# Vacuum Panel and Thick Insulation for Refrigerator/Freezers: Two Technologies That Work

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Various refrigerant, cycle and cabinet design changes have been proposed which could significantly reduce refrigerator/freezer (R/F) energy consumption. Two technologies, advanced vacuum panel insulation and thick foam insulation, can reduce heat leakage into the R/F cabinet, and the resulting power requirements.

The results of energy consumption calculations performed with the EPA Refrigerator Analysis (ERA) program, market studies and manufacturing cost impact analyses are presented for R/Fs which contained either added foam or vacuum panel insulation. Results show avoided costs as low $0.012/kWh, and the tradeoffs associated with the addition of foam or vacuum panel insulations.

## Introduction

Many technologies can be employed to reduce the energy consumption of residential refrigerator/freezers (R/Fs).[1] Improved cycle performance can be achieved with higher efficiency compressors and fans, larger evaporators and condensers, and better refrigerants. Improvements to the cabinet are limited to increases in the thermal resistance of the enclosure resulting from better gaskets and/or insulation. Insulation can be enhanced through the development of higher thermal resistance foam insulation, the addition of insulation to the cabinet and/or the incorporation of advanced vacuum panel insulation into the cabinet.

The addition of insulation has been resisted by R/F manufacturers, because thicker walls might reduce the marketability of their products. Many varieties of vacuum panel insulations have been studied.[2] There has, however, been very limited use of these technologies in R/Fs, because cost and life issues remain unanswered, and because commercial availability has been very limited. The benefits of these two technologies are compared and contrasted in the following paper, and the conditions where each should be employed to conserve energy are demonstrated.

## Methodology

Addition of insulation to a R/F will have a direct impact on the energy consumption, cost and marketability of the R/F. Analyses of these issues are considered in this article and are described below.

### Energy Consumption Analysis

Energy consumption of a R/F is dependent on the thermal load entering the refrigerated volume and the efficiency of the hermetic system. The EPA Refrigerator Analysis (ERA) program[3] was employed to perform the energy consumption calculations described below. A typical 1993 top-mount, automatic-defrost non-CFC refrigerator/freezer was selected as the baseline model. The characteristics of this unit are given in Table 1. Additional information on this unit can be found in Reference 1.

Finite element analyses of cabinets have also been performed to show that ERA accurately calculates the thermal load for R/Fs having added foam or vacuum panel insulations.[1,4,5] Comparisons to the energy performance of 1991 model R/Fs have also shown that ERA can accurately model the cycle.[1]

### Cost Analysis

Incremental cost analyses have been performed for the addition of foam insulation, and the manufacture and installation of powder-filled vacuum panel insulation to R/Fs.[6] Variable and fixed cost estimates were made for both technologies.

***Fixed Costs.*** Equipment, retooling, startup and design costs were determined for the addition of 0.5, 1.0, 1.5, or 2.0 inches of foam insulation to the outside of an 18 cubic feet R/F. Fixed costs were established for a "typical" production facility manufacturing one million top-mount, automatic-defrost R/Fs annually.[6]

*Table 1. Base 1993 Non-CFC Refrigerator/ Freezer*

Internal Volume: 18.0 $ft^3$

Recip. Compressor: 5.3 EER

Refrigerant: HFC 134a

Insulation

r-value: 7.5 h $ft^2$ °F/(Btu in)
Freezer Walls: 2.375 inches
Freezer Top: 2.375 inches
Freezer Door: 1.75 inches
Fresh Food Walls: 1.875 inches
Fresh Food Bottom: 2.0 inches
Fresh Food Door: 1.75 inches

Fans

Evaporator: 8W
Condenser: 10W

Production and installation cost estimates for powder-filled vacuum panel insulation were established for a facility that would serve a R/F plant making 300,000 vacuum insulated units per year. Each R/F was assumed to contain 30 square feet of one inch thick vacuum panel insulation, i.e., 30 board feet. Thus, the annual production capacity for the vacuum insulation plant was nine million board feet.

Fixed costs are amortized in this article over the total number of units produced in a five year period, i.e., five million R/Fs with added foam insulation or 45 million board feet of vacuum panel insulation. Interest on the capital investment was assumed to be zero, as opposed to assuming an interest rate but a longer period of depreciation.

***Variable Costs.*** Variable costs included materials and labor for both the added foam and vacuum panel insulation cases. A transportation cost increment was also required for the added foam insulation scenario. Cost increments were calculated by careful analysis of existing production facility costs. Cost quotations were also obtained from suppliers when existing data were not available, e.g., material costs for vacuum panel insulation.

### Market Analysis

The marketability of R/Fs which had added foam insulation was studied on three separate occasions during 1991. Each session employed one hundred female head of household focus groups to assess market acceptance of thicker walled R/Fs. Each panel was selected to obtain a socioeconomic distribution similar to that of the USA. An eleven point scale was used for all questions.

## Results

### Energy Analysis

Foam insulation was added in half inch increments to the inside or outside of a series of R/Fs having initial total interior volume between 16.2 and 26.5 cubic feet. Simulations were performed in sets with either the external dimensions held constant or the internal volume held constant. The results of several of these simulations are shown in Figure 1A. Solid lines connect results for adding foam to the interior of the cabinet, i.e., constant external dimensions but decreasing internal volume. Dashed lines connect results for adding foam to the exterior of the cabinet, i.e., constant internal volume but increasing external dimensions. For example, it is possible to add 0.5 inches of foam to the interior surfaces of a 24.2 cubic foot R/F and reduce its energy consumption from 763 to 657 kWh per year (13.9%). Its volume will, however decrease to 22.0 cubic feet. It is also possible to add 0.5 inches of foam to the exterior of a 22.0 cubic feet R/F and reduce its energy usage from 730 to 657 kWh per year (10.0%). In this case, however, the unit will become one inch higher, wider and deeper, as all dimensions are increased by an equal amount. The results of all of the simulations are shown in Figure 1B.

Clearly, adding insulation to the interior of the cabinet has a very significant effect on the energy consumption of the unit. This is achieved, however, at the expense of internal volume. Adding insulation to the exterior of the envelope also has a significant impact on the consumption of energy by the unit, without decreasing its usable volume. There is however a decrease in the market served as the dimensions of the R/F increase, i.e., the percentage of kitchen voids which will accommodate the unit decreases as dimensions increase due to added insulation or volume.[7] Results for the addition of foam insulation to the outer surfaces of the 18 cubic feet unit are also presented in Table 2.

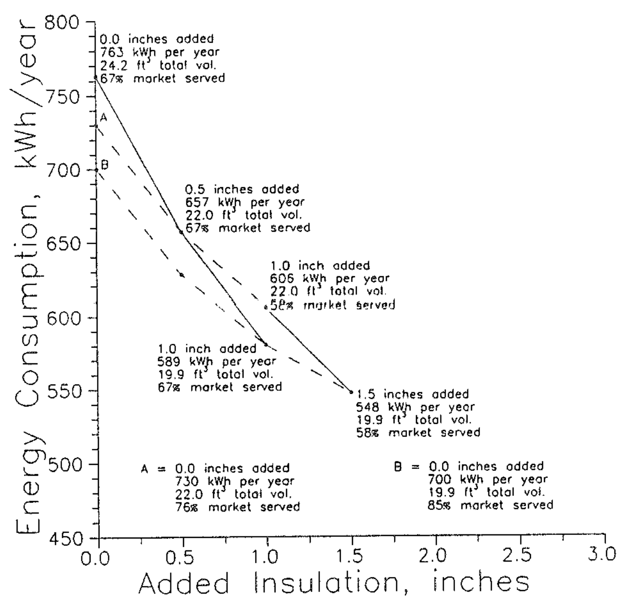



*Figure 1A. Annotated Description of the Dependence of Energy Consumption on Thickness of Added Foam Insulation: ———— corresponds to constant external dimensions, - - - - - - corresponds to constant internal volume.*

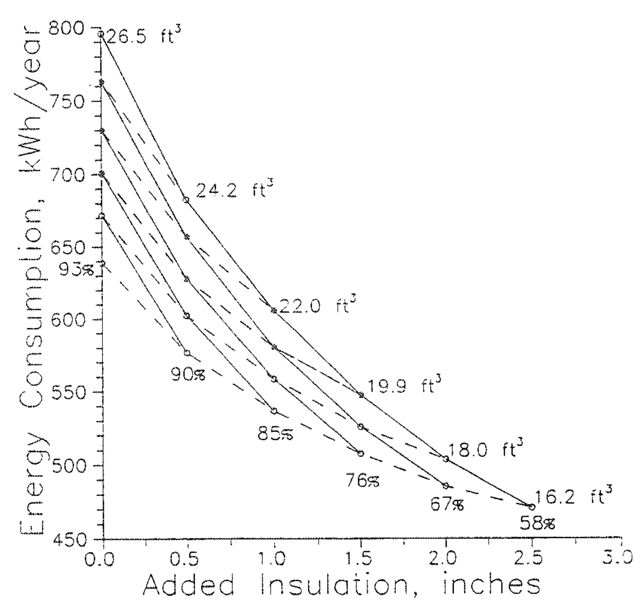



*Figure 1B. Relationship Between Energy Consumption and Added Foam Insulation: ———— corresponds to constant external dimensions, - - - - - - corresponds to constant internal volume. Numbers along the bottom of the drawing show the market served.*

*Table 2. Manufacturer's Cost Increment for Added Foam Insulation to an 18 ft³ Top-Mount Refrigerator/Freezer*[a]

| | Added Insulation Thickness (inches) | | | |
|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 |
| Variable Cost, $ | 12.30 | 20.80 | 28.50 | 37.70 |
| Fixed Cost, $million | 16.6 | 18.1 | 20.3 | 22.5 |
| Total Cost, $/unit | 15.60 | 24.40 | 32.60 | 42.20 |
| Energy Saved, kWh/yr | 70 | 115 | 150 | 170 |
| Avoided Cost, $/kWh | 0.014 | 0.012 | 0.012 | 0.014 |
| Market Served, % | 85 | 76 | 67 | 58 |

(a) R/F without added insulation consumed 673 kWh/yr and served 90% of the market.

One inch thick vacuum panel insulation having a thermal resistance of 20 (h ft$^2$ °F/Btu) was also used to replace one inch of foam insulation on all five surfaces of the R/F cabinet and in both doors. In these cases, the vacuum panel insulation was placed on the inner surface of the steel liner. Separate panels were assumed to cover the freezer section and fresh food section. A two inch gap was left between the panels and perpendicular walls, and on both sides of the mullion.

The panels covered about 70 percent of the outer surfaces of all of the R/Fs simulated. Incorporation of the vacuum panel insulation resulted in an average 20 percent reduction in energy consumption, see Table 3.

## Cost Analysis

The total variable costs, i.e., materials, labor and transportation, for adding foam insulation to the exterior of an 18 cubic feet top-mount automatic-defrost R/F ranges from $12.30 for 0.5 inches of insulation to $37.70 for two inches, see Table 2. Total fixed cost varies from $16.6 million to $22.5 million. Amortizing the fixed costs over five million units yields a total manufacturer's cost of $15.60 for 0.5 inches to $42.20 for two inches of added foam insulation per R/F.

Energy savings for adding 0.5 inches of foam insulation was 70 kWh/year, and increased to 170 kWh/year for the addition of two inches of foam insulation. Assuming a twenty year life for the R/F yields an average avoided cost for electricity of $0.013 per kWh for the four cases shown in Table 2. Assuming an average cost of electricity of $0.08 per kWh, the payback for adding foam insulation will be 2.6 years for one inch to 3.1 years for two inches. The rate of return will range from 38 to 32 percent.

Total variable costs, i.e., materials plus labor, for vacuum panel insulation are estimated to equal $1.30 per square foot for one inch thick silica-filled evacuated panels contained in a polymer barrier/container. Total fixed cost for production and installation of the vacuum panel insulation is estimated to equal $23.5 million. Amortizing the cost over 45 million board feet of insulation that could be produced and installed in five years yields a total cost of $1.80 per board foot.

The areas covered in a series of R/Fs are shown in Table 3. Based on the above cost estimate, incremental manufacturer's cost ranging from $70 to $90 per unit result. The incorporation of vacuum panel insulation into the R/Fs produce energy reductions of 125 to 160 kWh per year. Again assuming a life of twenty years yields avoided costs of approximately $0.03 per kWh.

Based upon $0.08 per kWh, the payback period for vacuum panel insulation will be seven years and the return on investment will be about 14 percent. Polymer-contained vacuum panel insulations will deteriorate with time. This deterioration will result in lower thermal performance and higher energy consumption. If a linear degradation over the life of the R/F is assumed, the cost for avoided energy and payback period will double, and the return on investment will be halved. Degradation can be reduced, but at added cost and with longer payback periods, etc.

*Table 3. Manufacturer's Cost Increment for Vacuum Panel Insulation*[a]

| | R/F Internal Volume (18 ft³) | | | | |
|---|---|---|---|---|---|
| | 16.2 | 18.0 | 19.9 | 22.0 | 24.2 |
| Panel Area, $ft^2$ | 40 | 42.5 | 45 | 48 | 51 |
| R/F Ext. Area Covered, % | 68 | 69 | 70 | 71 | 71 |
| Incremental Cost, $ | 72 | 77 | 81 | 86 | 92 |
| Energy Saved, kWh/yr | 125 | 135 | 140 | 150 | 160 |
| Avoided Cost, $/kWh | 0.029 | 0.028 | 0.029 | 0.029 | 0.029 |

(a) Panels are one-inch thick and have R-value of 20 h $ft^2$ °F/Btu.

## Market Analysis

The market research focused on consumer acceptance of thicker walled R/Fs. In the initial session, 100 participants were shown Figure 2 and told "Refrigerator B has thicker walls than Refrigerator A. Assume that both units have the same interior storage space, all of the features/options of importance to you (color, ice maker, etc.), would fit into the space that you currently have for a refrigerator and would cost $500." When asked "If you were going to purchase a refrigerator, which would you prefer?" On an eleven point scale with "Strongly prefer A" equal zero and "Strongly prefer B" equal 10, the average response was 8.3, a strong preference for the thick wall R/F.

In another session, the group was shown Figure 3 and told "Assume that your refrigerator has broken. You enter an appliance store prepared to purchase a refrigerator with the same interior volume as you now own for $500 (most people have an 18 $ft^3$ refrigerator)." When asked which would you prefer, the average response was 1.6 on the eleven point scale with "Strongly prefer A" being 0 and "Strongly prefer B" equal 10. Once again, a strong preference for the thick wall R/F was indicated.

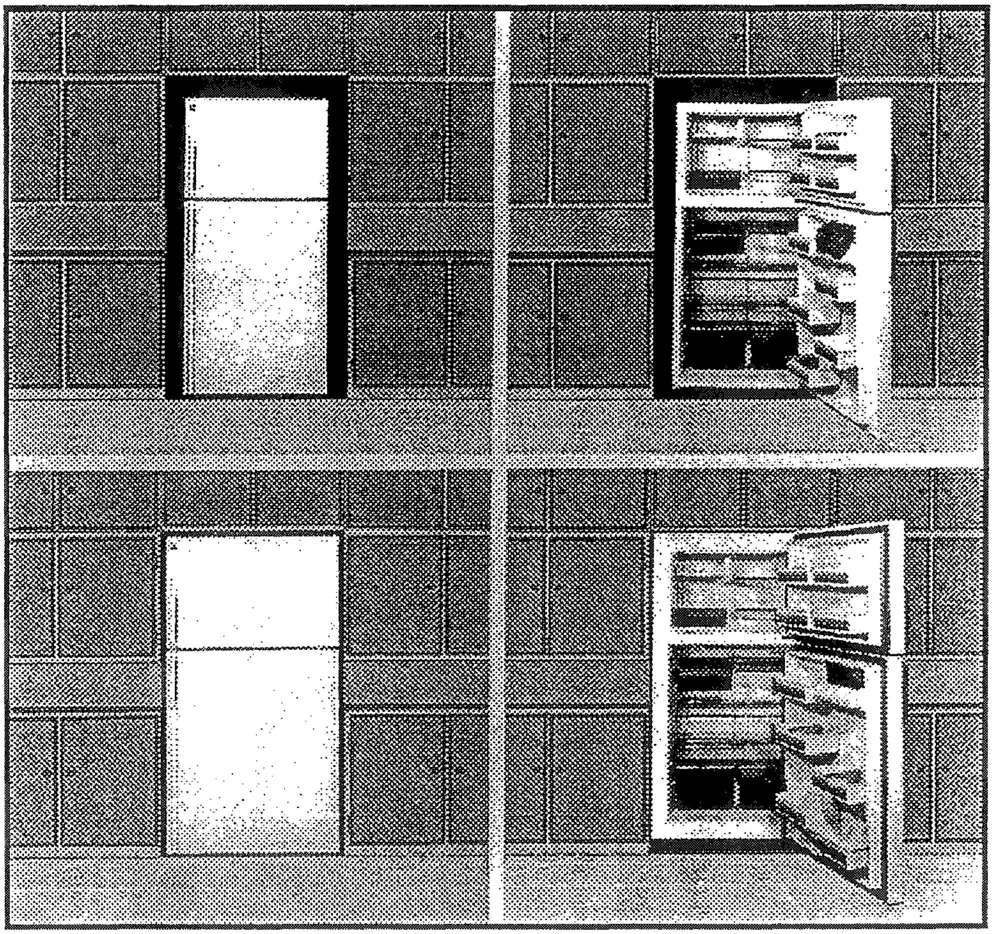
Clearly, consumers will accept thicker wall R/Fs when they have the features that they desire and fit into their kitchens. Additional questions relating to the panel's willingness to pay for energy conserving and/or pollution preventing features such as thicker foam insulation were also asked. In all cases, the responses clearly showed a willingness to pay for these features.[1] For example, when looking at Figure 2 and asked "If refrigerator B produces less pollution and EPA certifies that it is Earth Friendly, how much more would you be willing to pay for it?" The average response was $50.

## Discussion

Figure 4 shows a comparison of the three insulation options which will produce a 20 percent energy reduction in the 18 cubic feet baseline R/F. For this model, the tradeoffs are add 1.3 inches of foam insulation to the exterior of the R/F at a cost of about $30 and serve approximately 20 percent less of the market, add 0.8 inches of foam insulation to the interior of the unit for about $20 and give up 3.1 cubic feet but loose none of the market served, or add 43 square feet of vacuum panel insulation at a cost of $77 without loosing any of the market served or internal volume.

Data given in Figure 1 show that the market served decreases as the size of the R/F increases.[7] More than one inch of exterior foam insulation is required to achieve the same performance as adding vacuum panel insulation, see Table 4. For large R/Fs exceeding 22 cubic feet, this will result in a severe loss of the market which can be served. Thus, even while cost effective and desired by consumers, adding foam insulation to the outside of a large R/F may not make marketing sense. For 22 cubic feet R/Fs or smaller, the market lost will not be as great and the market served may be maintained by making several models with different aspect ratios, i.e., make some deeper to maintain volume while adding exterior foam insulation, some wider, etc.

Adding foam insulation to the interior of a R/F reduces its usable volume. Most consumers indicate that internal volume is a prime consideration, so this is not a viable




Refrigerator B has thicker walls than Refrigerator A. Assume that both units have the same interior storage space, all the features/options of importance to you (color, ice maker, etc.), would fit into that space that you currently have for a refrigerator and both cost $500.00.

*Figure 2. Thick Wall Refrigerator/Freezer Concept for First Market Analysis Study*

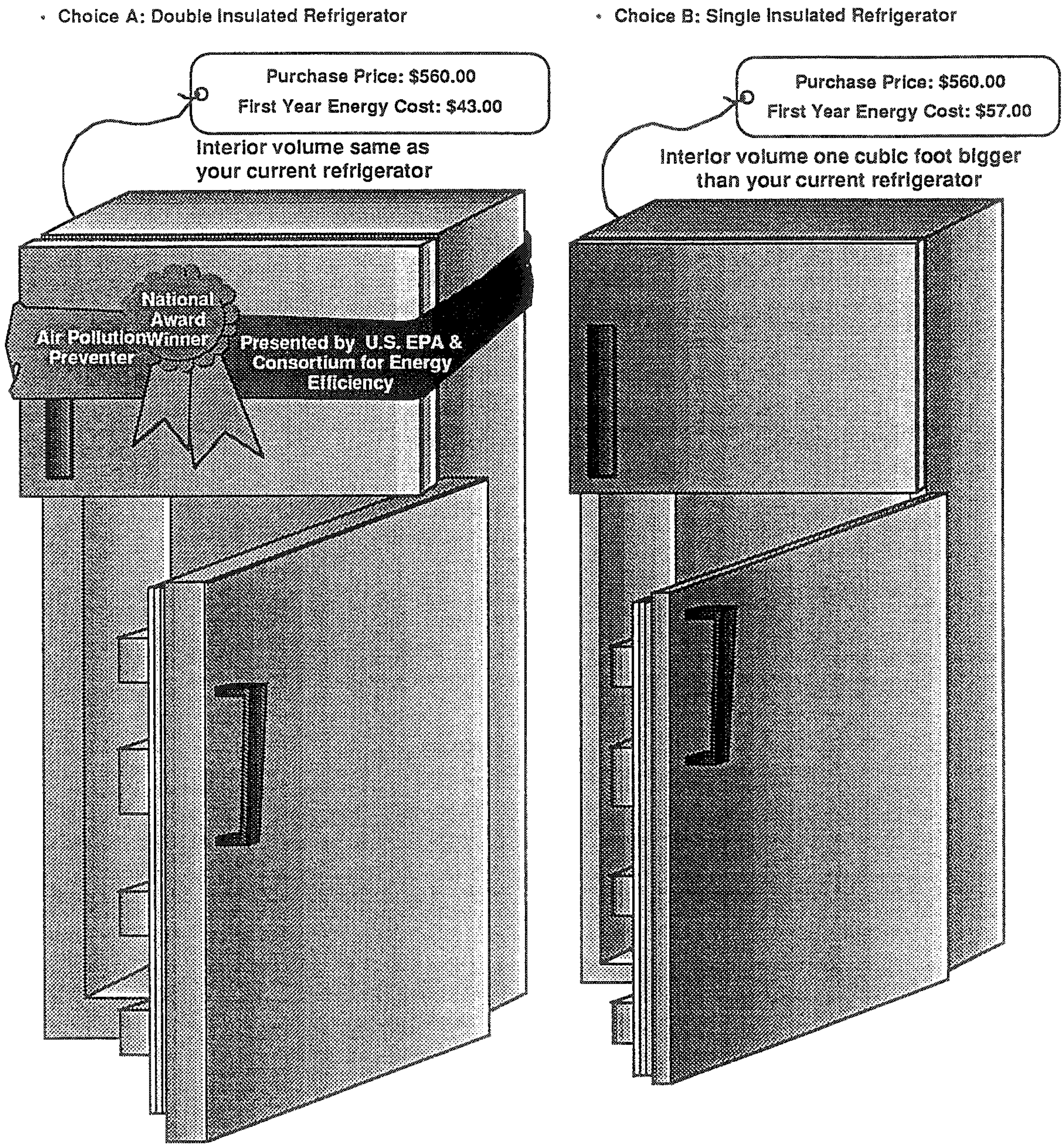
option to conserve energy. The remaining option is to incorporate vacuum panel insulation into the R/F. This is expensive on an avoided energy cost basis. Adding vacuum panel insulation will, however, allow the interior volume to be maintained while lowering energy consumption. Employing vacuum panel insulation to achieve equal performance in place of adding interior foam insulation adds, or at least does not consume, 3.1 to 3.7 cubic feet of usable volume, see Table 4. The manufacturer's cost for this added volume is the cost of the installed vacuum panel insulation. The $25 cost per added (or not lost) cubic foot is much less than the value of this volume for large R/Fs. Furthermore, this cost will be less than $10 per cubic foot, if a credit of as little as $0.02 per kWh is made for the value of the energy saved over the twenty year life of the R/Fs.

## Conclusions

- Adding insulation or incorporating vacuum panel insulation into a R/F can achieve significant energy reductions.
- Avoided costs for energy are about $0.013 when foam insulation is added to the exterior of a R/F.
- Avoided energy costs for vacuum panel insulated R/Fs are at least double those for added foam insulation.

Assume your current refrigerator has broken: You enter an appliance store prepared to purchase a refrigerator with the same interior volume as you now own for $500 (most people own an 18 $ft^3$ refrigerator).

The store manager offers you a special gift certificate for $60, which you can apply to one of two choices:




Assume both refrigerators would fit where you now put your current refrigerator.

*Figure 3. Thick Wall Refrigerator/Freezer Concept for the Third Focus Group Session*

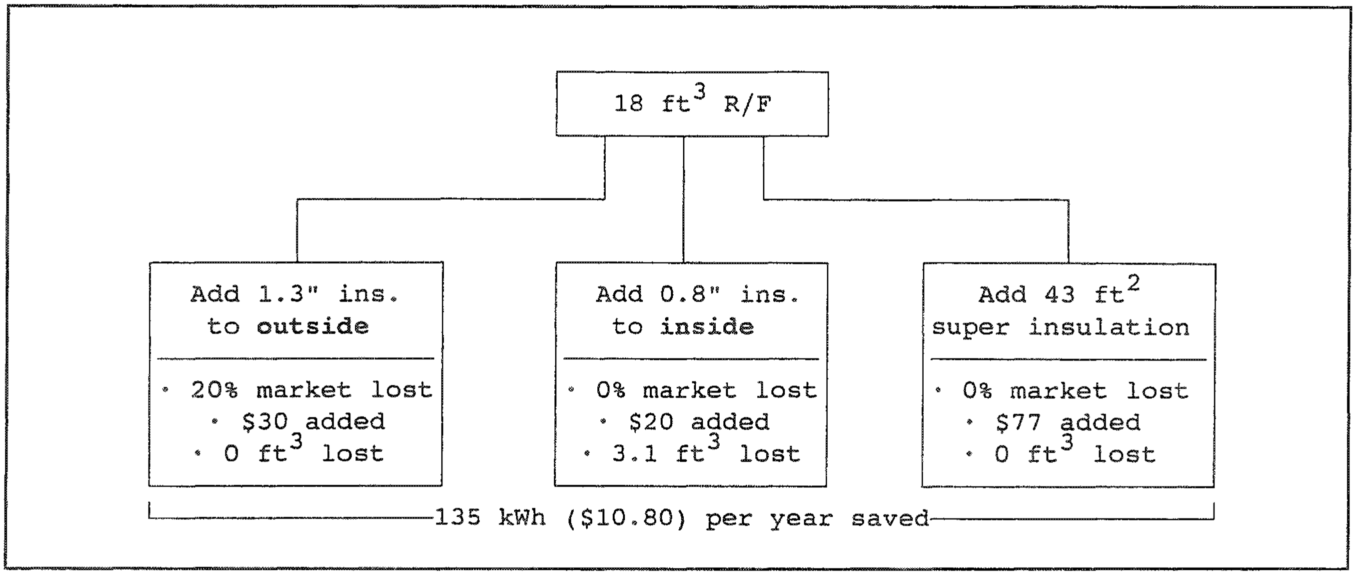



*Figure 4. Comparison of Insulation Options to Achieve a 20 Percent Energy Reduction for the 18 Cubic Feet Baseline R/F*

*Table 4. Added Foam Insulation Required to Obtain Equivalent Performance to Vacuum Panel Insulation*

| | R/F Internal Volume (18 ft³) | | | | |
|---|---|---|---|---|---|
| | 16.2 | 18.0 | 19.9 | 22.0 | 24.2 |
| Exterior, inches | 1.4 | 1.3 | 1.3 | 1.3 | >1 |
| Market Lost, % | 15 | 19 | 23 | 23 | |
| Internal, inches | | 0.8 | 0.8 | 0.8 | 0.8 |
| Volume Lost, ft³ | | 3.1 | 3.3 | 3.5 | 3.7 |
| Cost, $/ft³ | | 25 | 25 | 25 | 25 |

- Consumers will willingly accept thick walled R/Fs, if they will fit into their kitchens and have the features that they desire.
- Adding foam insulation to the exterior will be the most cost effective method of energy conservation for smaller R/Fs.
- Vacuum panel insulation adds over 3 cubic feet of usable volume and is an effective method for energy conservation for large R/Fs.

## Acknowledgements

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