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Optimization of the Insulation Wall Thickness of Refrigerator

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ABSTRACT

The inner volume and energy consumption ratio of the refrigerator are very important features to the consumers. In this paper, we suggest a method to determine the optimal thickness of the thermal insulation walls to minimize the energy consumption ratio while maintaining the same inner volume. Using this method, we find out the optimal thickness of each wall and the volume of freezer compartment and fresh food compartment.

1. INTRODUCTION

The temperature of refrigerator is low to preserve the food in it. The refrigeration cycle is needed to maintain the temperature of the inner side of the refrigerator and consumes the energy to operate. To minimize the energy consumption, the heat load from ambient air to inner side of refrigerator is minimized and/or the efficiency of the cycle is maximized. The energy efficiency is the ratio of the energy consumed to energy consumption limit which is a function of adjusted inner volume.

In this study, we suggest an optimization process of the wall thickness. Using this process, we find out the optimum volume of refrigerator compartment and freezer compartment. The refrigerator investigated in this study is ishown figure 1 and 26cuft side by side refrigerator made by LG electronics in 2002.

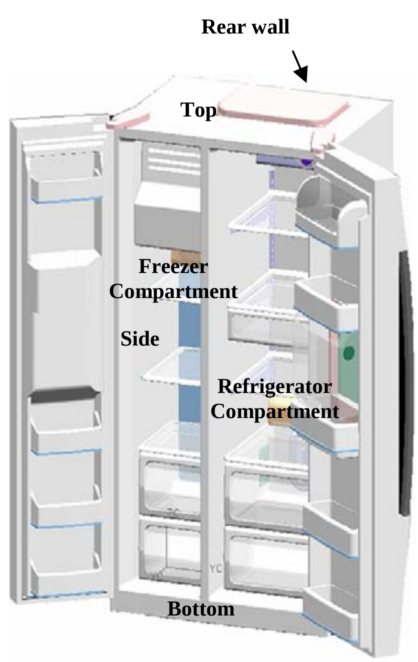

Figure 1. The side by side refrigerator investigated in this study

2. CYCLE SIMULATION

The energy consumption rate of a refrigerator is depends on the amount of the heat from the surrounding air into the refrigerator. The amount of the heat can be expressed as follows ;

$$L_C = \sum A^i h_o (T_\infty^i - T_{w,o}^i) = \sum A^i k_{PU} / t^i (T_{w,o}^i - T_{w,i}^i) = \sum A^i h_i (T_{w,i}^i - T_C^i) \quad (1a)$$

$$L_C = \sum (T_\infty^i - T_C^i) / (1/(A^i h_o) + t^i / (A^i k_{PU}) + 1/(A^i h_i)) \quad (1b)$$

where, $T_{w,o}^i$ and $T_{w,i}^i$ is temperature of inner and outer surface of the wall and related to T_C^i. **Error! Not a valid link.**is air temperature of inner part of refrigerator, and experimentally measured values.
This refrigerator is the 26ft^3 side by side refrigerator made by LG electronics with the LD series compressor made by LG. The refrigeration cycle simulation is conducted with performance curve of the compressor and evaporator curve. We assumed the cycle is steady state. The refrigerator has 2 operation points, the one has relatively higher evaporating temperature than the other one. When the air path between the freezer compartment and refrigerator compartment is opened, the evaporating temperature goes high because the warm air from refrigerator compartment flow through the evaporator coil. The ratio of the air flow rate from the freezer compartment and the air from the refrigerator compartment is about 8:2. We call this operating mode FR operation. If the air path between the freezer compartment and refrigerator compartment is closed, the air passes through the evaporator is only from freezer compartment. We define this mode as F operation. These operating points are depend on the performance curve of the compressor, specification of the evaporator, and air flow rate not on the thermal load. The thermal load effects only the operating ratio of the refrigeration cycle.
The energy consumption rate can be calculated using the power input of compressor, F-Fan and C-fan and operating ratio of the cycle and expressed as follows ;

$$L_R = Q_{FR,R} \cdot \varphi_{FR} \quad (2a)$$

$$L_F + W_{F-fan} \cdot (\varphi_{FR} + \varphi_F) = Q_{FR,F} \cdot \varphi_{FR} + Q_F \cdot \varphi_F \quad (2b)$$

Where, $Q_{FR,R}$ is the heat removed from refrigerator compartment at FR mode. $Q_{FR,F}$ is the heat removed from freezer compartment at FR mode. Q_F is the heat removed from the freezer compartment at F mode. φ_{FR} is the ratio of FR operating mode and φ_F is F mode operating ratio.
Using the operating ratios using the equations (2a) and (2b), the energy consumption rate can be calculated as follows ;

$$E = \varphi_{FR} \cdot W_{C,FR} + \varphi_F \cdot W_{C,F} + (\varphi_{FR} + \varphi_F) \cdot (W_{F-fan} + W_{C-fan}) \quad (3)$$

WALL THICKNESS OPTIMIZATION

The wall thickness optimization process developed in this study is as follows. We defined the relation between the variation of the wall thickness and inner volume of each compartments as follows ;

$$\Delta V_C^i = \Delta V_C^i (\Delta t_C^i) = A_C^i \Delta t_C^i \quad (4)$$

The variation of the energy consumption rate with the variation of wall thickness is calculated using the equation (3) and the following equation.

$$\Delta E_C^i = \frac{E_0 + b_C^i \Delta t_C^i}{1 + c_C^i \Delta t_C^i} - E_0 \quad (5)$$

The energy consumption sensitivity to the variation of inner volume is defined as follows using the equation (4) and (5).

$$s_C^i = \frac{d\Delta E_C^i}{d\Delta V_C^i} = \frac{d\Delta E_C^i}{d\Delta t_C^i} \Bigg/ \frac{d\Delta V_C^i}{d\Delta t_C^i} = s_C^i(\Delta t_C^i) \tag{6}$$

hereafter the energy consumption sensitivity to the variation of inner volume is referred to as sensitivity.

RESULTS AND DISCUSSION

Using the s values which make $\Delta V_C = 0$, we can obtain the optimal thickness' of the walls and energy consumption rate. The variation of the wall thickness for $\Delta V_R = 0$ and $\Delta V_F = 0$ are plotted in Figure 2 and 3. In the figure 2, this optimization process recommends the wall thickness of the rear and bottom walls to be thinner and the top and the side walls to be thicker than the original specification. The top wall is very thick in actual, but the reason why this process recommends the thicker specification is that the PCB is buried in there. But thicker wall is not good in design, maintaining the original specification is better. The optimization process recommends the bottom wall should be thinner, but the original thickness is chosen to satisfy structural strength. The process also recommends the rear wall has to be thinner, but the original specification is for the flow of PU.

Figure 3 shows that the freezer compartment walls thickness variation recommended by the optimization process. The side wall is 6mm thinner than optimum value and the other walls are 6~7mm thicker than recommended value. The thickness of top wall is selected to consider harmony with top wall of refrigerator compartment and the bottom wall is for the structural strength. The side wall thickness is for widen the freezer compartment or for customer convenience. The reason why the rear wall thickness is 6mm thicker than the optimal value is there are many parts in the rear wall foam such as the suction pipe heat exchanger, electrical wires etc and these are the obstacle to the flow of PU.

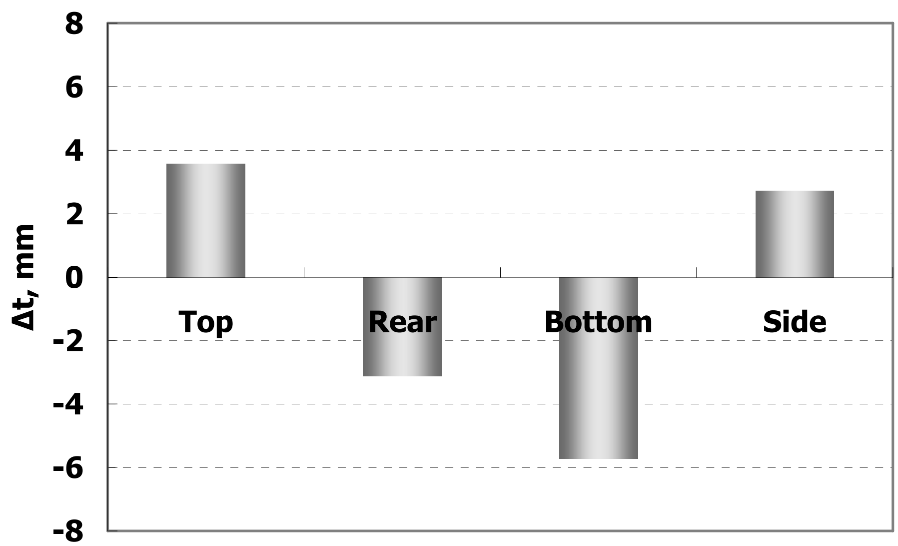

Figure 2. Difference between ideal thickness and actual thickness of refrigerator compartment

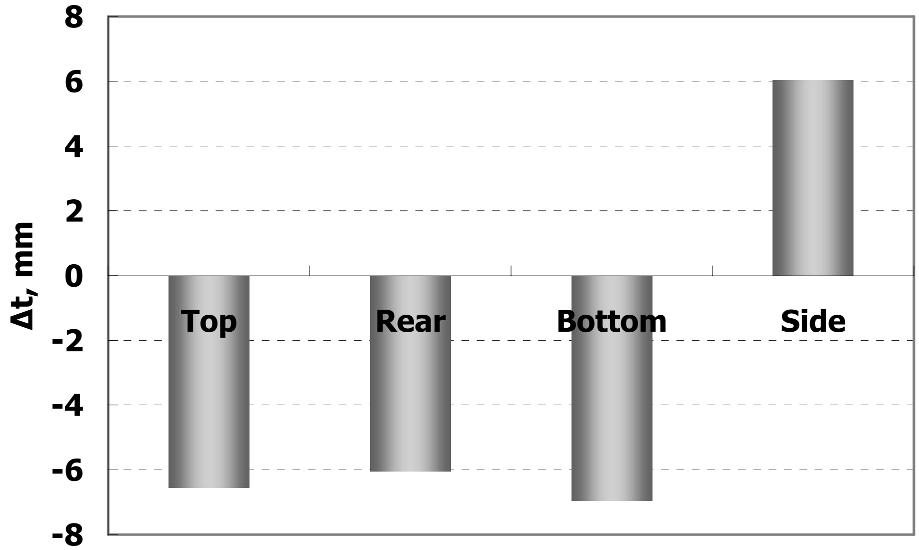

Figure 3. Difference between ideal thickness and actual thickness of freezer compartment

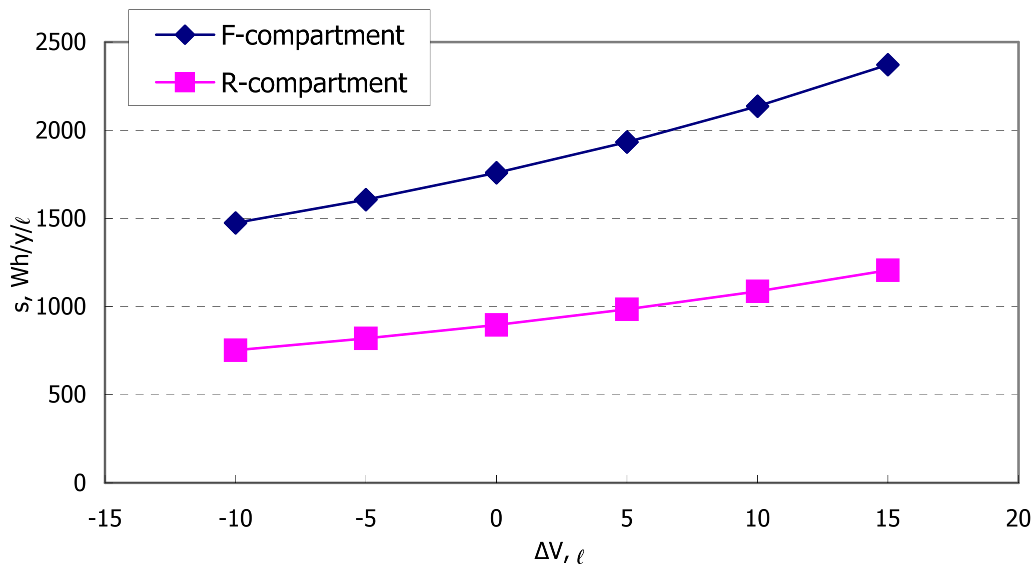

Figure 4. The variation of sensitivity with the inner volume

From the figure 2 and 3, the original specifications are somewhat different from optimal value, but these thickness of the walls are selected by considering the design, structural strength, and customer convenience. But hereafter we consider thermally optimal thickness.

Figure 4 shows the sensitivity of refrigerator compartment and freezer compartment with respect to the inner volume variation. The sensitivity of freezer compartment is 97% higher than that of refrigerator compartment. This means that the large amount of the energy consumption rate should be decreased by small decrease of the inner volume of the freezer compartment and the small amount of the energy consumption rate should be increased by large increase of the inner volume of the refrigerator compartment.

The following equation is the optimum volume relation between refrigerator and freezer compartment.

$$\Delta V_R = 2.9\Delta V_F + 74.2 \tag{7}$$

Substitute $\Delta V_R + \Delta V_F = 0$ to the equation (7), one can find $\Delta V_R = 18.9$, $\Delta V_F = -18.9$, this means that reducing the volume of freezer compartment by 18.9ℓ, and increasing the volume of refrigerator compartment by 18.9ℓ makes the lowest energy consumption with same total inner volume.

CONCLUSION

The design specifications of the wall thickness of 26 cubic ft side by side refrigerator are optimum values which are selected considering the design view, structural strength and customer convenience.
But the wall thickness should be changed in the point of thermal performance. In the case of maintaining the volume of refrigerator and freezer compartment respectively

- Refrigerator compartment : The thickness of the top and side wall should be decreased and rear and bottom wall should be thicken.
- Freezer compartment : Side wall should be thicker and the others should be thinner