They would like to have more information about it.

Compared with saying "technology from U.S. and Germany" and "Chinese quality standard," international standard is more convincing, unique, and persuading.

When they are told that it is one of the highest standards in the world, they are willing to purchase this type of refrigerator.

G. Most famous manufacturers in the world have adopted the CFC-FREE high-efficiency technique.

"The new product must be better than the old one, but I do not know the new product's benefits for me."

- a 25-45 aged woman in Beijing

This shows that the manufacturer is financially strong, the CFC-FREE technology is good and passed the quality test. But they are not sure of the specific product and its quality.

They believe CFC-FREE represents a trend in the future. But they don't know what are the benefits for themselves. They will not make purchasing decision until they know more about other benefits.

Almost all consumers do not think this promise is important and even consumers in Beijing (who were most interested in CFC-FREE) think it is among the most unimportant promises.

Only our groups in Shanghai think it is original.

H. This refrigerator has thicker insulation and therefore will keep food colder during power cuts.

"I like the idea of keeping food colder during power cuts, but it sounds stupid using thicker insulation."

- a 25-45 aged man in Beijing

All groups in 3 cities don't think this promise is important.

They all dislike "thicker wall" because it occupies more space, and seems more expensive and dull. It seems much thicker even though it is only 5cm thicker.

Consumers in Guangzhou, especially female respondents are interested in the point "maintains cool temperature longer during power cuts". And they wonder about the actual length of time that it will remain cool.

I. This refrigerator has 3 years free after-sales guarantee.

" This product, which has free after-sales service, must be good quality."

- a 25-45 aged woman in Guangzhou

After-sales service is necessary. It makes consumers feel at ease. Three years guarantee shows high quality and that the manufacturer is confident about its product. Consumers in Guangzhou even think it is more important than saving 40% electric power.

But it is not unusual. All refrigerators have quality guarantee.

If in-home service is guaranteed, it would be much better. It's too difficult to move a refrigerator around.

4 The symbol of CFC-FREE refrigerators

4.1 Consumers' suggestions as to ways in which CFC-FREE refrigerators can be distinguished from freon refrigerators

All groups in Beijing, Shanghai, Guangzhou indicate that a "label " could be used as a symbol to distinguish freon from CFC-FREE refrigerators.

Besides a label, they talk about the following methods:

- a special store or counter for CFC-FREE products
- mass media advertising campaign
- sales staff assistance
- an exhibition of the product

4.2 Consumer attitudes toward a government agency accreditation license

Consumers think a label is a good symbol to identify a CFC-FREE product. And they hope all the labels must have to pass agency accreditation license for guarantee. In consumers' minds, a reliable agency must be on a national level and have a standard on quality.

Consumers think that quality is more important than environmental protection. So among the list of agencies, all consumers consider " State Bureau of Technology Supervision" to be the best one.

"Environmental Protection Agency" is another acceptable agency and is regarded as the best for identifying CFC-FREE products.

Consumers in Guangzhou tend to prefer "U.S. Environmental Protection Agency".

Consumers in Beijing tend to prefer "National Environmental Protection Agency", though they believe that American technology is better than China's.

In Beijing, we asked consumers what they thought of " Beijing Household Electric Appliance Research Institute". In Shanghai and Guangzhou, we asked consumers what they thought of "China Household Electric Appliance Test Center".

Consumers in Beijing think that the regional level "Beijing" is not good enough as accreditation agency of China.

Consumers in Shanghai and Guangzhou think that "China Household Electric Appliance Test Center" is suitable as an accreditation agency.

But when we asked about the "State Bureau of Technology Supervision", they changed their opinions, because they believe that "SBTS" is more authoritative than "CHEATC".

All consumers considered that the other two agencies "National Council of Light Industry" and "State Economic and Trade Commission" were not suitable as accreditation agencies because they had no involvement in refrigerators.

4.3 Consumers suggestion for content of symbols

Consumers think that CFC-FREE is good, but it is not enough if a CFC-FREE product has poor quality.

They think that "the symbol, by itself, as a means to identify CFC-FREE refrigerators is not good enough for our selection".

It is more helpful if all the CFC-FREE products available on the market pass by a quality standard before they get the emblem.

And consumers suggested that the emblem must be communicated to all and be accepted by all.

Their suggestion for communication is :

- Mass Media
- Produce educational information in newspapers and on TV
- Direct Mailing free sample label and leaflets

VII. CONCLUSION

1. With regards to refrigerators, all consumers in Beijing, Guangzhou and Shanghai are realistic. They are most concerned about quality and features and regard these as criteria of a good refrigerator.

   But consumers know little about distinguishing good quality from bad. Besides consulting relatives and friends, they do not know any good clear way to check quality standards. They are deeply influenced by mass media and choose brands with high awareness that have been heavily advertised. On the one hand, consumers do not completely trust advertisements. But on the other hand, consumers have greatly depended on advertisements to get external information in their lives.

   ===> Consumers need a quality standard to distinguish good quality appliances from bad. Advertising (on TV and in newspapers) plays an important role in influencing consumers' selection process. It is important to establish a reliable image through convincing communication.

2. Consumers regard brand as a benchmark of quality. They choose brand as a guarantee of quality. They often choose local high awareness brands in consideration of after-sales service.

   ===> Famous local brands can enhance the value of the CFC-FREE product. Choosing several famous regional brands which pass quality standards such as ISO 9000 is very important in order to promote CFC-FREE products in China.

3. From this research, it can be seen that consumers would accept CFC-FREE and high-efficiency refrigerators based on the assumption that they pass an international quality standard and can save 40% of electric power.

   For consumers, the biggest attraction to "energy-efficient" is saving 40% of electricity costs. Even though consumers may care more about quality than price before they make their purchase, when they come to actually buy the product they will go to many different stores to find the most competitive price. Thus the importance of the product's total cost (including operating costs) should not be overlooked.

   ===> Before purchase, consumers care about reliability and durability, but when money has to be laid on the table then they start to worry more about the cost;

"reliable" is their focus in communication;
"economic" is their focus in purchasing.

4. Consumers think that refrigerator manufacturers that pay attention to governmental protection and adopt CFC-FREE technology have high social ethics, foresight and have better technology than others.

   For themselves, they think that "environmental protection" is a new concept, and it will be the trend in the future, though it sounds not so important as quality or price right now.

   Women think that "CFC-FREE" is more attractive because it is more healthy for them.

   ===> In consumers' eyes, paying more attention to environmental protection helps to establish a good image for refrigerator manufacturers.

5. A "label" as a symbol to identify CFC-FREE and high-efficient refrigerators was considered acceptable by all consumers.

   All consumers consider "State Bureau of Technology Supervision" as the most reliable and persuasive accreditation agency. Not only to identify CFC-FREE products, but they also hope the symbol can identify good quality too.

VIII. Appendix

1. Interview Guidelines:

A. Warm up

1. Moderator introduces participants

B. Demands, criteria and priorities in a refrigerator

1. In your mind, what factors should an ideal refrigerator have?
2. Which factors are the most important? Which factors are not so important?
3. Which factors do you think of when you choose a refrigerator in a department store? Which factor should be given priority, according to you? Why?
4. If the participants did not mention "price", "brand", "quality", "saving electric power (high-efficiency)" and "noiselessness" as criteria of refrigerators, we will remind them these factors one by one and ask the following questions:
   Do you think it is an important factor?
   If yes, how important is it to you? Why? (How much money will you care about?)
5. How did you get the information about refrigerators?

C. Promises of CFC-FREE high-efficiency refrigerators
To show each promise:

a. This refrigerator can save 40% electric power. (saving approximately 125 RMB/year)
   How about saving 50% electric power (160 RMB/year)?

b. This refrigerator uses CFC-FREE material for the purpose of environmental protection.

c. This refrigerator can use energy efficiently, thereby making additional energy available to help with China's economic development.

d. This refrigerator is a high-quality product using latest technique from US and Germany.

e. This refrigerator is certified by the Beijing Household Electrical Appliance Research Institute as meeting the highest Chinese quality standards for refrigerators.

f. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard -- ISO 9000.

g. Most famous manufactures in the world have adopted the CFC-FREE high-efficiency technique.

h. This refrigerator has thicker insulation and therefore will keep food colder during power outages.

I. This refrigerator has 3-year free after-sales guarantee.

After showing each promise, ask the following questions:

1. How do you like this kind of refrigerator? Why? What do you dislike about it?

2. Do you believe this promise ? Why?

3. Do you consider it important to you? Why?
   (As for "saving electric power", what percentage will you consider important?)

4. Do you think it worth paying for? Why?

5. Do you consider it original compared to what other refrigerators offer? Why?

6. Would you like to buy this kind of refrigerator? If not, Why?

Show all the promise boards A-H together and ask them the following questions.

1. If a refrigerator has all the promises mentioned above, how do you like this kind of refrigerator? Why? What do you dislike about it?

2. Which promise do you prefer most? Which one do you not prefer? Why?

3. Which promise is most important to you? Which one is not important? Why?

4. Which promise is most worth paying for ? Which one is not ? Why?

5. Which promise is most original compared to what the other refrigerators offer? Which one is not original? Why?

6. If this new refrigerator is a famous brand product, will you become interested in it? Why?

7. What else do you want to know about the CFC-FREE high-efficiency refrigerators?

We will ask the following questions about the concept created during the discussion.

8. Would you like to buy the kind of refrigerator which has your preferred promises? If not, why?

9. How do you like it if the price of this refrigerator is 5-10% (100-200 RMB) higher? How much will you care about?

10. How do you like if it has a 2.5 cm thicker wall and is therefore 5 cm wider than a standard refrigerator?

D. The indicia of CFC-FREE and high-efficiency refrigerators

1. How can you tell a refrigerator is CFC-FREE high-efficiency or not if you want to buy?

2. Do you have some good ideas on how to identify CFC-FREE high-efficiency refrigerators?

3. Which one will you believe? Why?

4. Which one do you remember and understand easily?

5. Which one is the easiest one to convey? Why?

6. Which one do you prefer most? Why?

7. Do you think it is a good idea if we use labels as indicia? Why?
(Show some label-samples, such as recycle label, wool mark and green label)

8. Do you believe the label?

9. What kind of organizations which endorse the label would you consider reliable?

Show the name list of organizations:

a. U.S. Environmental Protection Agency
b. U.S. Department of Energy
c. National Environmental Protection Agency
d. National Council of Light Industry
e. Beijing Household Electric Appliance Research Institute
f. State Economic and Trade Commission
g. State Bureau of Technology Supervision

What do you think about these organizations? Which organization do you consider most reliable? Which one is not?

10. What information do you want to know from the labels besides CFC-FREE and high-efficiency?

11. Do you think it is necessary that to receive a label a manufacturer must pass quality criteria in addition to CFC-FREE and high-efficiency?

12. By what channels would you get information about CFC-FREE and high-efficiency refrigerators?

13. Which channel do you think is the most reliable way? Why?

14. Through which channel do you think is most convenient? Why?

E. Perception and attitudes towards energy efficient and CFC-FREE

1. Do you care whether your refrigerator is energy efficient or not? Why?

2. What is the benefit of energy efficiency to you? Why do you think so?

3. Do you care whether your refrigerator is CFC-FREE or not? Why?

4. What knowledge do you have about freon? Do you know the affects of freon to us? Do you think it will effect you greatly ? Why?

5. What do you think if all the manufactures are forbidden to use freon as refrigerant in the future? Why?

F. Show a new refrigerator

2. Screening Questionnaire

Place: Time: Id: Sex:

Hello! I am an interviewer of a research company. Now I am processing a research project about refrigerators. I hope to get your opinions on several questions about refrigerators and I thank you for your support.

S1. Are you or your family numbers work in the following organizations?

1. refrigerator manufacturer or wholesaler -- Stop
2. marketing research company/ advertising company -- Stop
3. none

-- Continue

S2. How old are you?

1. Younger then 24 or old then 41 -- Stop
2. 25-40 -- Continue

S3. Have you purchased refrigerators in the last 6 months?

1. yes -- Go on to S5
2. no -- Continue

S4. Are you going to purchase a refrigerator in the next 6 months?

1. yes -- Continue
2. no -- Stop

S5. How much is your total family income?

1. less than 1999 RMB/monthly -- Stop
2. more than 2000 RMB/monthly -- Continue

S6. We are going to have a group discussion about refrigerators. Are you willing to come?

1. yes (Interviewer will provide invitation and notice the time and place.)
2. no -- Stop

3. Promises board

A. This refrigerator can save 40% electric power. (saving approximately 125 RMB/year). How about saving 50% electric power (160 RMB/year)?

B. This refrigerator applies CFC-FREE material for the purpose of environmental protection.

C. This refrigerator can use energy efficiently, thereby making additional energy available to help with China's economic development.

D. This refrigerator is a high-quality product using the latest techniques from US and Germany.

E. This refrigerator is certified by the Beijing Household Electrical Appliance Research Institute as meeting the highest Chinese quality standards for refrigerators.

F. This refrigerator is one of the few Chinese refrigerators that are certified to meet international quality standard ISO 9000.

G. Most famous manufacturers in the world have adopted the CFC-FREE high-efficiency technique.

H. This refrigerator has thicker insulation and therefore will keep food colder during power cuts.

I. This refrigerator has a free 3 year after-sale guarantee.

Ogilvy & Mather

APPENDIX D. Field Testing Data Tables

Table D1. Classification of Features That Households Found Most Satisfactory
(ranked by total number of households selecting the indicated feature)

Categories	First Item	Second Item	Total
Storage capacity	38	2	40
Helps protect the environment	3	29	32
Maintains desired temperature	27	4	31
Attractive styling	28	3	31
Good after sales service	1	28	29
High quality	9	11	20
Low energy use	7	12	19
Quiet operation	5	4	9
Good value for money	0	4	4
Ease of use*	2	1	3
Other (fill-in space provided)	0	0	0
Total responses	120	98	218

* i.e., easy to organize and find items in the refrigerator.

Table D2. Classification of Features That Households Found Least Satisfactory
(ranked by total number of households selecting the indicated feature)

Categories	First Item	Second Item	Total
Noisy operation	38	1	39
No automatic defrost	7	13	20
Unattractive styling	11	3	14
High energy use	3	3	6
Storage capacity	3	0	3
Poor quality	2	1	3
Hard to use*	1	0	1
Does not maintain desired temperature	0	0	0
Poor value for money	0	0	0
Poor after sales service	0	0	0
Other (fill-in space provided)	0	0	0
Total responses	65	21	86

* i.e., difficult to organize and find items in the refrigerator.

Table D3. Prototype Ratings
(by number of households selecting the indicated rating)

Characteristic	Poor	Fair	Okay	Good	Excel-lent	Total
Storage capacity	0	3	36	15	4	58
Maintains desired temperatures	0	10	22	20	6	58
Ease of use*	0	10	22	15	11	58
Noise	24	9	14	7	4	58
Styling/looks	2	14	24	14	4	58
Quality	1	5	33	14	4	57
Energy use	3	25	16	6	8	58
Value for the money	1	25	22	8	2	58
Reduced environmental impact	1	10	20	11	16	58
After sales service	0	6	8	29	14	57
Overall satisfaction	0	2	16	40	0	58

* i.e., easy to organize and find items in the refrigerator.

Table D4. Rating of Old Refrigerator
(by number of households selecting the indicated rating)

Characteristic	Poor	Fair	Okay	Good	Excel-lent	Total
Storage capacity	9	16	6	0	0	31
Maintains desired temperatures	4	16	8	3	0	31
Ease of use*	1	17	11	1	0	30
Noise	14	4	9	2	2	31
Styling/looks	2	12	16	1	0	31
Quality	1	12	15	3	0	31
Energy use	6	17	7	1	0	31
Value for the money	2	15	13	1	0	31
Reduced environmental impact	8	9	12	2	0	31
After sales service	4	7	8	10	0	29
Overall satisfaction	0	14	12	5	0	31

* i.e., easy to organize and find items in the refrigerator.

Table D5. Comparison of Ratings of Old and Prototype Models
(by number of households selecting the indicated rating)

Characteristic	Old Refrigerator					Prototype				
	Poor	Fair	Okay	Good	Excel-lent	Poor	Fair	Okay	Good	Excel-lent
Storage capacity	9	16	6	0	0	0	1	23	5	2
Maintains desired temperatures	4	16	8	3	0	0	6	14	9	2
Ease of use*	1	17	11	1	0	0	6	12	8	5
Noise	14	4	9	2	2	17	7	4	2	1
Styling/looks	2	12	16	1	0	0	6	14	8	3
Quality	1	12	15	3	0	0	2	18	9	2
Energy use	6	17	7	1	0	1	14	12	0	4
Value for the money	2	15	13	1	0	1	15	13	2	0
Reduced environmental impact	8	9	12	2	0	0	6	12	7	6
After sales service	4	7	8	10	0	0	3	6	17	4
Overall satisfaction	0	14	12	5	0	0	2	10	19	0

* i.e., easy to organize and find items in the refrigerator.