Outback Marine Systems

Refrigeration Systems

A good refrigeration and freezer system becomes a priority for remote area living. It is a certainty that the corner store or supermarket is often too far away for practical reach which drives the need to become self sufficient with refrigeration.

This application brief covers the basics of an optimal refrigeration system design. The number and size of boxes can be varied to meet individual needs. Operational objectives are similar to household refrigeration except that unique aspects of a mobile installation accentuate certain requirements:

- refrigerator and freezer product need to be kept at required temperatures
- modular service capability by way of quick connect/disconnect fittings
- operation independent of an engine driven power source
- fast temperature pull-down for newly stored product
- versatility for varying storage requirements
- low maintenance and high reliability
- minimal weight and quiet operation
- high energy efficiency

Insulation

The amount of energy required to run a refrigeration system is related to the amount of energy lost through the box insulation and the coefficient of performance (COP) of the refrigeration plant. Additional factors include the energy that is required to bring stored product down to temperature and the energy lost through exchange of air that occurs with door openings. For the sake of practical design, these losses are small and are not considered in the following discussion on insulation.

Enclosure Heat Loss

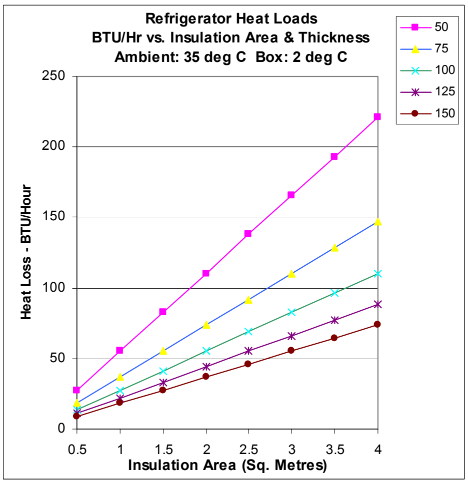
Four factors determine the energy loss through the enclosure:

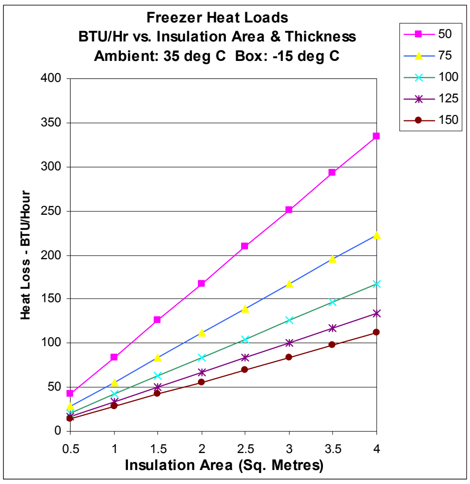
- **Temperature differential**: the difference between the inside box temperature and outside ambient temperature.
- **Insulation surface area**: larger boxes (with more surface area) require more energy
- **Insulation thickness**: thicker insulation requires less energy
- **Insulation factor**: higher performance insulation requires less energy

Energy loss is expressed in BTU's (British Thermal Units) per hour. The charts below show the heat loss in BTU's per hour for refrigeration and freezer enclosures of differing surface areas and insulation thickness - assuming quality Urethane or Styrofoam insulation (.17 K Factor).

First, calculate the outside surface area of the enclosure. For example, an enclosure measuring 700mm x 700mm x 700mm has an outside surface area of 2.5 square metres.

Second, reference the charts below to find the heat loss (BTU's per Hour) for the insulation thickness used. It is evident by the charts that insulation thickness has a dramatic effect on heat loss and subsequent energy requirements. We recommend 100 mm of insulation for refrigeration and 150 mm for a freezer. In our example above with recommended insulation and a surface area of 2.5 Sq M., we would lose about 80 BTU/Hr for the refrigerator and about 70 BTU/hr for the freezer.





Coefficient of Performance

The COP influences the amount of BTU's per hour that the refrigeration plant can transfer for a given amount of energy. It is a measure of system efficiency. Factors influencing the COP include:

- **Evaporation temperature**: lower plate temperatures decrease efficiency
- **Head pressure**: higher pressures require more power
- **Compressor characteristics**: higher compressor speeds decrease efficiency

Freezers require lower plate temperatures than refrigerators. In both cases however, selecting a larger evaporator plate will save energy as the plate temperature will be higher for any given box temperature. Spacing the evaporator away from the cabinet wall will effectively increase surface area as well.

The head pressure (or work load of the compressor) depends on the system load and the efficiency of the condenser. As the head pressure is directly proportional to condensation temperature, good condenser design and installation practices will improve both efficiency and performance.

Most DC systems used in mobile applications use Danfoss BD35 or BD50 type compressors. The compressor speed needs to be high enough to meet the system load but not to high as to lose efficiency. The speed should be matched to system requirements.

System Tradeoffs

It is important to realise that compromising insulation thickness (maybe to gain extra internal volume), will come at the cost of more energy to run the system and will have an impact on actual refrigeration performance.

Attention should be given to equipment capacity vs. box heat load: type and capacity of condensation system, evaporator plate sizing and technology, compressor size and box temperature.

A system analysis should always include the cost of energy generation to support the system in addition to the cost of refrigeration equipment. More often than not, the perceived low cost system is actually more expensive when taking the overall system into account.

Custom Enclosures

Custom made refrigeration enclosures offer many advantages over ready made counterparts:

- Optimum insulation thickness can be achieved and quality of insulation can be controlled
- Box dimensions can be tailored to best match available space
- Finished boxes can be integrated into galley furniture

The additional cost of a custom box can be offset by savings in energy generation as a result of increased energy efficiency.

This application example was developed to satisfy the requirements of a long range 15-metre cruising vessel. The owner specified a 300-litre refrigerator and two 95-litre freezers.

Refrigerator

Although a single 300-litre refrigerator was possible, the enclosure is separated into two compartments. The first compartment of 200-litre capacity is intended for storing product at refrigeration temperature—normally in the range of 1° to 5° C. The second compartment of 100-litres capacity is configured as a cool-box to operate in a typical range of 8° to 12° C. Each space has its own front opening door.

The 200-litre refrigerator is directly cooled by an evaporator plate with a thermostat regulating box temperature. By configuring the compartments side-by-side, the cool-box can draw cold air directly from the refrigerator. A thermostatic fan controls the cool-box temperature.

The enclosure has a nominal 100mm of Styrofoam insulation. This may be reduced in selected areas including the top, cool-box partition and doors (a trade-off in ergonomics). The insulation is encapsulated in fiberglass to seal the insulation from moisture . Further, the Styrofoam insulation has a closed cell construction to provide a second level of defense.

Interior finish is gel-coated. Both boxes have provision for adjustable shelves and a 100mm high splash/air barrier is fitted to the lower door openings. A condensate trough and drain is fitted to each lower door jam to avoid condensate weeping to the outside of the doors. Provision is made to drain the condensate.

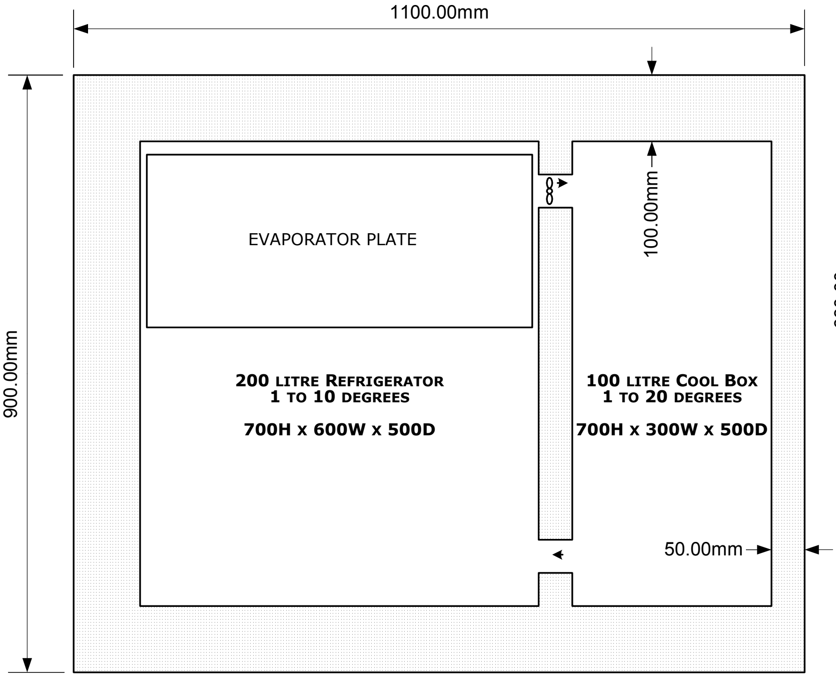
Assuming an average insulation thickness of 100mm; a target box temperature of 2° C for the combined refrigerator/cool-box and; an outside surface area of 4.8 square metres; the worst case heat load should be around 110 BTU's per hour.

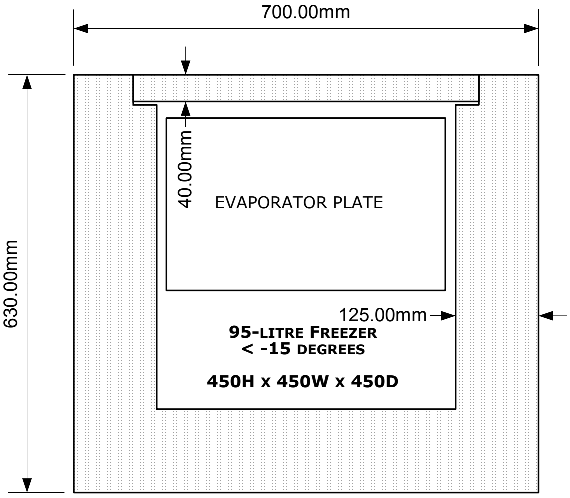
Freezers

Two freezers of 100-litre capacity each maintain temperature less than – minus 15° C. Each freezer has a dedicated evaporator plate and associated thermostat. The thermostats have a broad range of operation allowing the freezers to double as refrigerators if required. The freezers have top opening lids.

Insulation is a nominal 125mm of Styrofoam except for the lid which uses a vacuum panel to keep the overall thickness to around 40mm. The boxes are encapsulated in fiberglass with gel-coated interiors.

Assuming an average insulation thickness of 125mm; a target box temperature of minus 15° C and; an outside surface area of 2.7 square metres; the worst case heat load should be around 80 BTU's per hour.





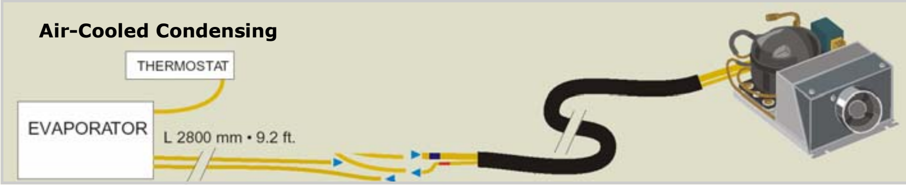
Refrigeration Plant

Many approaches have been taken to mobile refrigeration systems over the years. The biggest breakthrough was the advent of the Danfoss manufactured DC powered compressor in conjunction with efficient 12/24 volt DC energy systems.

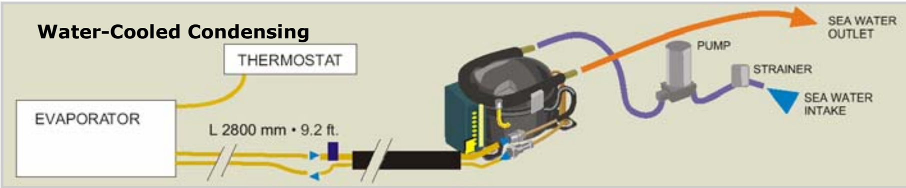
It was once required to use an engine driven compressor that would store energy in a holding plate type evaporator to chill the refrigerated enclosure. The compressor would be either belt driven directly from an engine or powered by an AC motor that required a generator set. It would need to be run for around two hours per day—once in the morning and again in the evening. They are relatively high in cost, heavy and require a person to start an engine at the time dictated by the system.

The Danfoss system runs directly from stored energy in the already present battery bank. The compressor will run when it needs to. They use a light weight evaporator plate that has little impact on enclosure volume. A system that is properly manufactured and configured provides excellent service at significantly less cost compared to a holding plate system.

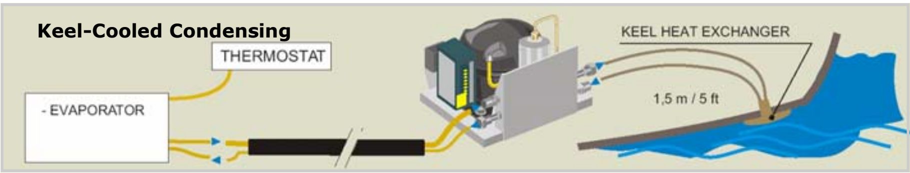
Selection of the right Danfoss system depends on box heat load and the preferred type of condensation method.



Air-Cooled Condensing



Water-Cooled Condensing



Keel-Cooled Condensing


Air-Cooled Set


Water-Cooled Set

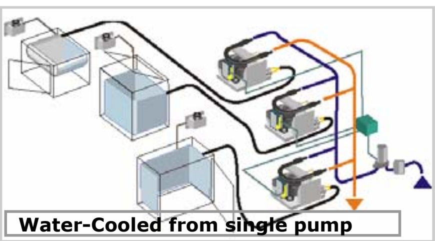

Keel-Cooled Set

Condensation Methods

The condenser takes the high pressure gas from the compressor and cools the gas to the point where it changes state to a liquid. In other words, energy taken from the refrigeration box is transferred to the water or air in contact with the condenser. The choice is predominately air cooled or water cooled. Water cooled comes in two variants—a pumped water system or keel-cooled system.

Air-Cooled Condensing

An air-cooled condenser cools the compressed refrigerant gas by use of a fan that blows ambient air across a finned condenser. They are the obvious choice for land based systems. An advantage for boats is their inherent simplicity and their ability to maintain refrigeration when the boat is dry. It is important to ensure cool air flow through the system—look for shrouded condensers and mount the system in a cool area—an air duct will help.


Water-Cooled from single pump

Water-Cooled Condensing

For vessels with larger box loads, water-cooling offers higher capacity and better efficiency. A DC powered pump sends filtered sea water through a tube-in-tube condenser to liquefy the gas. Up to three condenser sets can be driven by one common filter and pump. System capacity is up to 30% higher than air-cooled compressors.

Keel-Cooled Condensing

Keel-cooling is a unique form of water-cooled system. Instead of the condenser being mounted at the compressor and cooled by pumped water, the keel-cooler is in direct contact with the sea water. It is the most reliable of all systems. The only moving part is the compressor. It has similar performance to conventional water-cooled systems without the maintenance overhead of filter cleaning.

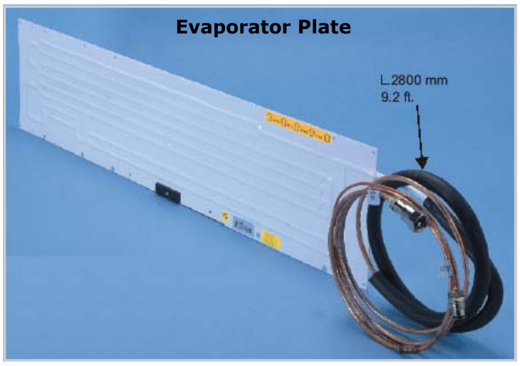
Evaporator Plates

The evaporator plate takes liquid refrigerant from the condenser. Through an evaporation process, the liquid expands to a gas and absorbs heat energy from the plate. The ability of the evaporator plate to absorb energy from the enclosure depends on plate temperature and surface area.

A plate of higher surface area is more efficient because the resulting plate temperature required to meet the target box temperature allows the system to work with a better coefficient of performance. Select the largest that fits.

If the plate is spaced away from the wall of the enclosure, effective surface area can be doubled. Another way of increasing performance is to pass flowing air across the plate. We call this a fan forced evaporator. Note that this type of evaporator is not suitable for freezer applications.

Evaporator plates perform better than holding plates on Danfoss systems.



Evaporator Plate


Fan Forced Evaporator

Refrigeration Plant

Compressors

The compressor is the final link in the chain. When combined with a condenser it is often referred to as a condenser set. The compressor fits between the evaporator plate and the condenser. For the condenser to change the state of the refrigerant gas to a liquid, the gas from the evaporator plate must be compressed to a level that causes condensation. The energy required to compress the gas comes from the compressor motor which draws power from the battery system.

The pressure required is directly proportional to the condenser temperature. Higher pressure causes more work for the compressor which is why a more efficient condenser will save energy.

Compressor Sizing

Each enclosure has a dedicated condenser set and evaporator plate. Condenser sets have capacity ratings expressed in BTU's per hour. The ratings will vary according to evaporator plate temperature, condensing temperature and compressor RPM. Danfoss compressors are not designed to be run on a continuous basis; doing so raises oil temperature to an unacceptable level.

As a rule-of-thumb, target the worst case duty cycle to be around 33% or in other words, multiply the box heat loads by three and match to the compressor rating. For the enclosure examples given earlier, the refrigerator would need a rating of 330 BTU's per hour and the freezer would require 240 BTU's per hour.

The table below shows the specification of two Frigoboat model air-cooled condenser sets for varying compressor RPM. If we chose a 50F model running at 3000 RPM, the fridge compressor would run for 7.5 hours total per day and consume 42 amp-hours of energy. Each freezer would run for 5.5 hours per day and consume 30 amp-hours. Note: these figures are guidelines only.

Smart Speed Control

To facilitate the highest energy efficiency, a Smart Speed Controller dynamically adjusts the compressor speed to match the cooling requirements of the associated box. A manual fast pull-down setting is available to rapidly chill newly stored product. A safety start is also provided to prevent overstress of components when starting the system from warm box conditions.

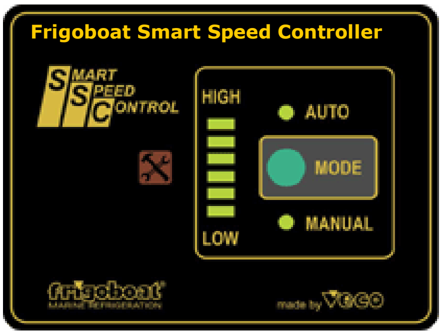
TECHNICAL CHARACTERISTICS	35F	50F	35F	50F	50F	50F
Compressor speed RPM	2000	2000	2500	2500	3000	3500
Capacity (-15°C/+45°) Btu/h	199	233	249	293	349	400
Consumption in Amp (12V)	2,6 A	3,6 A	3,4 A	4,6 A	5,5 A	6,4 A
Consumption in W	31 W	41 W	41 W	55 W	64 W	76 W


Frigoboat Capri 50 - Air Cooled


Frigoboat W50 - Water Cooled


Frigoboat K50 - Keel Cooled


Frigoboat Keel Cooler



Frigoboat Smart Speed Controller

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