Experimental and Analytical Evaluation of a Ground-Coupled Refrigerator-Freezer

Edward A. Vineyard, P. E.
Member ASHRAE

J. Benjamin Horvay, P.E.
Fellow/Life Member ASHRAE

Edward R. Schulak

ABSTRACT

In April 1997 the U.S. Department of Energy (DOE) promulgated the third refrigerator-freezer standard in a series dating back to 1990. The standard, which takes effect in July 2001, requires manufacturers to reduce energy consumption by an average of 30%, compared to 1993 models. In addition, global concerns over greenhouse gases have prompted the elimination of hydrochlorofluorocarbon R-141b, used as a foam blowing agent in refrigerator cabinet insulation, by January 2003. The leading replacement candidate at this time, hydrofluorocarbon R-245a, is expected to have a minimal impact on energy consumption. However, should it fail to be a viable candidate due to toxicity or other concerns, additional replacements, such as cyclopentane or hydrofluorocarbons R-134a or R-134, would result in energy penalties ranging from 8% to 12%. These potential penalties, coupled with the 2001 standard, would require appliance manufacturers to reduce energy consumption approximately 40% in the next five years.

In response to efforts to reduce refrigerator-freezer energy consumption, several design options based on using a ground-source heat exchanger as a means of rejecting heat from the cabinet and condenser were investigated for improving the energy efficiency of a 15.5 ft^3 (440 L) domestic refrigerator-freezer. The options included (1) a cooling circuit throughout the cabinet to reduce the cabinet heat gain, (2) a liquid-cooled condenser and smaller compressor, and (3) a secondary cooling circuit in the fresh food section during winter operation. An additional option, increasing the cabinet volume by reducing the insulation thickness, was also investigated as a means of reducing costs. This was accomplished by using the cooling circuit to maintain the same cabinet heat gain as for the original baseline cabinet rather than reduce energy consumption. The modeled results for all the options show that the energy consumption could be reduced by 24.0% with a cabinet cooling circuit, 40.4% with the addition of a liquid-cooled condenser and smaller compressor, and 51.1% from utilizing a fresh food cooling circuit during winter operation. Modeling simulations also show that the cabinet volume could be increased by 2.4 ft^3 (70 L), a 15.3% increase, by utilizing the cabinet cooling circuit to reduce the insulation thickness rather than reduce energy consumption. These improvements do not account for the pumping power required for circulating the coolant. In addition to the modeling exercise, a laboratory prototype was fabricated and tested to experimentally verify the energy consumption of a unit with a cabinet cooling circuit. The resulting energy consumption was 1.35 kWh/d, a substantial energy-efficiency improvement of 24.0% compared to the 1997 model baseline unit (1.78 kWh/d). Abbreviated test results with the addition of a liquid-cooled condenser and smaller compressor show a savings of 39.9% (1.07 kWh/d).

INTRODUCTION

Following the release of scientific data from the United Nations Environmental Programme and the World Meteorological Organization showing carbon dioxide to be the main contributor to increased global warming (UNEP 1991), attention was focused on greenhouse gases and their damaging effects on the atmosphere. At a recent meeting of the parties in Kyoto, Japan, an agreement was reached to limit the production of greenhouse gases to 7% below 1990 production levels starting in 2008 (*USA Today* 1997). For domestic refrigerator-freezers operating on alternative refrigerants such as hydrofluorocarbon R-134a, the indirect contribution from the energy consumption of the unit is approximately one hundred times greater than the direct contribution of the refrigerant alone. Moreover, approximately 62 million new units are manufactured worldwide each year and hundreds of millions

Edward Vineyard is a consultant with Vineyard Associates, Knoxville, Tenn. **Ben Horvay** is a consulting engineer with Horvay Associates, Isle of Palms, S.C. **Edward R. Schulak** is president of Edward Schulak Equities, Inc., Birmingham, Mich.

are currently in use (UNEP 1995). It is anticipated that the production of refrigerator-freezers will substantially increase in the near future as the result of an increased demand, especially in certain developing, countries where growth is expected to be on the order of 10% to 15% per year for the next few years. In response to global concerns to limit greenhouse gases, efforts are being made to produce refrigerator-freezers with low energy consumption (Fischer et al. 1991).

In addition to the concerns of the global community over greenhouse emissions, refrigerator-freezers are also required to meet certain minimum energy-efficiency standards set up by the U. S. Congress under the National Appliance Energy Conservation Act (NAECA) and administered by the U.S. Department of Energy (DOE) (NAECA 1987). The initial standards went into effect January 1, 1990, and had one revision in 1993 that resulted in a cumulative 40% reduction in energy consumption. In the next revision, scheduled for implementation in July 2001, the standards will require an additional 30% reduction in energy consumption (*Appliance* 1997b). A historical chart showing actual and projected improvements in the electrical energy use of refrigerator-freezers is shown in Figure 1.

Customer expectations and competitive pressures impose an unwritten set of constraints on refrigerator-freezers produced in the United States. The excellent characteristics of chlorofluorocarbon R-12 and its use over a fifty-year period resulted in highly efficient and reliable refrigeration system components (UNEP 1991). Studies have shown that refrigerator-freezers give satisfactory performance for approximately 13 years on average (*Appliance* 1997a). This high degree of reliability has caused consumers to expect long lifetimes and trouble-free operation from refrigerator-freezers and all appliances in general. Additionally, refrigerator-freezers have become a relatively low-cost commodity item. Therefore, increased costs associated with efficiency improvements must be justified on the basis of an improved environment and lower operating cost to the consumer. Unless consumers are motivated to spend more for efficiency, further improvements will be hard for manufacturers to justify based on existing market conditions. External forces, such as rebates, new selling techniques, or standards, are required to further reduce refrigerator-freezer energy consumption from existing levels and generate markets for high-efficiency products.

The purpose of this study is to address some of the aforementioned issues by investigating the improvements in energy efficiency that are realized from circulating a coolant from a ground-coupled heat exchanger through a cabinet cooling circuit (Figure 2) and condenser to reduce the cabinet heat gain and refrigerant condensing temperature. In this design, coolant flows throughout the cabinet and condenser, where it picks up heat. The coolant then flows to a heat exchanger buried in the ground, where it gives up the heat. Using the ground as a heat source and sink to reduce energy consumption has been used in residential heat pump and large commercial chiller applications. Applying this same technology to a

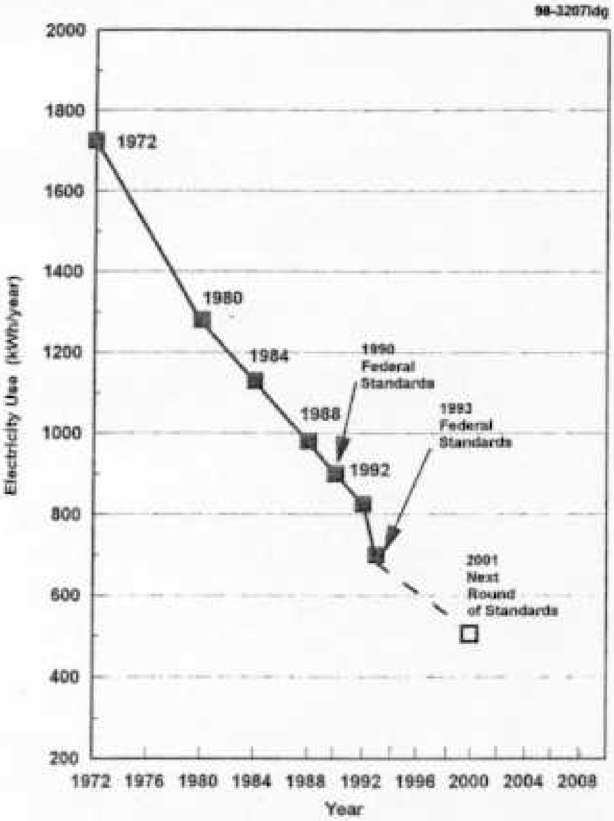

***Figure 1** Actual and projected refrigerator-freezer energy improvements from 1972 to 2001.*

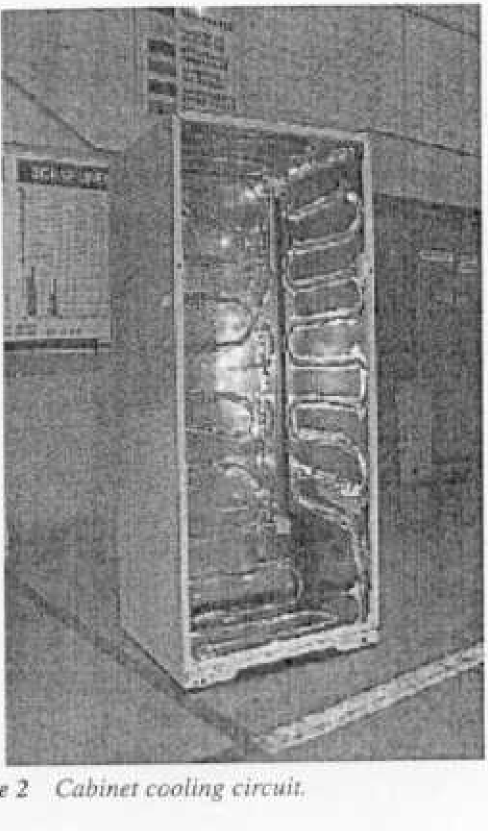

***Figure 2** Cabinet cooling circuit.*

domestic refrigerator-freezer, the energy consumption of a 15.5 ft^3 (440 L) top-mount, automatic-defrost refrigerator-freezer was determined to assess potential energy savings.

A patent covering a similar invention related to this project was initially issued in 1994 (Schulak 1994). The original concept was to cool the condenser by means of outside air introduced through external ductwork. Additional work followed to expand the concept to include cooling the cabinet and refining the design for better control of the outside air (Schulak 1995, 1996). Discussions were held with DOE to allow the externally vented refrigerator-freezer to be tested using the 90°F (32.2°C) closed-door test procedure. Following the discussions, DOE issued an amendment to the test procedure that allowed for the testing of externally vented refrigerator-freezers (*Federal Register* 1997). The idea to incorporate a ground-coupled heat exchanger was introduced to aid in reducing the temperature fluctuations that would be encountered from using ambient air (Schulak and Horvay 1997).

MODELING ANALYSIS

A widely distributed computer model that combines a cabinet heat load model, a refrigeration system model, and an on/off cycling algorithm was used to evaluate the different options for improving energy efficiency (EPA 1993). The model, while simple to operate, is able to accommodate system hardware and refrigerant changes, a feature normally found in more empirically specific simulation models used by appliance manufacturers. The model also enables the user to assess the energy-saving potential of options, such as improved door gaskets, by defining a percentage improvement. A summary of the output information from the model includes (1) cabinet heat loads in both compartments (freezer and fresh food), (2) compressor run time, (3) power consumption for the compressor, fans, and heaters, and (4) total energy consumption. More detailed information, such as breakdowns for the cabinet heat loads and component efficiency information, is also available.

In order to take full advantage of the ground-coupled design, the following options for the circulating coolant were modeled as a means of improving energy consumption: (1) reducing the cabinet heat gain by means of a cooling circuit throughout the cabinet and doors, (2) reducing the condensing temperature by means of a liquid-cooled condenser, and (3) providing cooling to the fresh food section during winter operation with a secondary coolant circuit. Beginning with the baseline unit, the design options were sequentially added to the model so that the cumulative effects of each option could be accounted for. Manufacturer's specifications for cabinet dimensions and refrigerating system components were used as inputs to the model for the simulation calculations. In addition, the model was used to determine the insulation thickness reduction that could be achieved by using the cooling circuit to maintain the same cabinet heat gain as for the baseline cabinet. Reducing the insulation thickness enabled the cabinet volume to be increased, resulting in a potential cost savings.

Since the laboratory was not equipped to perform reverse heat loss tests, it was necessary to model the effects of the cooling circuit on cabinet heat gain rather than perform experimental tests. This was accomplished by inputting the parameters that describe the cabinet and refrigeration system into the model to determine the baseline energy consumption. Minor adjustments were then made to some of the parameters where uncertainty existed to arrive at an equivalent energy consumption as was measured experimentally. The results, shown in Table 1, indicate that the cabinet heat gain was 192.9 Btu/h. In order to assess the effects of the cooling circuit on reducing the cabinet heat gain, the thermal resistivity of the foam was increased until the modeled energy consumption matched the result in the experimental tests. As shown Table 1, the cooling circuit reduced the cabinet heat gain to 136.1 Btu/h, or 29.4%, compared to the baseline cabinet.

Next, the model was used to estimate the energy consumption of a unit with a liquid-cooled condenser and a smaller compressor to determine if the energy savings supported additional modifications to the refrigerator-freezer. The smaller compressor was investigated as a means of increasing the compressor run time. From the initial experimental test results with the cooling circuit, the compressor run time was around 30% (Table 1). Low run times indicate that the compressor is oversized, resulting in increased cycling losses. The liquid-cooled condenser was used to lower the refrigerant condensing temperature, thus reducing the compressor power. The results (Table 1) show that the changes to the refrigerator-freezer, when coupled with the cooling circuit, would result in an energy consumption of 1.06 kWh/d, a 40.4% reduction.

Finally, the model was used to determine the energy consumption of a unit with a secondary cooling circuit to cool the fresh food compartment during the winter when ground temperatures are below 45°F (7.2°C). The approach

TABLE 1
Modeling Results—Energy Savings and Cabinet Heat Gain (Cabinet and Condenser Cooling)

Case	Option	Cabinet Heat Gain (Btu/h)	% Reduction Cabinet Heat Gain	Energy Consumption (kWh/day)	% Energy Savings
A	Baseline	192.9	—	1.78	—
B	Cabinet w/cooling circuit	136.1	29.4	1.35	24.0
C	Case B + liquid-cooled condenser + smaller compressor	136.1	29.4	1.06	40.4

TABLE 2
Modeling Results—Energy Savings and Cabinet Heat Gain (Fresh Food Cooling—Winter Operation*)

Case	Option	Cabinet Heat Gain (Btu/h)	% Reduction Cabinet Heat Gain	Energy Consumption (kWh/day)	% Energy Savings
A	Baseline	192.9	—	1.78	—
D	Case B + fresh food cooling	117.9	38.9	1.12	37.1
E	Case C + fresh food cooling	117.9	38.9	0.87	51.1

*Results are average of fresh food cooling (six months) and normal operation.

to modeling this arrangement was to use high resistivities for the insulation around the fresh food compartment so that the heat gain was essentially zero. This simulates all of the fresh food cooling being provided by the secondary cooling circuit. The results in Table 2 indicate that the energy consumption is 1.12 kWh/d (37.1% reduction) when combined with the previous cabinet cooling circuit modification and 0.87 kWh/d (51.1% reduction) when all the options are used. The results are an average of six months of normal operation and six months with the secondary coolant circuit operating during the winter months.

CABINET COOLING CIRCUIT FABRICATION

A 15.5 ft^3 (440 L) top-mount, automatic defrost refrigerator-freezer with a static condenser was selected as the test platform due to scheduling difficulties that would have been encountered with fabricating a larger cabinet at the factory. The preference would have been a 20 to 22 ft^3 (570-630 L) model with a forced-air condenser on the basis of its popularity and corresponding high market share. With the exception of the savings from the liquid-cooled condenser, the results should not be significantly affected by this selection. The energy savings with a liquid-cooled condenser, compared to a forced-air model, would probably be slightly lower due to the improved heat transfer characteristics for forced-air condensers. The label energy consumption for the baseline unit (1.75 kWh/d) corresponded to the 1993 NAECA standard for units of this size and type. The original compressor had a capacity of 840 Btu/h with an energy efficiency ratio (EER) of 5.49.

The cooling circuit (Figure 2) consisted of 1/4 in. (0.635 cm) copper refrigeration tubing bent on 6 in. (15.24 cm) centers to form a serpentine path throughout the cabinet. The tubing was fabricated in sections to aid in transporting to the site. Once the sections were laid out on the inside surface of the exterior steel cabinet, they were fastened together with compression fittings. Aluminum tape was used to secure the tubing to the inside surface and aid in heat transfer. The cooling circuit for the doors (Figure 3) was assembled in a similar manner. Penetrations for the tubing were strategically placed so as to not interfere with the insulation molding apparatus (Figure 4).

Once the cooling circuit was completed, the plastic inner liner was put in place and the unit was sent to the insulation station. The unit was inserted into the insulation molding

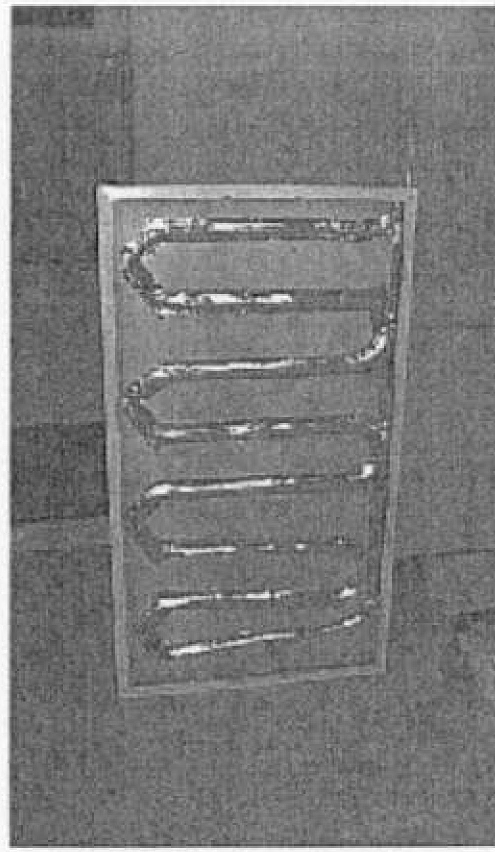

Figure 3 Door cooling circuit.

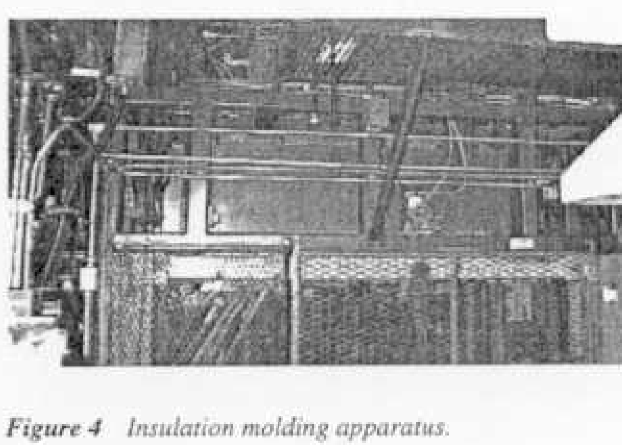

Figure 4 Insulation molding apparatus.

apparatus (Figure 4) by hand to ensure that the tubing did not damage any of the molds and result in shutting down the assembly line. Following the injection and expansion process for the foam, the unit exited the insulation station and was sent down the production line for final assembly.

TEST PROCEDURE

The 90°F (32.2°C) closed-door energy consumption test procedure as specified in section 8 of the Association of Home Appliance Manufacturers (AHAM) Standard for Household Refrigerators and Household Freezers (AHAM 1988) was used to quantify the effects on energy consumption for the different options. The tests were performed in an environmental chamber with airflows and temperature fluctuations within the specifications of the AHAM standard. In the procedure, the refrigerator-freezer is operated at two different control settings in a 90°F ± 1°F (32.2 ± 0.6°C) environmental chamber. Energy use and compartment temperatures are measured from the onset of one defrost cycle to the beginning of the next defrost. The test points are then used to calculate the energy consumption over a 24-hour period based upon a reference 5°F (−15.0°C) freezer temperature and 45°F (7.2°C) fresh food temperature. Other requirements of the test procedure are an outlet voltage level of 115±1 volt AC and an air circulation rate of less than 50 ft/min (15 m/min) in the environmental chamber. The high ambient temperature, 90°F (32.2 °C) is used to simulate the contribution of door openings and food loadings. Comparisons of field performance data to closed-door test ratings indicate that the laboratory procedure is a quite valid indication of energy use in field service (Meier and Jansky 1993). Previous refrigerator-freezer tests indicate that the test procedure with two different thermostat settings gives a broader indication of appliance performance at different ambients and internal operating conditions than a single-point test (Sand et al. 1993).

EXPERIMENTAL PLAN

Initially, the unit was baseline tested (Figure 5) to determine how well the results matched the label energy consumption. Since units should test very close to their label energy consumption, the baseline testing serves two purposes: (1) it gives an indication of the accuracy of the test facilities and (2) it shows that the unit hasn't sustained any damage following shipment, such as loss of refrigerant. In this particular instance, the baseline test would also indicate if the cabinet cooling circuit fabrication process resulted in a loss of cabinet thermal integrity due to the tubing interrupting the flow of insulation as it was foamed into the cabinet.

Following the baseline tests, water at 56°F (13.3°C) was circulated through the cabinet cooling circuit to simulate a closed-loop system with brine flowing from the cabinet to a ground-coupled heat exchanger. The 56°F (13.3°C) temperature was selected as an average groundwater temperature for the U. S. Water flow rates were measured using a rotameter for each circuit (Figure 6). Water was provided by a well at a constant temperature and directed to a drain after it passed through the cooling circuit. Thus, pumping power is not included in the energy consumption. In an actual production unit, the cooling circuit would be a closed-loop system that would require a circulating pump. An energy penalty would be incurred based on the time the pump ran and the amount of coolant that was pumped.

Additional tests were performed with ½ in. (1.27 cm) of polystyrene insulation added to the exterior of the cabinet (Figure 7). The purpose of this exercise was to simulate locating the tubing 1/4 in. (0.64 cm) away from the inner cabinet wall to reduce exterior sweating and reduce the coolant flow requirements to achieve the desired heat gain reduction.

Prior to the final testing, the original static condenser was replaced with a liquid-cooled model. In addition, the compressor was replaced with a smaller capacity unit since previous test results indicated that the compressor run times were very low.

EXPERIMENTAL RESULTS

Energy consumption tests were initially performed without water flowing through the cooling circuit to establish the baseline energy consumption. The results, in Table 3, show that the energy consumption was 1.78 kWh/d. The DOE standard for a unit of this type and size is 1.75 kWh/d. The slightly

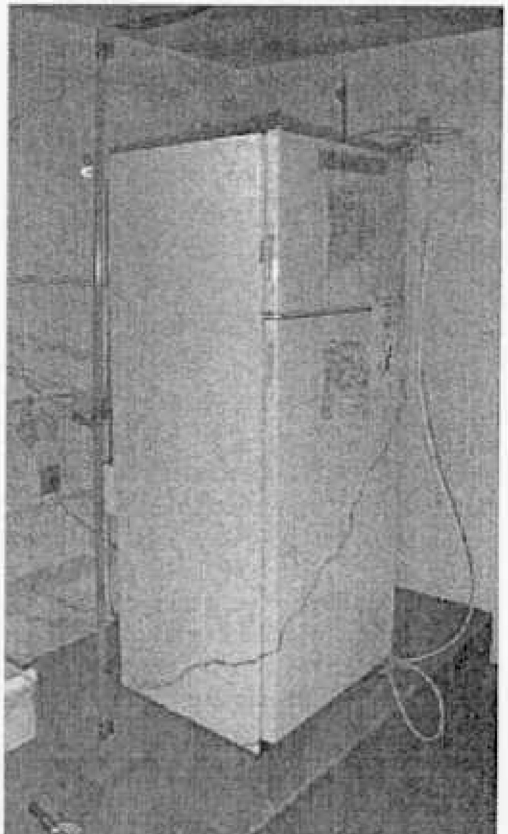

Figure 5 Baseline cabinet energy test.

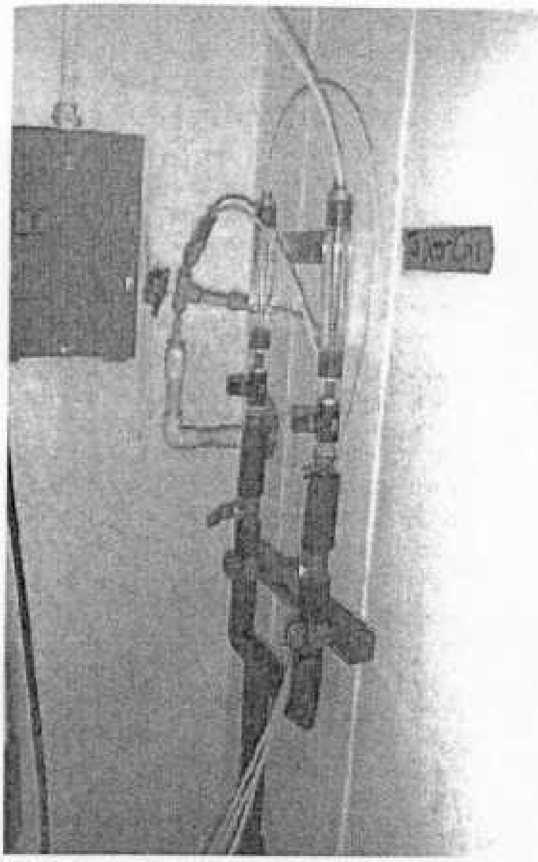

Figure 6 Water flow rate measurement.

Figure 7 Exterior cabinet insulation.

higher energy consumption is probably the result of the tubing inside the refrigerator displacing some of the foam insulation, resulting in a higher cabinet heat gain.

The second test series, with 56°F (13.3°F) water circulating through the cooling circuit at a 5°F (2.8°C) temperature difference between the entering and exiting temperature, reveals that the energy consumption was reduced by 24.0% to 1.35 kWh/d (Table 3). The results also show that the compressor run time is 31.5%, indicating an oversized compressor. Low run times result in higher than normal cycling losses, which, in turn, increase the energy consumption.

As previously mentioned, ½ in. (1.27 cm) insulation was added to the exterior of the cabinet to simulate placing the insulation 1/4 in. (0.635 cm) away from the inner wall to reduce sweating and reduce the flow required to lower the cabinet heat gain. For the test, the water flow rate was adjusted to yield the same temperature difference as in the previous test series with the cabinet cooling circuit. The results for the third series of test, shown in Table 4, indicate that the flow rate for the water circulating through the cabinet and doors was reduced from 0.40 gal/min (1.51 L/min) to 0.25 gal/min (0.95 L/min), a 37.5% reduction. While not shown, the energy consumption was equivalent for both tests, as would be expected.

For the fourth test series, the static condenser was replaced with a liquid-cooled model. In addition, the original compressor (840 Btu/h, 5.49 EER) was replaced with a lower capacity model (544 Btu/h) with a slightly lower EER. For the tests, water entered the condenser at 56°F (13.3°C) and exited at 62°F (16.7°C), a 6°F (3.3°C) difference. The test results in Table 1 show that the energy consumption was 1.07 kWh/d (a 39.9% reduction). It is noted that this is an estimate based on one cycle. The compressor failed following a defrost, which prevented the completion of a full test series.

COST SAVINGS

It is beyond the scope of this study to determine the costs of the changes required to incorporate a ground-coupled design with conventional refrigerator-freezers. However, since any design change that reduces energy consumption is inherently more costly, ways to reduce the costs were investigated. It is recognized that the installation costs and circulating pump are the two most costly items. Thus, the effort concentrated on ways to reduce or offset their costs.

Several pump manufacturers were contacted and given the design requirements for the circulating pump. The main requirement was that the energy consumption fall below 10 W, given the amount of coolant circulated and the head. After several discussions with one of the manufacturers, they indicated that circulating more coolant would significantly improve the hydraulic efficiency. Increasing the coolant flow rate would also further reduce the cabinet heat gain and result in even greater energy savings. Additional energy savings would also result from replacing the present AC motor with a brushless DC motor. Together, these improvements would

TABLE 3
Experimental Results —Energy Consumption (Cabinet and Condenser Cooling)

Case	Option	% Run Time	FF Temp @ 5°F FRZ	Energy Consumption (kWh)	% Energy Savings
A	Baseline	39.9	39.3	1.78	—
B	Cabinet w/cooling circuit	31.5	37.7	1.35	24.0
C*	Case B + liquid-cooled condenser + smaller compressor	36.5	36.2	1.07*	39.9

*Estimate based on power comparison for one cycle.

TABLE 4
Experimental Results—Water Flow Rates

Component	Flow Rate (gpm)	
	Without Insulation	With Insulation
Cabinet	0.25	0.15
Doors	0.15	0.10
Liquid-cooled condenser	0.65	0.65
TOTAL	1.05	0.90

probably achieve the desired power draw for the pump. Other methods that could reduce the power draw to less than 10 W are under investigation.

An investigation was also conducted to determine how much the cabinet volume could be increased by using the cabinet cooling circuit to maintain the same heat gain as for the baseline cabinet and reduce the insulation thickness rather than reduce the energy consumption. Any increase in cabinet volume could help offset the increased cost of the other design improvements since consumers are willing to pay more for larger refrigerator-freezers. Estimates of $30.00 - $35.00 per cubic foot (retail), depending on the cabinet size and type, are typical consumer costs. Using the model to perform the analysis, it was determined that a volume increase of approximately 2.4 ft^3 (a 15.5% increase) could be achieved. Similar percentage increases could be achieved in larger cabinets.

CONCLUSIONS

Legislation in global and domestic markets to produce environmentally safe refrigerator-freezers is becoming more prevalent. Several major events have occurred in recent years, such as the NAECA standards and the phaseout of hydrochlorofluorocarbon R-141b, that will impact the design of refrigerator-freezers for the next few years. The major impact of these changes is that the energy consumption must be reduced 30% by July 2001, and the foam-blowing agent must be replaced by 2003, possibly resulting in an energy penalty. The design changes that must occur to achieve the required energy savings and replace the foam-blowing agent are expected to increase the cost of producing refrigerator-freezers by $40 to $50. These costs could double or triple by the time they reach the consumer. Thus, there is opportunity for investigating new approaches to significantly reduce the energy consumption for refrigerator-freezers.

The ground-coupled design presented in this study could achieve energy savings up to 51.1%, depending on the options. Even without fresh-food cooling, which could only be utilized in northern climates, the energy savings was 40.4%. It is noted that these savings would be decreased when pumping power is included. However, assuming the worst case, where the pump power is 10 W, the savings would still be 37.5% with fresh-food cooling and 27.0% without. Other methods for circulating the coolant that would result in a lower energy penalty are under investigation.

Several ideas were investigated for reducing or offsetting the costs of the design. The idea with the greatest merit involved increasing the cabinet volume by using the cabinet cooling circuit to maintain the same heat gain as for the base case and reducing the insulation thickness. The resulting increase in cabinet volume was 15.5%. While this approach reduced the energy savings, it is possible to achieve both energy savings and increased cabinet volume by increasing the water flow rate.

CLOSING REMARKS

American manufacturers of domestic refrigerator-freezers have established an enviable record of consistent improvements in the energy efficiency of their product. Widespread use of this appliance as a result of its efficiency, convenience, and reliable performance have made it a target for additional refinement. However, the margins for improving performance are reaching a point of diminishing returns. Switching to a design that performs well in standardized energy-consumption tests but sacrifices many of the convenient and dependable features of this essential appliance would be a mistake for an established industry.

Clearly, there is a rationale for retaining many familiar aspects of a product design that has been refined and used for 30 years. However, some changes are needed to further reduce energy consumption and produce appliances that are more environmentally acceptable. The ground-coupled design could have a significant effect on the energy use of refrigerator-freezers. However, the increased unit hardware cost must be determined for the design. In addition, since consumers have come to expect a long life from their appliances, the reliability of the new design must also be determined.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to Intertek Testing Services (ITS) in Cortland, New York, for performing the energy consumption tests on the cabinet. In addition, appreciation is extended to Teresa DiMorier (technician) and John Sabelli (project manager) at ITS for the many hours of time they spent on the project. Tina LaPorte at Edward Schulak Equities, Inc., deserves a special acknowledgment for coordinating all the correspondence between the parties and following up to ensure that the project flowed smoothly. Finally, Joe Pietsch, who determined ground temperatures and initially modeled performance of a ground-coupled refrigerator-freezer in several locations throughout the U. S. is given credit for his contribution.

REFERENCES

AHAM. 1988. *AHAM standard for household refrigerators and household freezers.* Chicago: American Home Appliance Manufacturers.

Appliance. 1997a. A portrait of the U. S. appliance industry 1997. Oak Brook, Ill.: Dana Chase Publications.

Appliance. 1997b. Washington report—DOE publishes refrigerator standard. Oak Brook, Ill.: Dana Chase Publications.

EPA. 1993. Multiple pathways to super-efficient refrigerators, EPA-430-R-93-008. Washington, DC: U.S. Environmental Protection Agency.

Federal Register. 1997. Test procedures for externally vented refrigerators and refrigerator-freezers; final rule. 10 CFR Part 430. Washington, D.C.: U. S. Department of Energy.

Fischer, S.K., P.J. Hughes, P. D. Fairchild, C.L. Kusik, J.T. Dieckmann, E. McMahon, and N. Hobday. 1991. *Energy and global warming impacts of CFC alternative technologies.* AFEAS/DOE.

Hakim, S.H., and I. Turiel. 1996. Cost-efficiency in support of the energy conservation standards for refrigerator/freezers. *ASHRAE Transactions* 102 (2).

Meier, A., and R. Jansky. 1993. Field performance of residential refrigerators: A comparison with laboratory test. *ASHRAE Transactions* 99 (1).

NAECA. 1987. *Public Law 100-12*, March 17 (as amended by National Conservation Policy Act, 9 *Public Law 95-619*), Part B--Energy conservation for consumer products other than automobiles. National Appliance Energy Conservation Act, U.S. Department of Energy.

Sand, J.R., E.A. Vineyard, and V.D. Baxter. 1993. Laboratory evaluation of an ozone-safe nonazeotropic refrigerant mixture in a lorenz-meutzner refrigerator freezer design. *ASHRAE Transactions* 99 (1).

Schulak, E. R. 1994. Energy efficient domestic refrigeration system. U.S. Patent No. 5,291,749.

Schulak, E. R. 1995. Energy efficient domestic refrigeration system. U.S. Patent No. 5,402,651.

Schulak, E.R. 1996. Energy transfer system for refrigeration components. U.S. Patent No. 5,520,007.

Schulak, E.R., and B. Horvay. 1997. Energy transfer system for refrigerator/freezer components. U.S. Patent No. 5,666,817.

UNEP. 1991. Technical progress on protecting the ozone layer—Report of the Refrigeration, Air Conditioning and Heat Pump Technical Options Committee. New York: United Nations Environmental Programme.

UNEP. 1995. Montreal protocol on substances that deplete the ozone layer—Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee. New York: United Nations Environmental Programme.

USA Today. 1997. Global warming pact OK'd. December 11, 1997. Arlington, Va.