

Improving the Efficiency of Refrigeration Appliances



Commercial refrigeration appliances, including visicoolers, hard top freezers and glass top freezers shown above, collectively use a large amount of energy

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Introduction

Climate change is one of the most critical challenges facing our planet. Its implications for our planet are profound and wide-ranging, with potential impacts on biodiversity, water resources, public health and agriculture. In this context, the energy efficiency of air conditioning and refrigeration equipment and reduction of their carbon footprint have assumed high priority. Though the energy consumption of domestic and commercial refrigeration appliances is relatively small on a per unit basis, the total energy consumed by them globally is large, considering that these equipment are used in millions all over the world.

This article discusses some methods of improving the energy efficiency of commercial refrigeration appliances such as glass door refrigerators (popularly termed visicoolers) and freezers. Many of these measures are relevant to domestic refrigerators as well.

The most obvious method of improving energy efficiency that would occur to any refrigeration engineer is to optimize the refrigeration system. This involves the selection of a suitable

refrigerant, use of an energy efficient compressor, liberal design of the heat exchangers, optimizing the capillary to suction heat exchanger, and optimizing the refrigerant charge. Appliance manufacturers have been addressing all these measures and have already achieved a fair degree of success, though there is always scope for further improvement. This article discusses some of these issues and some others related to the cabinet, since the latter determines the heat load on the refrigeration system.

Energy Consumption of some Commercial Refrigeration Appliances in India

Before proceeding with further discussion into the various measures for improving energy efficiency, let us briefly examine

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the present status of commercial refrigeration appliances in India. *Table 1* gives typical energy consumption figures for some common commercial refrigeration appliances. Typical figures for a domestic refrigerator are also shown for the sake of comparison.

With an estimated population of about 50 million units, domestic refrigerators account for about 15% of the energy consumption in the domestic sector in India. Among refrigeration appliances, only domestic refrigerators have been accorded energy star labeling by the Bureau of Energy Efficiency, India. Commercial refrigeration appliances number much less, but their individual energy consumption is significant in comparison to domestic refrigerators. As such, there is a strong case for introducing energy star labeling for commercial refrigeration appliances. It is possible, incorporating the suggestions given in this article, to reduce the present energy consumption values by 35 to 50%.

Let us now look at some measures for reducing energy consumption.

Hydrocarbon Refrigerants

The substitution of conventional refrigerants like R-134a and R-404a by natural hydrocarbon refrigerants, such as R-290 (propane) and R-600a (isobutane), offers significant savings in the energy consumption of cooling appliances. Refrigerators operating on R-600a refrigerant consume about 30% less energy than those using R-134a. Similarly, it has been possible to obtain energy savings of 30 to 40% in chest freezers operating on R-600a over fluorocarbon refrigerants. This improvement arises out of the favourable refrigerant properties of HC refrigerants, such as low viscosity, high thermal conductivity, high latent heat and low pressure ratio. Incidentally, HC refrigerants have the added advantage of negligible global warming potential.

On the flip side, HC refrigerants present a fire hazard on account of their flammability. Appliances using HC refrigerants have to comply with stringent international safety standards in their design, manufacture and application. Nonetheless, millions of refrigerators, visicoolers and freezers have been in use mainly in Europe and China over the last decade.

Variable Speed Compressors

It is possible to achieve energy savings of 30 to 40% by the use of variable speed compressors. A compressor is usually selected to cater to peak cooling demand, which occurs at high ambient temperatures, 'pull down' of warm product loaded inside, freezing load and door opening load. But, much of the time, the appliance will run in the 'closed door' mode at an average ambient temperature, with the stored product 'pulled down' near the set temperature. The cooling capacity required in this condition is obviously much lower than the selected compressor capacity.

This requirement is met by the variable speed compressor. At times of high cooling demand, the variable speed compressor,

Table 1: Typical energy consumption per day at high ambient temperature (43°C)

Refrigeration appliance	Cabinet temperature	Energy consumption (kWh/ 24 hrs.)
300 L Visicooler/ Display Unit	1 to 7°C	7.5
300 L Chest Cooler (Metal Top)	1 to 7°C	4
300 L Chest Freezer (Metal Top)	-18 to -23°C	4
300 L Chest Freezer (Glass Top)	-18 to -23°C	4.8
200 L Domestic Refrigerator (direct cool)	5°C (Freezer: < -5°C)	3 Star: 1.1/ 5 Star: 0.8
300 L Domestic Refrigerator (frost free)	5°C (Freezer: < -18°C)	3 Star: 1.5/ 5 Star: 1

with the help of its associated electronics, runs at a high speed to deliver peak capacity. As the cooling demand drops, the compressor runs at reduced speeds to match the cooling demand. At lower speeds, the cycle efficiency is improved because of reduced friction loads in the compressor, higher evaporating temperature, lower condensing temperature and reduction in the number of start-stops. Since a compressor draws peak power at the time of every start, minimizing the start-stops contributes to energy saving.

However, the electronics used to run the variable speed compressor is expensive and also consumes about 5% of the compressor power by itself. A simple and inexpensive alternative is a two speed compressor, which switches between its high and low speeds depending on the load. It has been experimentally observed that the energy saving achieved with the two speed compressor in a cooling appliance is fairly close to that obtained with a variable speed compressor.

High Efficiency, Variable Speed EC Motors

The shaded pole motor has been traditionally used for small fan drives, which are typically used in visicoolers, freezers and display cabinets. Its advantage is mainly its low cost and simplicity. However, it has a poor starting torque, power factor and a low efficiency of the order of 20 to 25%.

The brushless DC Electronically Commutated (EC) motor is a relatively recent development. EC motors offer the advantages of brushed DC motors in terms of their ability to have variable speed control, but without the problems posed by conventional brushes. The power supply can be DC, or single or three phase AC. EC motors are high efficiency (65% to 80%) electric motors and maintain a high efficiency level even at part speed. In this respect, they score over single phase, capacitor motors. In most cases, EC motors use about one-third to one half of the electricity used by traditional induction motors. EC motors are however expensive, but because of their superior performance, efficiency and durability, offer a great opportunity to reduce energy consumption of the evaporator and condenser fans in commercial cooling appliances.

Cycling the Evaporator Fan

While the condenser fan runs whenever the compressor switches on, the evaporator fan inside the cabinet usually runs continuously, even during the off-periods of the compressor.

Cycling the evaporator fan off and on during the compressor off-period is one way of reducing the heat load within the cabinet, and consequently the energy consumption.

Cabinet and Door

The energy efficiency of commercial refrigerators and freezers is directly influenced by the overall thermal performance of the cabinet and doors.

Viscoolers are provided with a double glazed door, with low-e (emissivity) coating as a standard feature. Double glazed glass comprises two glass sheets, separated by a gap of about 16 mm, which may be filled with air, or preferably argon, which has two-thirds the thermal conductivity of air. Double glazing reduces heat transmission into the cabinet through the conduction and convection modes. The low-e coating is transparent to short-wave radiation of visible light, so that visibility of the product stored inside is not much affected, but reflects away the long-wave infra-red radiation incident upon the glass. Double-glazed, low-e glass with argon fill has a U-value of about $1.9 \text{ W/m}^2\text{K}$.

However, even with a double glazed, low-e coated glass door, the heat ingress through the glass constitutes 45 to 50% of the total heat transmission into the cabinet. This can be further reduced by using a triple-glazed glass door with low-e coating and argon fill, which has a U-value of about $1 \text{ W/m}^2\text{K}$, i.e. nearly half that of the double glazed unit. However, triple glazing increases the thickness of the glass (to 35-45 mm), which renders the glass heavy and unwieldy, while increasing its cost.

Vacuum Insulated Glass

An alternative to triple-glazing is a relatively new development called vacuum insulated glass. Similar in principle to the double-walled thermos vacuum flask, vacuum insulated glass consists of two glass panes separated by a small gap of 1 to 2 mm, which is evacuated to a pressure of the order of microbars (Figure 1). This gives a glass panel that is only about 10 mm in thickness and has U values of 0.7 to $1 \text{ W/m}^2\text{K}$.

The cost of vacuum insulated glass is comparable to that of triple glazed glass panels. Though its use is currently limited to window panes and glass façades of buildings, it offers an

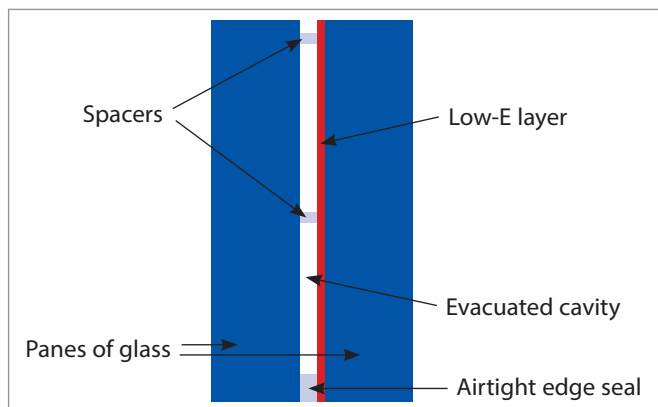


Figure 1: Construction of vacuum insulated glass



Figure 2: Viscoolers with partial glass door

excellent opportunity to minimize heat ingress into glass door refrigerators and improve their energy efficiency.

Partial Glass Door

A simple way to reduce the heat ingress is to provide a partial glass door, with conventional double glazing, as shown in Figure 2. If the area covered by the glass is restricted to about one-third of the total face area of the door, the heat ingress through the door can be halved. Needless to say, this reduction is achieved at the cost of partial loss of visibility of the product inside the cooler.

Opaque Cover on Glass

Since heat ingress through the glass occurs mainly by radiation, covering the glass door (or the glass lid in a chest freezer) during the night contributes to energy saving.

Vacuum Insulation Panels

An obvious method of improving the thermal insulation of the cabinet is to increase the insulation thickness of the walls. However, this is achieved at the cost of either a larger footprint or lower internal storage volume.

Vacuum Insulation Panel (VIP) is a relatively new high efficiency insulation product offering five to ten times superior insulation properties in comparison to conventional insulation materials. The VIP consists of a rigid, highly porous core material such as expanded fiberglass pad or fumed silica, enclosed within a multilayered gas barrier bag. Also included within the bag is a chemical, known as a getter, to absorb any gases which may leak into the VIP or which may be released by the materials used in the VIP. The VIP is evacuated to a pressure ranging between 0.05 and 1 Torr. The thermal conductivity of VIPs is of the order of 5 W/mK , but increases rapidly as the internal pressure rises above 100 Torr.

Figure 3 depicts a cut-away view of a vacuum insulated

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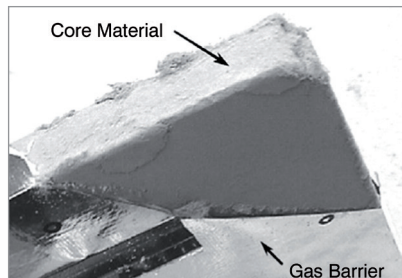


Figure 3: Cut-away view of vacuum insulated panel

panel, while *Figure 4* illustrates its basic construction.

One problem with the VIP has been a gradual loss of vacuum, and hence its insulation properties, over a period of time. The

VIP is also vulnerable to mechanical damage which may release its vacuum and render it useless as an insulation material. Therefore, it is usually foamed within a conventional insulation panel of rigid PU foam. The composite panel offers superior insulation, thereby limiting heat transmission into the cabinet of a cooling appliance and enhancing its energy efficiency. Alternately, the VIP also offers designers an option to reduce the thickness of the insulated wall of a cabinet, thereby releasing valuable usable space within it.

LED Lights

Many visicoolers continue to use conventional fluorescent tubes or CFLs to illuminate the stored product inside. These lights form a significant heat load on the refrigeration system. Substituting them by low wattage LED lights more than halves the energy consumed by lighting within the cabinet. Many

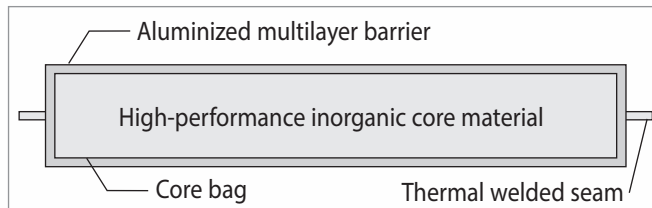


Figure 4: Construction of vacuum insulated panel

manufacturers abroad have already switched to the use of LED lighting in visicoolers.

Conclusion

Many of the measures described above come at a higher first cost. However, the life cycle cost will be lower since the additional first cost can be recovered in a few years through lower energy costs. Additionally, the cooling appliance will be a 'greener' product, with a significantly lower contribution towards global warming and climate change, which present a huge challenge facing our planet today.

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