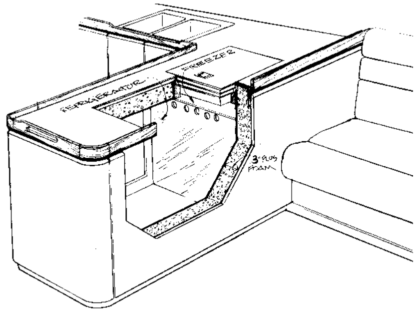
REFRIGERATION

While a lot of cruisers do without refrigeration, a good system can work wonders for better morale aboard. The longer a cruise lasts, and closer to the equator the course is, the more important the fridge system becomes.

The problem is that a cruising fridge system involves more than just keeping food cold. It also involves engine running time for the compressor (with direct drive), or producing the amps required for an electric system. The gear, operational costs, and maintenance this entails frequently doubles or triples the cost of the fridge system itself.

Of course, there are alternative ways to keep your food and drinks chilled. Many of the principles that apply to refrigeration also apply to ice, except, of course, that ice doesn't last on extended passages.



The key to an efficient fridge system is the box design. This includes insulation quality and quantity, door layout and gaskets, and the amount of surface area for the entire box.

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OBJECTIVES

There are several key objectives to be kept in mind with the fridge system. First, it must be reliable. In the event of failure, you either need to be equipped to handle repairs, or you need to have a backup system available. (Learning the basics of refrigeration repair is pretty easy.) Next, the system should be efficient. Running an engine or genset for two or three hours a day for the sake of a cool drink gets old after a while.

Principles of Refrigeration

The principles of refrigeration are easy enough to understand. You start out with something colder than the surrounding air, then insulate it via the fridge box lining to keep it cool as long as possible. Because marine systems don't have a continuous source of power, they usually use holding plates to maintain cold. Inside these plates is tubing cooled by refrigerant chemical. This material is in liquid form and enters the plates through an expansion valve (TX valve). Inside the TX valve is a small, adjustable orifice. As the refigerant liquid squeezes past it begins to boil inside the evaporator coil tubing. The boiling of the liquid changes to a gas, and in the process absorbs heat from the surrounding area. This change of state, going from a liquid to a gas, is what creates the cooling process. The TX valve regulates the flow of refrigerant into the plates by sensing the temperature on the outlet side of the tubing. It is designed to make sure that all liquid has turned to gas by the time it has reached the sensing bulb. The cold is then stored in some type of liquid, usually called a eutectic solution.

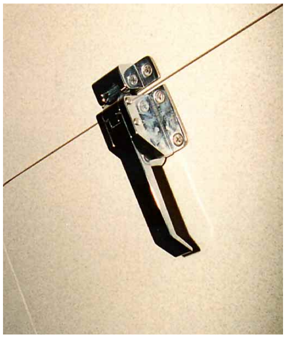
The gas is sucked back from the plates by a compressor, which takes the gas and compresses it back into liquid form. This process generates heat, so right after the compressor you have a heat

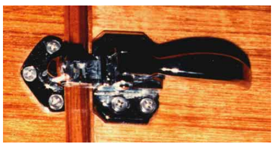
Access into the box is usually in conflict with the most efficient design. For access you want front-loading doors. For efficiency you should have top loading, to minimize heat gain when the door is opened.

We typically make the fridge a front loader — the fridge has lower heat-loss potential than the freezer and is used more often.

The left photo is from a Sundeer 64. We find it best to keep leftovers and drinks in one section, and long-term storage in another (usually the bottom). This minimizes the number of times you must open both doors.

The right photo shows Jos and Kelly Archer's *Mistral*. Note top and front access to the fridge. The freezer is top loading only.





Door hardware must be far more robust than what you find at home. You need hardware beef to compress gaskets evenly.

This leads to an aesthetic conundrum. Good-looking hardware is typically a bit light. Heavy, industrial-grade hardware looks clunky. We usually bite our tongue and go with the heavy-duty gear since it works so much better.

Make sure that hinges and catches are *adjustable*. This is the only way to get the door gaskets to seal correctly.

Over time it will be necessary to tighten the hardware as the door gaskets take a set.

Door handles can be real bruisers if set on the face of a cabinet. We frequently inset the handle into the face of the door. This looks nice and gets the handle out of the traffic pattern. There are two negatives: it adds man hours to the building process, and you lose a considerable amount of insulation around the handle.

exchanger. With your home fridge, this is just a series of small tubes with some fins and a fan blowing ambient air over them. But on a boat, seawater is used in the heat exchanger, since it's readily available and much more efficient than ambient-temperature air.

Running Time

Before getting into system detail, let's talk for a minute about running time. It doesn't make much difference whether you use an AC electrical system running off a generator, an engine-driven compressor, or a DC electric system using batteries that must be periodically recharged. Whenever those diesels are turning over (for charging batteries, making AC current, or powering a compressor), on-board ambience suffers radically. Therefore, it's important to minimize running time for refrigeration needs if you intend to spend much time aboard.

When we started cruising on *Intermezzo*, our supposedly first-class fridge system required an hour of engine time a day in California and two hours a day in the Marquesas Islands. That appeared to be the norm among most of the boats we met. Well, if you have to listen to a bloody engine running that long every day, you soon begin to wonder if cold drinks are worth the hassle.

But along the way we learned a few lessons, re-engineered the system, and cut running time by more than 50 percent. By the time we built *Intermezzo II* we knew how to limit time to under an hour a day with much more storage capacity. On *Sundeer* and *Beowulf* running time was reduced to about 20 minutes a day.

Obviously, a superefficient system won't help much if you have to run the engine or genset an hour a day for other reasons. One of the keys is to balance daily running cycle against the boat's other power needs.

The Box

Regardless of which of the numerous plumbing and compressor approaches is eventually chosen, the final efficiency of the system comes down to how well the fridge/freezer box itself is designed. Cold leakage from the box is a function of several factors. First is surface area. The more surface area, the more the cold dissipates. You want to have the most interior volume for the least surface. Ideally your box will be cube shaped. While this isn't often possible, beware of long, slender designs (typically along the hullside) with small interior volumes and big surface areas.

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Then you have the loss that comes with opening and closing the fridge/freezer doors. Top loading is more efficient here, because with a front loader the cold air tends to spill out. But top loaders are hard to use. Linda hated the top loader on *Intermezzo* (although she did look kind of cute with half of her body inside the box). Spillage from front loaders can be reduced several ways. The first is to have a deep lip at the bottom of the door. Next, shelves can be made of solid sheets of plastic, possibly with hinged fronts, so that the air doesn't drop down when you open the door. The fridge doors should be as small as practical. Finally, a filled fridge loses less cold air when opened than a somewhat empty box.

Usually the best compromise is to have a top-loading freezer, which isn't opened that often, and a front-loading fridge. Hopefully the freezer will have some form of a basket or inventory system to minimize the time necessary to keep the door open. The Schmidts used a system of stacking stainless baskets in their freezer aboard *Wakaroa*. Not only did this make it easier to find things, but it reduced the heat load from the freezer door being open while the food hunt was underway.

On our boats, the fridge gets opened most often for drinks. I feel it makes sense to have a small compartment just for drinks, if there's room. Or, you can keep a cold-drink vacuum thermos handy on the outside, which is reloaded on a periodic basis. We've also found that a cold-water tank inside the fridge, with a spigot plumbed outside, helps reduce door openings.

The ideal fridge liner is smooth, with low heat-transmission qualities, and tough enough to take years of removing frost. Stainless meets most of this criteria. It is smooth, easy to clean, and will withstand frost removal. However, it is a much better heat conductor than fiberglass. On balance, we prefer stainless for its advantages and put up with the slight reduction in efficiency. Surprisingly, it is usually no more expensive to use a stainless liner than one made from fiberglass.

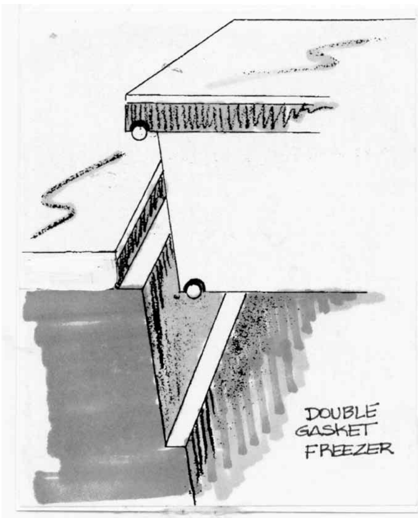
In the upper right photo, Cheryl Schmidt proudly shows off *Wakaroa*'s freezer. The interior and access hatch are coordinated so that stacking baskets can be used to store and separate food stuffs. The door into the freezer has a single gasket, while the counter lid (which she holds in her right hand) has a second gasket.

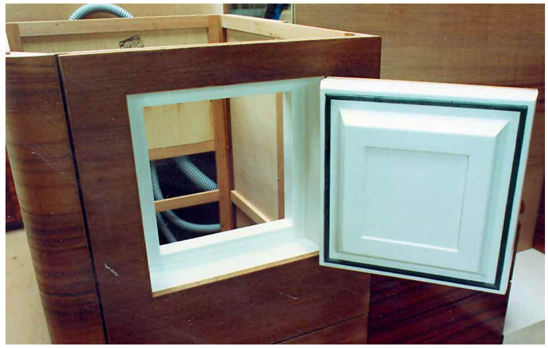
With a top-loading freezer, it's essential to work out a system to keep spills from getting past the gaskets. This requires a small dam or fiddle around the perimeter, or, as in the case here, a trough around the outside of the counter gasket that drains to the bilge.

Temperature gauges are handy to keep track of the fridge system. We like to install them in each box.

Gaskets

The last area of leakage is around the door gaskets. There are two problems here. One is heat loss. The second, more serious, is allowing humidity to enter the box. This forms condensation on the cold plates, which turns to frost and impairs their operation. Gaskets should be soft, easily compressed, and form a good seal all the way around. Hinges and latches should be heavy-duty so as to really put pressure on the gaskets. The fridge can get by with a single set of gaskets, but the freezer should have a double set.





Gasket design is tricky. You want a material that gives a good moisture seal and minimizes heat leakage. The gasket needs to be soft enough to conform to irregularities. Hollow gaskets are commonly used on land, but, they allow quite a bit of heat leakage.

We tend to use soft solid gaskets and the heavy hardware necessary to compress the gasket material. The freezer should have double gaskets as in the drawing above. Fridges are okay with a single gasket. With a production boat you have the opportunity of creating recesses into which the gaskets can fit with your tooling. However, on custom projects the norm is to have the gasket attached to a flat on the door.

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INSULATION

Insulation of the box is, of course, a key ingredient in overall efficiency. Until recently, the only really functional material was polyurethane foam, typically 2 pounds per cubic foot in density (the lighter the better).

In the last few years isocyanurate foam has been available in sheet form with a higher "R" value than PU foams.

Stay away from cheaper polystyrene or bead foam — it doesn't insulate well at all.

When building or re-insulating a box there's frequently a question about whether to use board stock or pour the foam. Poured foam is nice in that it fills all crevices and adheres to the sides of the walls. However, the quality of the poured foam can vary markedly and this has a big impact on insulation value.

Over time, all foams try to absorb moisture. As they do, they lose insulating values. After a couple of years an unsealed foam insulation will have its "R" values reduced by half or more.

To get around this the fridge box should be carefully sealed with some form of a barrier on the outside. The foam should be sealed as well.

Some foams are more hydroscopic than others. Polystyrene foams are like sponges. Isocyanurates are more hydroscopic than PU foams.

We used the isos on *Beowulf* but sealed the sheets with epoxy to keep them moisture-tight.

Poured foam tends to be more hydroscopic than sheet foam.

FREEZER

BTU HEAT LEAK IN 24 HRS.	BOX VOLUME IN CUBIC FEET / INCHES OF POLY. FOAM INSULATION. 6	4	3	2
5200	16	11	8	
				5
5000				
		10		
4800	14		7	
4600				
	12			4
4400		8	6	
4200				
	10			
4000			5	
				3
3800		6		
	8			
3600			4	
3400	6			
3200				
		4	3	2
3000				
2800	4			
		3		
2600			2	
	3			
2400				
2200		2		1
	2			
2000				
			1	
1800				
		1		
1600	1			
1400				
1200				
1000				

REFRIGERATOR

BTU HEAT LEAK IN 24 HRS.	BOX VOLUME IN CUBIC FEET / INCHES OF POLY. FOAM INSULATION. 6	4	3	2
5200				14
5000				
				13
4800				
4600			20	12
4400			18	11
4200				10
			16	
4000				
3800		20	14	
3600		18		8
			12	
3400		16		
				7
3200		14	10	
	20			
3000		13	9	6
	18			
2800		11	8	5
2600	14	10	7	
				4
2400	12	8	6	
2200	10		5	
		6		3
2000	8		4	
		5		
1800	6			
		4	3	2
1600				
	4	3		
1400			2	
	3			
1200		2		1
	2			
1000			1	

Compressor running time and/or holdover time is a function of box surface area and insulation. You can generalize to an extent with box volume and use the data above. As an example, a fridge with a volume of 8 cubic feet and 4 inches (100 mm) of insulation would have a heat leak of 2,400 Btu per day. This is based on a sheet polyeurethane foam of around 2.2 pounds/cubic foot density. Data courtesy of Marine Air/Grunert.

Foam Thickness

Foam should be as thick as possible; for tropical cruising, 3 to 4 inches (75 to 100 mm) on the fridge and 6 inches (150mm) on the freezer. If you're only going to be sailing in temperate climates, 2 and 4 inches (50 and 100 mm) would do the job.

Here we get into one of those trade-offs. Since space is limited below decks, the fridge box has to fit a finite volume. More insulation means less net storage volume for food. As you add to the insulation thickness the interior volume is rapidly reduced. On the other hand, there is nothing as nice as an efficient fridge system, running on solar panels or requiring little engine time. We've always gone for the highest insulation values. If a smaller box was the result, we've felt that was a good trade-off.

Here, sheet polyeurethane foam is used to insulate a freezer (6 inches/150mm thick). Note the foil moisture barrier on the back side. Poured form is used to seal the corners. The top edges also need to be sealed with a film or resin, or moisture will eventually find its way into the foam, reducing the insulating value significantly.

High-Tech Panels

Now comes some very exciting news. There are two new high-tech insulating systems on the market with three to ten times the value of foam. The first is a system developed in Europe. It involves plastic vacuum panels filled with a special ingredient with "R" values around 20 for a 1-inch (25mm) thick panel (that's the equivalent of 4

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An Owens-Corning Aura insulation panel. This is the most efficient insulation available, with "R" factor of 60 for 1-inch (25mm) thick panels. (Glacier Bay Photo)

to 5 inches [100 to 125 mm] of normal foam). The second is the Aura panel, made by Owens-Corning. This is a true metal vacuum panel with "R" values of around 60! Both are available from Glacier Bay.

Think of the possibilities this brings. Huge reductions in fridge running time, to the point where four solar cells can easily handle a medium-size box in the tropics. More net storage space is another factor.

Our experience is that in normal usage, about half of all heat load comes from opening the fridge or freezer and/or introducing warm food to the interior of the box. This means that half the heat load comes through the insulation.

Cutting this heat load by two-thirds will reduce running time by about one-third. And, when you leave the boat for a period of time so that the doors stay closed, holdover or running time is reduced by two-thirds! This has enormous implications for the rest of your systems on board.

We'll be using these panels on a boat currently under way. Our plan is to bury them in a poured foam matrix, 3 inches (75mm) thick. This takes care of the corner leakage issues and leaves us with reasonable insulation values if for some reason a panel were to fail.

Temperature

Cold loss (or, more correctly, heat load) is a direct function of the temperature differential between the inside of the box and the ambient outside air. Bearing this in mind, the colder the interior of the box is, and the warmer the outside surfaces, the longer the daily compressor running time.

This has an impact on the location of the outside of the box. Ideally, the entire box will be freestanding in the interior. If one side is up against the hull, or an engine room bulkhead (where the ambient temperature will be higher) additional insulation should be allowed.

Temperature versus Food Longevity

The colder the boxes are, the longer foodstuff will last, but of course colder means more running time, so you don't want the box any colder than is necessary. We've found that keeping the top of the freezer at 25 degrees Fahrenheit and the bottom about 10 degrees F colder will keep most frozen goods three to six months without deterioration. But for longer periods, colder temperatures are needed. In the fridge, a 45- to-50-degree temperature will work well if running time is a concern. But a 5 to 10-degree-colder range will keep leftovers longer.

Fridge/freezer temperatures are controlled by the set point of the eutectic solution in your holding plates, the amount of surface area of the plates, and air movement over the plates. Along with these factors goes heat load on the box. Temperature of the plates can be lowered by over running the compressor, but this is very inefficient and can lead to long-term problems with the compressor.

The easiest way to keep track of box temperature is with external gauges. These can be purchased at any fridge supply house for under $20. We like to monitor each box separately. A simpler approach is an internal thermometer left inside and checked when the fridge or freezer is opened.

Interior Volume

A major decision has to be made in space utilization, and this depends on cruising style. If you're close to sources of frozen goods, you'll want more fridge and less freezer space. But when you're really out in the boonies, with lots of long passages in the making, freezer space becomes more critical. Also, the freezer takes more running time because it's colder, so having more freezer than you really need is counterproductive.

On *Intermezzo* we had a 7-cubic-foot (net of holding plates) fridge and 2-cubic-foot freezer. In those carnivorous days we could pack 80 pounds of meat (carefully) into that little freezer. Next

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we graduated to a 7-cubic-foot freezer and 12-foot fridge on *Intermezzo II*. On *Sundeer* we stayed with the 7-foot freezer but went to a combination fridge/vegetable box, each of the latter being 7 cubic feet. The advantage here is with temperature. The vegetable box can be kept at a higher temperature than the fridge, reducing heat loss and compressor running time. Of course, not everyone wants to devote the space or the machinery necessary to maintain such a large capacity. A 3- or 4-cubic-foot box, with perhaps 1 foot of freezer worked in, will keep you in very good shape most of the time.

It's also possible to have combination boxes. When we did the original *Deerfoot* there was a section between the fridge and freezer that could be used as either by changing the temperature of the plate.

You do have to be careful about getting the fridge too cold and freezing vegetables and fruit. Also, if any of the stored items touch your holding plates they're likely to freeze in the contact area. So careful packing will be in order. (We usually put cheese, yogurt, butter, and other non-temperature-sensitive items back against the plates to shield the fruits and veggies.)

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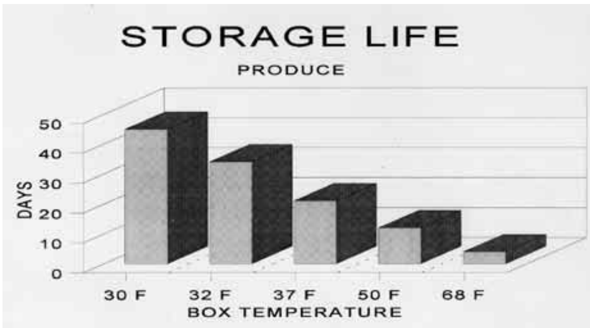


FOOD	LONG	SHORT	FRZ.
APPLES	30-32	38-42	28.4
ASPARAGUS	32	40	29.4
BACON	0-5	36-40	25.0
BANANAS	56-72	56-72	30.2
BEANS, GREEN	32-34	40-45	29.7
BEANS, DRY	36-40	50-60	N/A
BEEF, FRESH	30-32	38-42	N/A
BEETS, TOPPED	32-35	40-50	26.9
BLACKBERRIES	31-32	42-45	28.9
BROCCOLI	32-45	40-45	29.2
BUTTER	N/A	40-45	15.0
CABBAGE	32	45	31.2
CARROTS, TOPPED	32	40-45	29.6
CAULIFLOWER	32	40-45	30.1
CELERY	31-32	45-50	29.7
CHEESE	32-38	39-45	N/A
CHERRIES	31-32	40	28.0
CORN, FRESH	31-32	45	29.0
CRANBERRIES	36-40	40-45	27.3
CREAM	34	40-45	N/A
CUCUMBERS	45-50	45-50	30.5
DATES, CURED	28	55-60	N/A
EGGS, FRESH	30-31	38-45	31.0
EGGPLANT	45-50	46-50	30.4
FISH, FRESH	25	25-30	30.0
FISH, DRIED	30-40	N/A	N/A
GRAPEFRUIT	32	32	28.4
GRAPES	30-32	35-40	27.0
HAM, FRESH	28	36-40	N/A
HONEY	31-32	45-50	N/A
ICE CREAM	N/A	0-10	N/A
LEMONS	55-58	N/A	21.8
LETTUCE	32	45	31.2
LIVER, FRESH	32-34	36-38	N/A
LOBSTER, BOILED	25	36-40	N/A
MAPLE SYRUP	31-32	45	N/A
MARGARINE	34-36	N/A	15.0
MEAT, BRINED	31-32	40-45	N/A
MELONS	34-40	40-45	28.5
MILK	34-36	40-45	31.0
MUSHROOMS	32-35	55-60	30.2
NUT MEATS	32-50	35-40	20.0
ONIONS	32	50-60	30.1
ORANGES	32-34	50	27.9
OYSTERS	N/A	32-35	N/A
PARSNIPS	32-34	34-40	28.9
PEACHES, FRESH	31-32	50	29.4
PEARS, FRESH	29-31	40	28.0
PEAS, GREEN	32	40-45	30.0
PEAS, DRIED	35-40	50-60	N/A
PEPPERS	32	40-45	30.1
PINEAPPLE, RIPE	40-45	50	29.9
PLUMS	31-32	40-45	28.0
PORK, FRESH	30	36-40	28.0
POTATOES, WHITE	36-50	45-60	28.9
POULTRY	28-30	29-32	27.0
PUMPKIN	50-55	55-60	30.2
RASPBERRIES	31-32	40-45	30.0
SARDINES, CANNED	N/A	35-40	N/A
SAUSAGE, FRESH	30-36	36-40	N/A
SAUERKRAUT	33-36	36-38	N/A
SQUASH	50-55	55-60	29.3
SPINACH	32	45-50	30.8
STRAWBERRIES	31-32	42-45	30.0
TOMATOES, RIPE	40-50	55-70	30.4
TURNIPS	32	40-45	30.5

Temperature and storage life are closely linked, as you can see in the data above (from Glacier Bay). Note that there are optimum maximum and minimum temperatures given for a series of different items. The freezing temperature is also important — below this temperature, the fruit or veggy in question will be ruined.

HOLDING PLATES

When you have a constant supply of power, such as with a house fridge, the compressor can run whenever required. In this case, the compressor works with what is called an evaporator coil. The evaporator is cooled by the expansion of the refrigerant gas, and the evaporator cools the surrounding air. Sometimes a fan or two is involved to move air over the evaporator. Because the evaporator/compressor combination runs often, the load on it is light. The compressor is therefore smaller than what would be found on a boat.

A boat, without continuous power available, requires a compressor system that can be run for short periods of time, typically when the engine is running. This being the case, some form of storage for the cold created by this compressor is required. Here holding plates come into the equation.

How Holding Plates Work

Certain liquids go through a change of state when they are cooled below a given point. Large quantities of energy are required to achieve this change of state. Fresh water is a good example. At 32 degrees Fahrenheit (0 degrees Celsius), water begins to freeze. In the process of freezing, huge amounts of energy are absorbed, changing the water to ice, roughly 1,140 Btu per U.S. gallon (3.8 liters). Because it is a *true eutectic solution*, all of the water in a given area will freeze before the temperature starts to drop beyond the eutectic point. When the eutectic begins to thaw, the reverse happens. The same amount of energy is required to warm the solution up past the freezing point. The temperature of the solution will remain constant until the last molecule of the eutectic has had its change of state. This eutectic property is the key to storing cold energy in the fridge system. With a true brine solution (salt-based) at a temperature of around 7 degrees Fahrenheit/-14 degrees Celsius, you have a holdover capacity of approximately 800 Btu per U.S. gallon.

Here's a simple experiment you can conduct at home to prove this principle. Take a glass of water with several ice cubes, and check the temperature of the water. After a while the water temperature will be at 32 degrees Fahrenheit/ 0 degrees Celsius. It will remain at this temperature as the ice melts, as that is the eutectic point of fresh water. On your thermometer you will see a steady temperature until the last of the ice has melted, at which point the temperature of the water will begin to rise.

Unfortunately, there are few true eutectics. Fresh water, as you know, is one. Adding salt to water maintains the eutectic properties but lowers the temperature at which the freeze/thaw point is reached. Salt, however, is corrosive and cannot be used in plates unless the plates and plumbing are made of stainless or galvanized steel. You cannot use salt solutions with stainless and copper, for example, due to corrosion occurring in the copper plumbing.

Just to complicate this problem a little more, there is a mechanical problem with water-based eutectics. They expand as they freeze. This can cause all sorts of problems with your plate and plumbing, unless proper allowance has been made in advance.

Non-Eutectic Solutions

All sorts of other ingredients can be added to water to reduce the freezing points. One is ethylene glycol, the antifreeze you use in your car. Another approach is to use methylated spirits with water. Both of these lower the freeze point of the solution. However, because they are not a true eutectic solution, several things happen.

First, there is no steady temperature point at which the plate will sit on a stable basis for a long period of time. This makes it difficult to keep the fridge or freezer at a set temperature. Second, because there is no true change of state, there is a loss in holding capacity of anywhere from 40 to 65 percent compared to a true eutectic. Finally, because the temperature continues to drop as the solution is cooled (rather than sitting at a fixed eutectic point until the whole plate is frozen) the compressor operates at a lower average temperature. This reduces compressor efficiency.

Arne Adams (left) and Tim James (right) calculate the results of the before-and-after plate tests aboard *Sundeer.*

Super Juice

Tim James and Arne Adams, two rocket-scientists-turned-cruisers, saw the problems with the two choices just discussed and set out to solve the problem. They came up with a patented true eutectic solution with a capacity to absorb heat similar to that of salt water, but one that is non-corrosive and that *contracts* rather than expands upon freezing.

We built *Sundeer*'s fridge plates in the usual fashion in New Zealand — a combination of stainless liners, copper tubing, and a water/methylated spirits solution.

However, we made allowances for changing the solution when we got the boat back to the States. Upon our return, Tim and Arne came down to the boat and connected a strip chart recorder to the freezer. We tracked the holdover, temperature ranges, and amp hours consumed on a daily basis.

We then changed the solution to their super juice and went through the same data again. Where before we had a 36-or-so hour holdover, we now had a capacity of four days plus. And, compressor amp hours (or running time) was down by 40 percent!

These results are typical for any *true* eutectic solution.

Eutectic Temperature

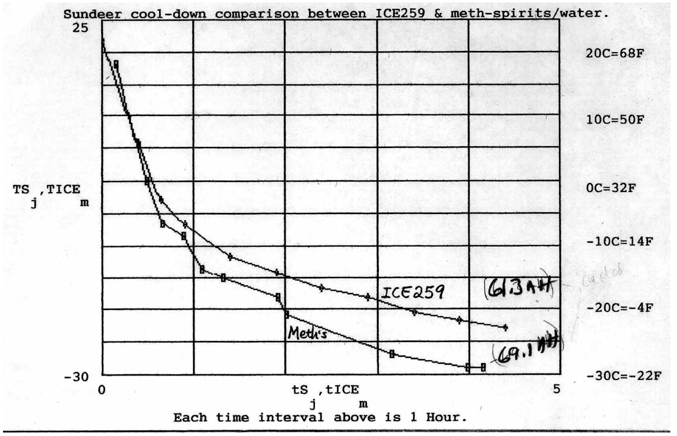
Whether you make your own plates or buy them already made, you need to decide what temperature eutectic solution to go for.

The industry standard is 26 degrees Fahrenheit for fridges and 0 degrees to –5 degrees Fahrenheit for freezers. The temperature at which the box will run is a function of the surface area of the plate, air flow over the plate, heat load on the box, and temperature of the frozen solution inside the plate.

Two issues push us toward the *highest* acceptable temperatures. One, the warmer the box is, the less difference there is between inside and outside air and the lower heat load is on the insulation. The lower the heat load, the less compressor running time.

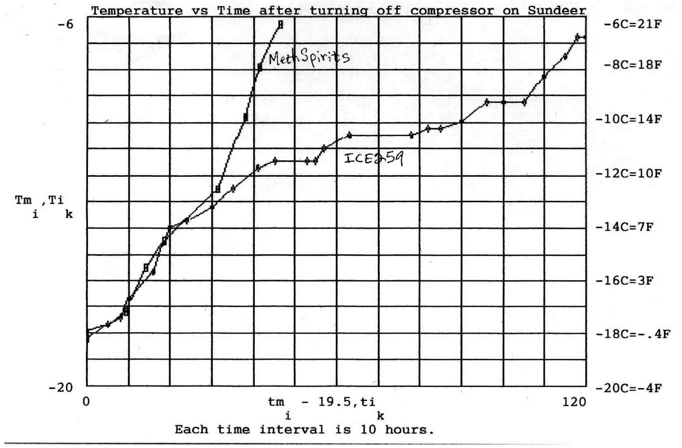
If the ambient temperature is 75 degrees Fahrenheit, and the freezer is at 0, there's a differential of 75 degrees. If you let the freezer run at 15 degrees Fahrenheit, there is only a 60-degree differential. That's a difference of 20 percent in heat load.

The other issue is compressor efficiency. The higher the temperature at which it operates, the more efficient it will be.



A comparison between methylated spirits/water plate solution and "super juice" on *Sundeer*'s freezer. The bottom line is the meth's solution. Note how it drops to a lower temperature and takes more power than the upper graph of Super Juice. A 15-percent difference in amp hours is required to solidly freeze the plates.

The lower graph illustrates what happens after the compressor has been shut down. There's a 36-hour holdover with the meths and 105 hours of holdover with "super juice." When you consider that just 61 amp hours were required to achieve the 105 hours of holdover time versus 69 amp hours for the shorter holdover, you begin to realize the inefficiency of anything other than a true eutectic solution!



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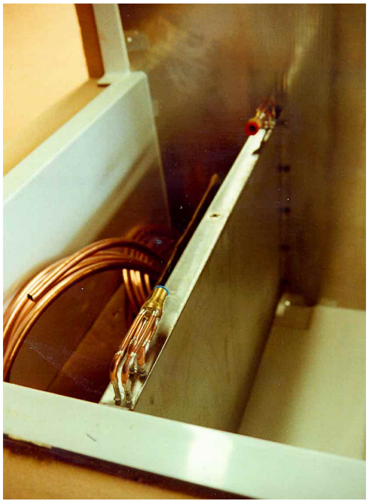
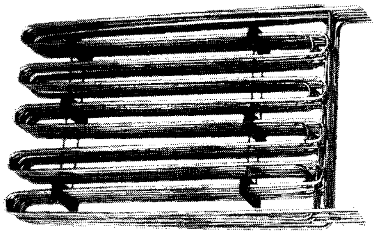




Three different approaches to coil installation and design. The upper two photos show the Sundeer 64 freezer with a center-mounted plate and a Glacier Bay "spider" coil inside the plate. The centered location has several advantages. First, it divides the freezer. Second, both sides of the single large plate are exposed to the food. Third, the plate is easily cleaned on the two largest sides (and it is easier to remove accumulated frost).

The bottom photo shows a stainless liner with two sets of built-in coils before installation aboard *Beowulf.* There is 50 feet (15.4m) of 5/8-inch (16mm) copper pipe in each coil. This is designed to work with a 1/2-horsepower compressor.

Surface Area versus Temperature

We mentioned plate surface area as having an impact on temperature. For a given heat load and given box size, you need a certain plate temperature to achieve your desired results. By increasing the surface area of the plates you can achieve a lower temperature in the box. Alternatively, you can use greater plate area to maintain a given temperature while raising the eutectic temperature (which means a more efficient compressor).

Most stand-alone plates are held off the surface of the fridge or freezer by about 3/4 inch (19mm), so that air can circulate around both sides.

This helps plate efficiency, but it is impossible to clean behind the plates.

In general, box temperatures run 10 to 15 degrees Fahrenheit above the surface temperature of the plates.

Use of Fans to Augment Air Flow

Since air flow is a key ingredient in the box-temperature equation, you can lower the temperature of the box by moving air over the plates with a small muffin fan. These can be thermostatically controlled and have a tremendous impact on box temperature. If you are shy on surface area or want to use a plate with increased eutectic temperatures, a small fan is the way to go.

Plate Location

Fridge plates are best located, when possible, at the top of the box. This keeps them in the warmest spot, where they are least likely to maintain a frost line, and where thermocyling of the air will be most effective over the plate.

This has the further advantage of removing the possibility of freezing vegetables that inadvertently sit against the plate.

Freezer plates are also best mounted on the top, although sides work well, too.

The very best approach, however, is to use the freezer plate in a freestanding installation, where it is a divider in the center of the box. This allows you to get at both sides to clean. It also gets the best air flow around the plate.

Built-In Plates

In many instances it makes sense to use a built-in plate, where the plate is actually a part of the fridge liner. You start out with a stainless-steel liner for the box. This forms the inner wall of the plate. An outer wall is then welded to the inner to form an enclosed tank.

The advantage of this type of approach is that the inside of the fridge is a smooth, easily-cleaned stainless-steel surface, with no hidden areas to collect grunge.

The negative is that only a single side of the plate is in contact with the air, so more surface area is needed.

Plate Plumbing

As the liquid refrigerant is pumped out by the compressor, it flows down the liquid lines (small pipes) toward the box. Just before the plate there is an expansion (TX) valve. This TX valve has a small needle valve in a tiny orifice that is operated by a temperature-sensing bulb,

As the liquid refrigerant hits the needle valve, it is turned into a fine spray of extremely cold gas. As the gas flows down through the plate plumbing, it absorbs heat from the surrounding solution.

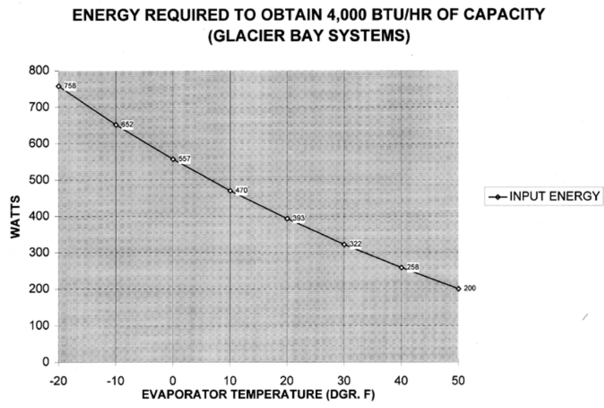
The temperature-sensing bulb regulates the flow of gas. The proper setting of this, called the “super heat” setting, is critical to efficient operation. Being off just a little bit can reduce efficiency by 50 percent or more.

The design of the plumbing run after the TX valve, and how it absorbs heat, has a major impact on your system’s efficiency.

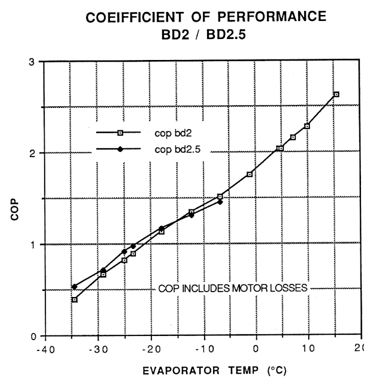
The gas inside the tubing runs at 15 to 20 degrees Fahrenheit below the eutectic point of the evaporator coil at the beginning of the cycle. Eventually, this causes the solution closest to the tubing to freeze. This frozen material then forms an insulating barrier so that the compressor has to make even colder gas (and run at a lower, less efficient temperature) to freeze the rest of the solution.

With a true eutectic, all of the solution theoretically changes state at the same time. In reality, this is somewhat true, although there is always some early change of state (freezing) around the plumbing from about halfway through the cycle.

The more surface area there is, the better heat transfer. At the beginning of the cycle this is based on compressor capacity, but toward the end of the cycle it is based on the capacity of the semi-insulated plumbing pipes to absorb heat.



The lower the temperature at which the compressor operates, the less efficient it is. This is a function of eutectic temperature in your fridge plates. The graph above illustrates the difference in watts required to obtain 4,000 Btu per hour from a Glacier Bay system. Between +20 and -20 degrees Fahrenheit, there’s almost a 2-to-1 ratio. Add in the greater heat load on a box which is kept colder, and you can see why a system set to run as warm as is tolerable is significantly more efficient on power needs.



The left chart shows compressor efficiency for a Danfoss-style 12V compressor.

Coil Design

Coil design varies with compressor capacity. The ideal solution is to use an air-conditioning *evaporator* coil of appropriate size. This coil has a combination of lots of tubing and interspersed aluminum fins, so that there are large amounts of surface area in contact with the surrounding solution. With this approach the partial freezing of the eutectic has much less impact.

The problem is that these coils use copper tubing and aluminum fins. Put all this in a stainless tank and add some salt water, and you have a big battery. However, this approach will work to improve the efficiency of the noncorrosive noneutectic solutions (such as ethylene glycol and water).

Another approach, used by Glacier Bay, is what they call a spider coil. It uses 120 feet (37 m) of 1/4-inch (6mm) stainless-steel tubing. If this were laid out in a single run, the pressure drop would be too great and there would be a loss in efficiency. Instead, they have the tubing manifolded in a series of parallel runs. This results in good surface area with little pressure drop.

Oil Traps

Your refrigerant travels through the system carrying a mist of oil with it. When the plate is designed, it must take into account this oil and make sure there is enough velocity (speed) of the gas so that oil is carried along back to the compressor.

Plates have specific orientations to make sure the oil is pulled through correctly. You will want to observe this when installing them.

Plate Capacity

If you are using an engine-drive compressor, you will want at least a 24-hour holdover time. Twice this would be preferable. However, there are limits, since plates take up interior-storage area.

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With electric-based systems, where you have large battery banks, plate size is typically determined by what is needed to make the electric compressor most efficient, the majority of the holdover coming from the battery capacity, which is then replenished by the engine.

Using Evaporator Coils

If you have a large battery bank, consider a system based on a simple evaporator coil. This is the same as the approach used in home systems. You still have the cold gas running through the pipes, only now there is no eutectic. The plates cool the air directly. The heat transfer, evaporator coil to air, is more efficient than what happens in a holding plate where you first have to cool the solution (with the freezing complications) and then the solution cools the air.

But there is no storage capacity with this approach except for what is available in the batteries.

Whose Plates?

There are all sorts of claims about plate efficiency, how they are made, and how they compare to the opposition. Assuming you are starting from scratch, there are several basic choices.

Glacier Bay makes plates with very efficient spider coils that use a salt-water-based true eutectic solution. Another approach is available from Grunert. Bob Williams, of Sea Air Land Technologies was involved in the development of these plates, and Bob says they also have a true eutectic solution. An alternative way to go is with galvanized steel plates made for ice cream trucks by the Dole Company. The Dole plates use salt water. For some reason people don’t like the galvanized steel. However, I think they are fine. You can frequently find them used.

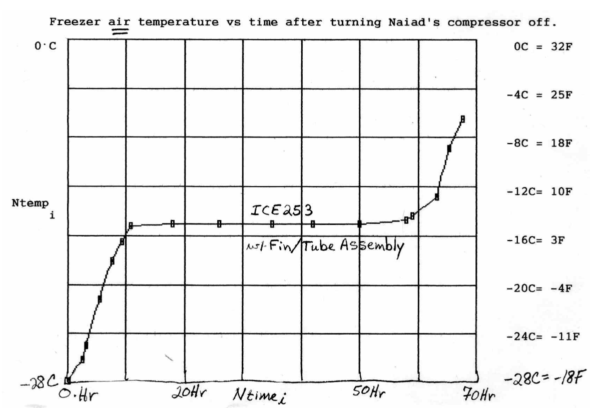
Finally, you can make up your own plates. It’s not that big a deal, and while you will probably not save any money, you might end up with something just the right size. If this is your approach, I would aim toward plates using the “super juice” we mentioned earlier, with air-conditioning finned evaporators.

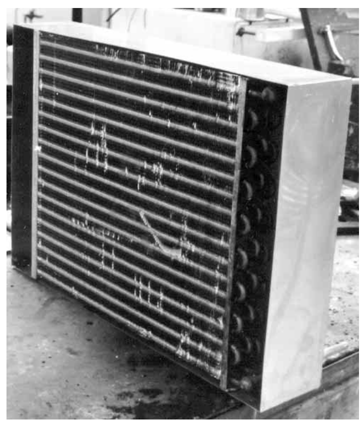
Testing an Existing Plate

If you want to find out quite easily if your existing plates have a true eutectic, you will need a recording thermometer, available from most refrigeration-supply houses.

Take the probe and tape it onto the middle of your plate. Use an insulating tape so that it only reads plate temperature, not outside air temperature.

If the plate is eutectic, you will see the temperature drop or rise at a steady rate. When it hits the eutectic temperature, the graph will flatten out until the solution has reached the change-of-state temperature, at which point the temperature will again change. If you don’t see this flattening of the temperature range, you do not have a true eutectic solution.





For the most efficient holding plates and pull-down, you need to combine an air conditioning–style evaporator coil (right) and a true eutectic solution. The air conditioning coil has lots of copper tubing manifolded with huge quantities of flat aluminum fins to conduct heat. This eliminates the efficiency loss due to early freezing around the pipes carrying the refrigerant gas.

The problem comes in the eutectic solution. A true salt-based brine will cause electrolysis in the copper and aluminum evaporator coil. But Tim and Arne’s Super Juice is noncorrosive, and that, combined with a properly sized finned evaporator, will perform significantly better than anything else.

The chart above shows how the freezer plate on Tim’s boat performed. Compare this to the curves for *Sundeer* and you will see a much flatter pull-down and holdover. The eutectic is the same. The difference is that *Sundeer* had a plain copper evaporator, while Tim’s boat used the finned evaporator.

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THE COMPRESSOR

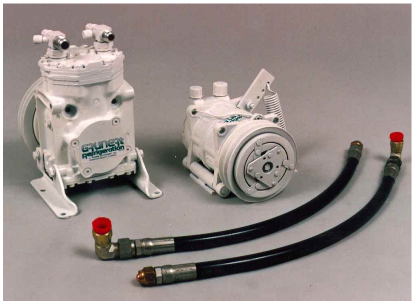
The type of compressor chosen for the fridge system has a major impact on your other systems approaches. Therefore, carefully review all your vessel's requirements against the compressor choice.

Engine Drive

Until recently, the most popular way to go was with an engine-driven compressor. And in many cases, this is still the best, especially with modest DC or AC electrical generating capacity. The engine drive system makes use of the daily battery charging cycle for power, and it's pretty efficient, due to a direct transfer of power from engine to compressor.

There are several direct-drive compressors, all from the automotive business, where they're used for air-conditioning. Depending on the mounting flexibility of your engine and available space, you can choose either a rotary or a straight-line compressor. Rotaries are a little more efficient, but the old-fashioned Tecumseh and York 10-cubic-inch models have greater capacity than most rotaries — typically about 1.5 horsepower, compared to 0.75 horsepower. Mounting brackets should be sturdy, with provision for adjusting belt tension. Most of these compressors can be turned up to 5,000 or 6,000 rpm, so using a large-drive pulley to increase compressor speed when the engine is idling will give you a faster pull-down on the plates.

The compressor must be connected to the rest of the system with flexible hoses. If copper is used, there will be vibration cracks in a short period of time. However, it's important to minimize the amount of rubber used. Rubber refrigeration hose is somewhat porous and acts as a semi-permeable membrane with moisture. In a warm, humid



All engine-drive compressors start life as automobile air-conditioners. They are, therefore, optimized for higher temperatures than you find in a fridge/freezer system. However, with so much power available from the engine, this lack of efficiency is typically not a problem.

There are two basic types, both of which are shown above. On the left is a conventional unit available from either York or Tecumseh. To the right is a rotary. Rotaries are somewhat more efficient but have less capacity.

Note the flexible hoses to isolate vibration. All flexible hose is osmotic — i.e., it allows moisture into the system. As a result, driers need to be changed more often. Flexible hoses should be kept to the shortest length possible. (Marine Air/Grunert photos)

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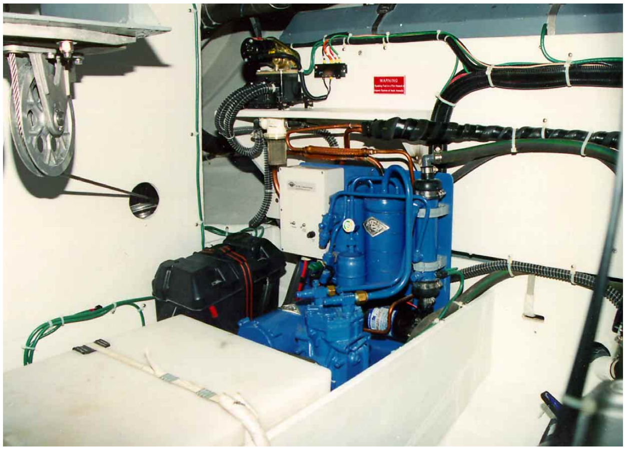
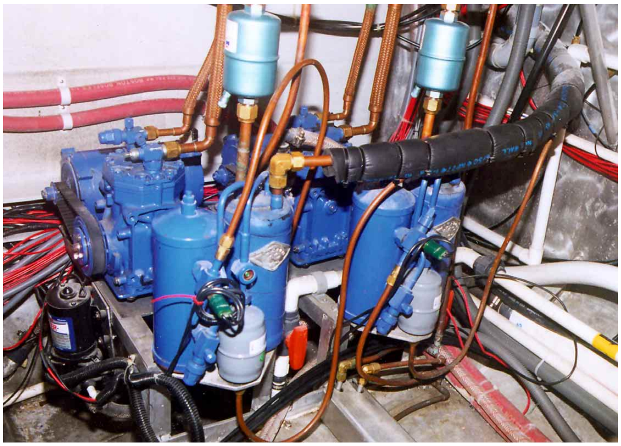
Model No.	Head Press.	Speed RPM	BTU/HOUR AT VARIOUS HEAD PRESSURES — EVAPORATING TEMPERATURE °F: 40°	30°	20°	10°	0°	−10°	−20°	−30°	−40°
HGC 1000	120#	500	10400	8250	6500	5200	3800	2800	2100	1550	1100
		750	15500	12500	9800	7800	5900	4300	3250	2350	1700
		1000	20500	16750	13100	10300	7800	5800	4400	3150	2270
		1250	25000	20150	16000	12500	9750	7200	5300	3900	2800
		1500	29000	23600	18750	14700	11600	8600	6300	4600	3400
		1750	32900	26500	21200	16700	13300	9950	7200	5300	3800
	150#	500	9300	7500	6000	4450	3300	2500	1750	1250	900
		750	14000	11200	8850	6700	5000	3700	2650	1800	1300
		1000	18600	14900	11800	9000	7000	5000	3550	2450	1800
		1250	21700	18200	14450	11000	8300	6200	4400	3050	2300
		1500	26500	21250	16800	13000	10200	7400	5350	3800	2800
		1750	30000	24200	19150	14800	11250	8500	6200	4300	3200
	180#	500	8300	6600	5150	3950	2900	2200	1400	850	650
		750	12500	10000	7750	5900	4400	3250	2200	1400	950
		1000	16550	13300	10500	8000	6200	4200	2900	1800	1300
		1250	20200	16250	12800	9800	7300	5300	3700	2450	1700
		1500	23800	19200	15150	11600	9000	6350	4400	3050	2200
		1750	27000	21850	17250	13200	9950	7300	5250	3650	2550
	210#	500	7500	5900	4650	3500	2550	1850	1200	750	450
		750	11250	9000	7000	5250	3600	2800	1850	1250	800
		1000	15000	11900	9300	7000	5200	3800	2500	1700	1200
		1250	18400	14700	11450	8700	6300	4700	3150	2200	1450
		1500	21600	17300	13550	10300	7600	5550	3700	2500	1700
		1750	24700	19750	15500	11800	8750	6400	4300	3100	2100

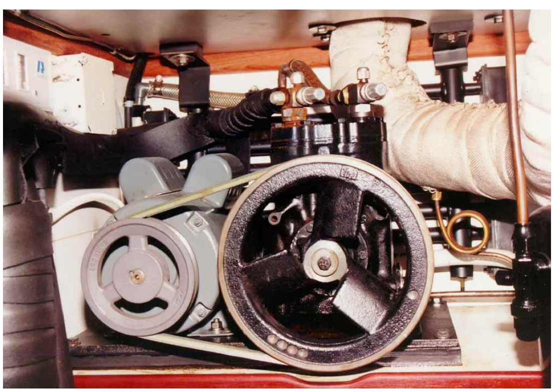
This chart shows the relationship between compressor rpm, evaporator temperature, and Btu capacity for the Tecumseh HGC 1000 compressor. It is also representative for York compressors. These make up the bulk of engine drive systems. Note how quickly capacity builds with rpm, which is why you want a very large drive pulley on the engine. Also note how fast capacity drops as temperature is reduced in the holding plates.





Two Glacier Bay DC compressor installations.The upper is on one of our production boats. Note the vibration isolators between the compressor and plate plumbing in both photos.

The second photo is a dual compressor setup. Each fridge and freezer has dual plates serviced by one compressor — i.e., each compressor does a fridge and a freezer plate. This offers a totally redundant system, so that if either fails, the second serves as a backup.



An industrial Tecumseh freezer compressor with an AC motor (although it could be DC driven). Note the large fly-wheel-effect pulley. The weight in this smooths compressor operation, making it quieter and helping longevity.

engine compartment, moisture will be sucked into the hose, causing all sorts of maintenance problems. About 18 inches (457mm) is as long as you should go with the rubber.

You may be asking what to do with this system at the dock. It would certainly be nice to avoid running the engine when shore power is available. Short of installing a second compressor, one approach is to take an AC motor — typically 1/2 horsepower and well geared down via drive pulleys — and mount it opposite the compressor. When you're in port, slip off the engine-drive belts and use the electric motor for power.

The engine-drive system has the advantage of enormous capacity and parts readily available from any junkyard in the world. The main disadvantage is that you must run the engine for cooling. If you want to leave the boat for a few days, either the box warms up or someone has to come aboard every day or two to run the engine.

In addition, engine-drive systems require more compressor maintenance than electric systems, and in general they tend to be a little less reliable. If you do have an engine-drive system, you need to have a good knowledge of servicing your system.

Sealed AC Compressors

If a generator is aboard, then a sealed, AC-powered compressor bears looking into. Sealed compressors are inherently more reliable than automotive-style units and will run off a genset, an invertor, or shore power. But with most gensets, assuming other accessories are running during the fridge cycle, you'll be limited to a maximum of about a 1.5-horsepower compressor. (Above this size you have to jump to 220 volts.) You're still stuck with the problem of leaving the boat unattended. Someone has to run the genset every so often to provide power for the fridge system.

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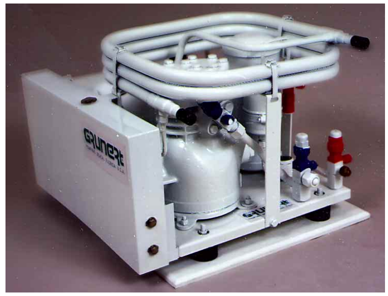
DC Compressors

An old-fashioned approach, which I would have turned up my nose at a few years ago, is now looking pretty good. I'm speaking of a DC motor–powered compressor. In the old days, with small DC alternators, it took so long to make the DC power for these compressors that the engine or genset ended up running for hours and hours to put enough charge into the batteries to run the compressor. This just didn't make sense. But now, with high-powered alternators available, the DC motor–powered compressor is a more viable option.



A sealed AC compressor does not have shaft-seal or hose-maintenance problems. However, it is 15 to 25 percent less efficient than a pure DC system. (Marine Air/Grunert photo)

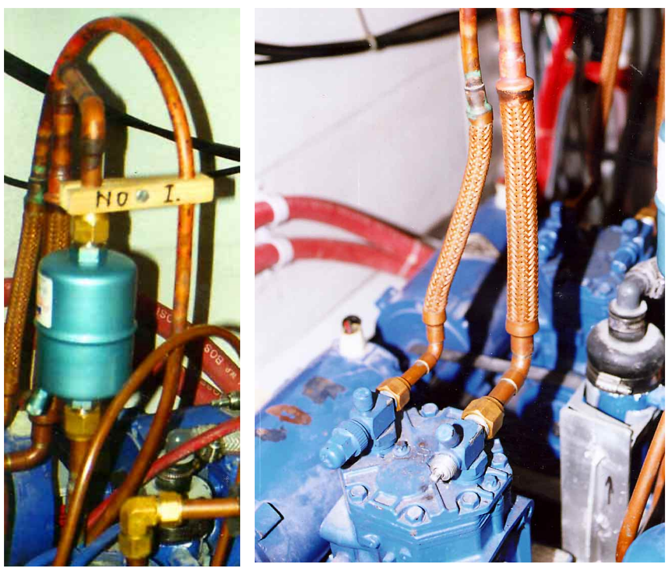
The DC compressor is more efficient in power consumption than the AC system, as much as 15 to 20 percent more penurious with the watts. With a DC-powered system, alternate sources of power such as solar, wind, or water generators can be used to recharge the batteries. This opens up the possibility of leaving the boat unattended for longer periods of time. If shore power is available, the battery charger can take care of the daily power needs of the DC compressor.

However, there are a few negatives. First is cost. The normal DC system, say 1/2 horsepower, is approximately twice as expensive as its AC counterpart. Next, you need a good-sized battery bank with lots of charging capacity. Last, these systems are typically about 50 percent heavier than any of the others mentioned.

AC or DC?

Why not use an AC compressor with an efficient inverter? Certainly if you have a genset aboard, an inverter can be the means of running the compressor when the genset is down. If there's commensurate charging capacity on the main engine, this also provides a backup. But there are two levels of power loss here. First is the inherent disadvantage of the AC compared to DC motor. The second is the inverter losses when it changes DC back to AC power.

Linda and I have debated all the above points more than once. In fact, I've debated them with just about everyone I know. Until a few years ago, in my mind the hands-down winner was the engine-mounted compressor. Then we went to AC systems for a while when the small Japanese diesels started being converted to gensets. Today we're using the DC motor–driven compressors. We've found that these give us the most flexibility for backup and the shortest running time for charging with the engine. But, as we've already mentioned, the choice of the DC approach is based on the ability to have extremely high charging rates from our alternators. With a more conventional charging setup, I'd go back to engine drive.



Vibration in fridge fittings causes more problems than anything else to do with these systems. Generous loops of copper, with secure clamping to limit harmonic vibration, helps (left photo). The best approach is to use an isolation hose, but one that is not osmotic, as shown in the right photo.

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Size and Efficiency

When looking at different compressor systems, consider size versus efficiency. For a variety of reasons with AC and DC compressors, larger means more efficient at converting electrical watts to refrigeration Btu. A 1/2-horsepower unit is up to 30 percent more efficient. Jump to 3/4-horsepower and you get another increase. Bearing in mind plate capacity, which must be balanced, and electrical capacity, bigger is generally better.

Danfoss

I've left the sealed DC compressor for last. A few years back the Danish company, Danfoss, began to market a small-capacity, DC-powered system with an internally driven compressor. These have been used by many of the marine fridge marketers in "cold machine"–type systems. For weekending, in very tight areas, or if the fridge budget is small, they can make sense. However they have one major drawback — they're very inefficient at converting watts to cold. These compressors take about 40 percent more power to do the job than the larger externally driven DC systems.

If you go with this approach, try to install a system with provisions for a water-cooled condensing coil. These are more efficient than air-cooled models. If you decide on air-cooled, make sure there's a good air flow to the coils.

Dual Circuiting

Many fridge plates come with two circuits of tubing. These can be plumbed in series, to put them all on one large compressor, or used with two different compressors. The advantage with the latter approach is backup. Engine drive for anchored-out use and a small DC or AC system for use at the dock is a popular combination. Also, it makes sense to use two electrics in the same system. However, using two compressors cuts down on the efficiency of the system, as only half the surface area of tubing is available for each compressor.

Another form of backup is to use the single large compressor with the dual plate coils plumbed in series, and a second Danfoss-style compressor with its own cold plate for backup.

Heat Exchangers

The heat exchanger uses seawater to cool down the hot refrigerant liquid after it's been through the compressor. A common mistake is for a unit to be too small for the tropics. Be sure there's lots of capacity. There's such a thing as too much capacity when you come back to cooler climates, but you can control this by throttling down the water flow through the heat exchanger with a valve.

A typical automotive compressor with a 2-to-1 overdrive on engine rpm will need around a "two-ton" heat exchanger in tropical waters.

Be sure your heat exchanger is made of *cupro nickel*.

Cooling Pumps

Fridge pumps are not typically self-priming. This means they're sensitive to air in their saltwater feed line. Be sure they're mounted *below* the waterline, and that the feed hose to them is flat or at a slightly up angle. *Avoid bends that can trap air.* The routing from the pump to the heat exchanger should also be fair.

If the compressor frequently kicks out due to overheating, the odds are the culprit is air in the centrifugal pump. If this problem can't be cured by replumbing, your bleeding job can at least be made easier by putting a T at the pump with a valve for releasing air.

With modern shallow-bottom designs like our boats, it can be a real challenge to keep a centrifugal pump operating. To avoid this we typically specify a self-priming impeller pump — a little less efficient, but much easier on the crew.

Hull Coolers

Years ago we had one of our boats hauled out for a few days with a full freezer. It seemed like a big hassle to connect a hose to our compressor for cooling water. So, as an experiment, we put about 100 gallons (385 liters) of water in the engine-room bilge. We then put a bilge pump in the fridge-cooling circuit, set up so it would come on at the same time as the compressor. The bilge pump cycled the bilge water through the compressor heat exchanger. The exhaust from the bilge pump was run back into the bilge, so we were pumping the same water around and around. Guess what? It worked great!

Taking this the next step, when we built *Beowulf* we had a large tank welded to the hull in the engine room. This tank is plumbed to a circulating pump for one compressor and has a coil of aluminum pipe through which the second compressor runs its refrigerant directly.

The idea is to transfer heat to the water and then from the water in the tank to the hull, and from the hull to the surrounding seawater. Both compressors work great. In the tropics, with both compressors running, compressor head pressures are normal.

The advantages? No problems with priming. No salt-water corrosion. And for one of the systems, no water pump.

Liquid-Side Subcoolers

As the refrigerant gas returns to the compressor, it is quite cold. At the same time, the gas that the fridge has condensed into liquid is pretty hot before it has run through the heat exchanger. A liquid subcooler runs the gas by the liquid, thereby using some of the cold in the returning gas to cool down the hotter liquid.

Some companies offer liquid subcoolers as standard. With other companies, you have to ask for it. For the most efficient system, be sure to get one.

Automatic Cycling

If you expect to be off the boat for long periods of time, it's nice to have some form of automatic control — with manual override, of course. You can use a temperature-actuated system, which measures plate temperature, instead of box temperature, to trigger the compressor; or you can use a timer cycle. The latter isn't quite as sophisticated, but it seems to work well once you get the hang of adjusting the time.

Digital thermostats give fairly accurate control but are much more expensive than a simple manual system.

Whatever you use, understand how the system works. First, there's a trigger point at which the T-stat tells the compressor to turn on. Then there is a temperature range — how many degrees of difference there is between the starting and finishing temperature.

Ideally, the system would come on just as the last molecule of eutectic thaws and turn off just as the last molecule is frozen. Going past this point is very inefficient.

In practice, surface plate temperature never truly equates to eutectic points. The easiest way to find this is with a strip chart recorder. Barring this, careful hourly logging of the plate temperature can be graphed to approximate the eutectic point.

Dual T-Stat Systems

With an electric system that runs on demand, you really have two needs. One is for the system to cycle when the plates have thawed. The other is for it to cycle if there is a source of power present — if the engine or a genset is running.

Many T-stats have dual sets of controls. If this is the case, one can be set up to run on normal automatic with the second set to turn on at a given signal, such as an engine starting or the push of a button.

Another advantage of this is that you can run the system just before going to bed, so the compressor won't come on in the middle of the night.

Driers

Every system has a drier filled with a desiccant to remove moisture in the refrigerant. If you see moisture through the sight glass, then the drier needs to be changed. Valves should be on each side of the drier so it can be changed without opening up your system. If you're having a system built, put in the biggest drier you can find.

Driers should be mounted where they are easy to get to, as they need frequent changing on most systems. Having a valve on each drier allows you to seal the system when putting on a new unit.

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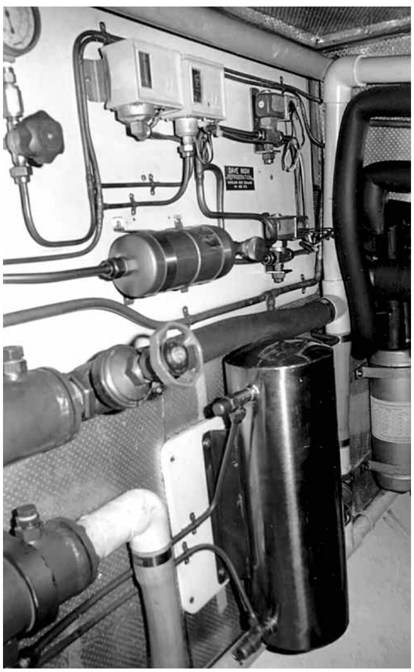
If practical, we prefer to mount our expansion valves outside the box so that they are more easily serviced. This creates a problem with condensation on the valve and is slightly less efficient. However, the benefits are significant when the time comes to replace an orifice or make an adjustment. Insulation should be applied to all fridge plumbing that runs outside the box. The above photo has four solenoid valves at the bottom. These control the two sets of plates in the fridge and freezer.



Installing a system from components gives you a chance to lay everything out in a neat, easily-accessible manner. The approach I like best is a flat panel where you can really see what is going on.

Refrigerant Receiver

A good system will have a large-capacity receiver built into it. This does two things. First, during pump-down, it's a place to store the refrigerant in the system. Second, if the receiver is oversized, you can put extra refrigerant into the system, allowing you to keep operating in the face of a small leak. However, be wary of combination receivers and drier systems. These make it impossible to change a drier without recharging the system.

Oil and Gas Separator

There's always some oil present with the refrigerant gas. This is necessary to keep the compressor lubricated. In some large systems this oil may puddle in the plates, starving the compressor for lubrication. The oil separator removes the oil from the refrigerant gas and returns it to the compressor. You usually find these on engine-drive systems.

High-Pressure Cutout

If you lose your cooling water or have too much refrigerant in the system, the compressor temperature and the pressure of the refrigerant gas will rise dramatically. The high-pressure cutout switch senses this and shuts down the system. It's essential in any system.

Sight Glass

The sight glass does two things. It tells you if you're low on refrigerant (you'll see bubbles and gas flowing through), and it indicates if moisture is present in the gas by the color of a small dot in the middle of the sight glass.

It is commonly assumed that the sight glass can be used to determine the correct charge of refrigerant when recharging a system. This is a fallacy and can lead to overcharging and a damaged compressor. It's much better to use pressure gauges to monitor the difference in the high and low sides to find the right level of refrigerant. It's really quite simple to learn how to do this. In a pinch, the sight glass can be used with care. But gas must be added very slowly, over a long period of time.

Typically, the sight glass starts out almost empty, then begins to fill as the compressor begins working the gas down. It is only at the end of the cycle that the glass will be full.

Expansion Valves

As mentioned earlier, these control the flow of refrigerant into the cold plates, changing it from liquid to gas in the process. They're pre-

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set at the factory and rarely need to be adjusted. If it appears that adjustment is necessary, it's usually symptomatic of something else being out of sync — usually moisture in the system. The danger in adjusting the TX valve improperly is getting liquid refrigerant back to the compressor. If you do adjust the TX valve, do it a quarter turn at a time and allow five minutes between each adjustment for the system to balance out. (And keep a written note of what's being done so you can come back to the original setting if things really get messed up.) TX valves are usually adjusted by temperature. This will vary with your system. Be sure you have the right data.

Super Heat Setting

The adjustment of the TX valve is called the super heat setting. The proper setting is critical to the efficient operation of your system. Being off just a little bit can impact your running time by 50 percent or more.

The proper super heat setting varies with compressor and the type of plates being used. The actual number will be established by the gear supplier.

However, checking it is sometimes difficult. This involves taking pressure and temperature readings at the plate and compressor. A problem sometimes arises because of the long distance between the compressor and the plates. A pressure reduction takes place on the suction side of the system, which has to be estimated. If that estimate is off, your super heat setting may be wrong. One way around this is to install a Schrader valve port at the outlet of each holding plate. This is then used to accurately determine pressure on the plate without having to worry about losses due to the plumbing run to the compressor.

Plumbing

The average shoreside fridge mechanic is accustomed to having that wall plug to power his system. He or she is not as sensitive to the issue of running time as you are and needs to understand that efficiency must be maximized and line restrictions must be kept to a minimum. Every foot (0.3m) of piping and every bend or corner restricts flow and increases running time. It's important to use the shortest runs possible and to minimize bends. Nice, gentle corners are more efficient than neat-looking soldered joints.

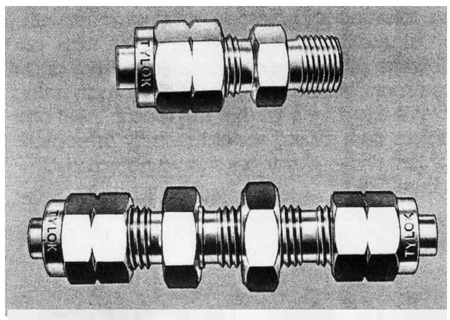
Pipe sizes should be maximized. I like to use at least 5/8-inch (15.8mm) copper for the suction line and 3/16-inch or 1/4-inch (4 to 6mm) for liquid refrigerant. If the runs are really long, we'll use 3/4-inch (19mm) for the suction side.

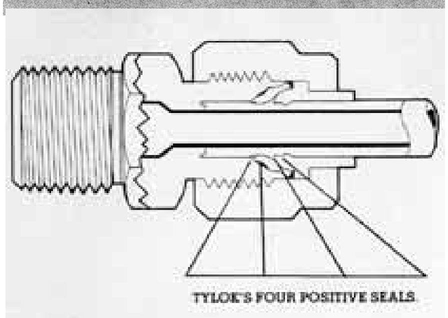
Joints should be minimized, as each is a potential leak point. Should a leak ever develop, *you'll want to know the location of each joint in your system*.

Chafe and corrosion are both potential problems, especially where plumbing passes through bulkheads. Keep copper out of the bilge.

Both suction and supply lines should be run tightly bundled together, inside of 1/2-inch-thick (12.6mm) insulation. Every bit of pipe from the outside of the fridge/freezer box to the compressor should be insulated. This makes the system more efficient and prevents condensation buildup in the bilges.

Expansion valves should be located outside the box, where they're easy to service. These should be insulated, too.





The very best way to make a plumbing connection is to solder it. You will never have to worry about leaks. You do, however, have to use the correct solder and flux, and in the case of some of the new refrigerants, purge the system with nitrogen gas after soldering.

The next best approach is well-made flares. These are fairly easy to do, although care should be taken with the flaring tools. Also, be sure to use refrigeration-grade connections.

Finally, there are compression fittings, such as those shown above. These use a copper compression ring for their seal. If done correctly they apparently give good service. Some vendors say they are easier to do right than a flare.

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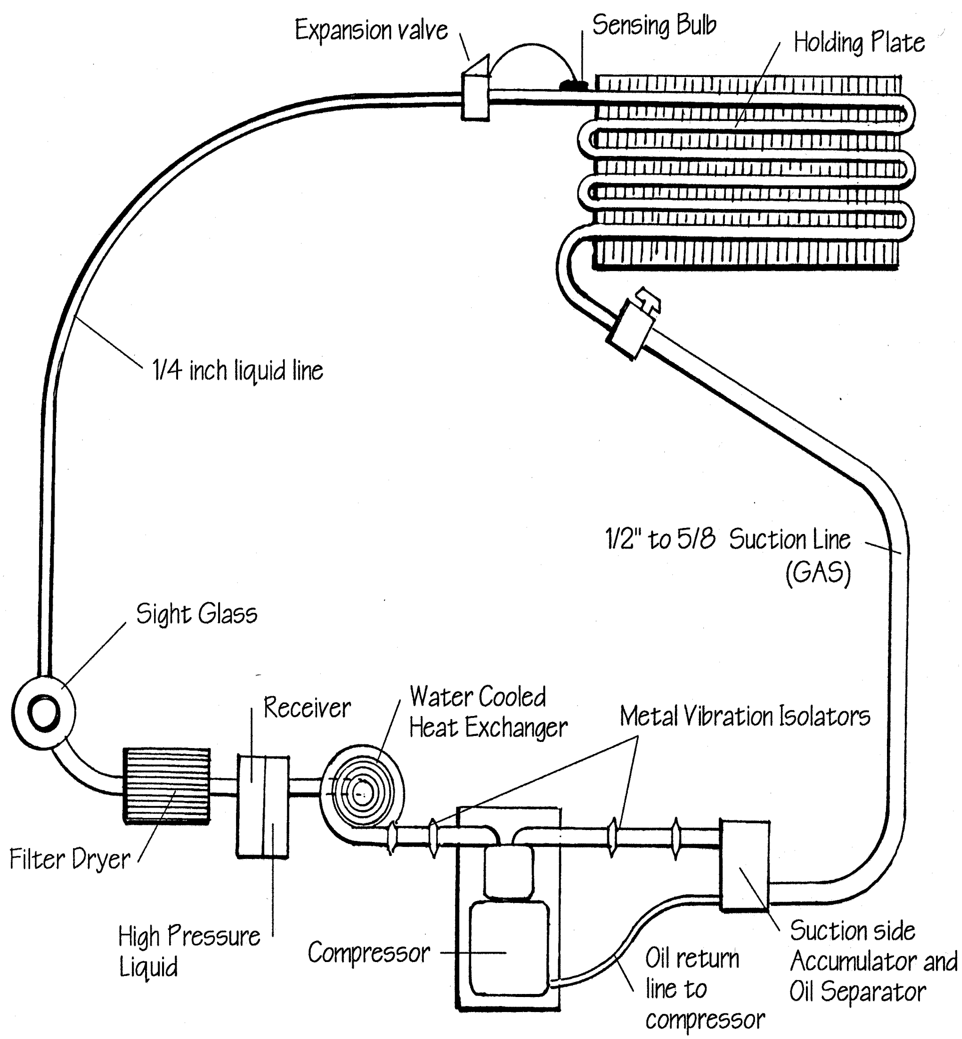

Now that we've taken you through the fridge cycle, here's a recap drawing of an ideal system. Start at the compressor, which sucks refrigerant gas from the evaporator (cold) plate in the fridge or freezer. Notice how this comes through a suction-side accumulator and oil separator. This helps prevent compressor damage from loss of oil and/or getting liquid refrigerant back to the compressor (due to a misadjusted expansion valve).

The gas is quite cool when it returns to the compressor, but gets heated during compression. It then goes through a cooling device — in our example, a water-cooled heat exchanger. This cools the gas, condensing it to a liquid. The next step is a liquid line reciever, a storage tank for liquid refrigerant which can also be used to hold refrigerant by means of shutoff valves during maintenance.

Next is a filter drier unit where any debris and moisture is removed. After this comes a sight glass, which is used to check the level of refrigerant.

Finally, the liquid heads out to the expansion valve, which measures the flow of refrigerant into the cold plate by means of a sensing bulb placed just after the expansion valve. During the change of state of refrigerant from liquid to gas, the refrigerant absorbs heat from the holding plate, and then is drawn back to the compressor to start the cycle off again.

The Pump-Down Cycle

Whenever you work on the system or leave the boat for a long period of time, you'll use the compressor to pump all the refrigerant out of the system into a receiving tank. With really large systems this is necessary to prevent liquid refrigerant from settling into the bottom of the cold plates and then being drawn into the compressor itself. If liquid refrigerant gets into the compressor, it will ruin it in short order.

There are two ways to accomplish the pump-down. First, you can turn a valve on the receiver tank or just after it. Or, an electric solenoid can be used to do the same thing, but from a remote location like the control panel. The compressor is then turned on. You continue to pump until you just start pull a vacuum on the suction side of the system. A valve on the other side of the receiver tank is then closed, and the compressor is turned off. You have then captured all your refrigerant in the receiver tank.

Maintenance

Ninety-five percent of the problems in a fridge system can be easily repaired by the owner. All you need is a good refrigeration handbook, a few tools, and some modest spares. Spending a couple of hours with a fridge mechanic will help immeasurably. Also, some of the marine-fridge companies offer maintenance courses for their customers.

It's important to learn how to tell if the system has enough refrigerant gas in it and how to put more in; how to tell if the drier needs to be changed (by observing the sight glass) and the process involved in changing the drier itself; diagnosing expansion-valve problems (usually due to moisture); adjusting expansion valves, and clearing them of ice if there's moisture in the system (using heat); analyzing high-pressure shutdown of the compressor (water flow, too much refrigerant, restrictions in the system); basic understanding of the use of refrigeration gauges; checking for leaks with soap bubbles and a halide or electronic leak detector; use of copper flare tools and brazing with Mapp gas for repairs; how to evacuate the system using the compressor itself, after repairing the system and before putting in new refrigerant.

Spare Parts

Here's what we carry aboard: a 30-pound can of refrigerant gas, pressure gauges, refrigeration wrench, leak detector, three driers, two TX valves, water pump, motor control solenoid, motor brushes, and a moderate assortment of copper-pipe flare fittings and flaring tools. When we have a mechanical compressor, we always carry a spare for it, along with an extra electric clutch.

Deciding on a System

Obviously this is a fairly complex subject. How do you know what is right for you? The first step is to determine just what you want the fridge system to do, and what sort of ambient air and water temperatures in which it will have to operate. Then you can put together your own system, which I've done several times. A trip to the junkyard will turn up all sorts of nice old compressors. Then it's off to one of the refrigeration suppliers in your area for the rest of the parts. If you can work a set of flaring tools, you have the required manual dexterity to proceed. Or, armed with your fine-tuned definition, find a good marine-refrigeration mechanic. Figure out with him or her what you can do on your own and what he'll need to do for you.

The two best sources of package systems are Marine Air and Glacier Bay. We've had good results with both. If you are checking on Marine Air, call Bob Williams at Sea Air Land Technologies in Marathon, Florida. Bob is the smartest overall systems guy we know in the business and can help with a fully integrated system of fridge, solar, wind, inverter and charging gear.

Eutectic in a Jug

Holdover refrigeration systems work most efficiently when the fridge or freezer compartments are nearly full. The contents actually add to holdover capacity and reduce the amount of free air space.

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Ideally, you'd be able to adjust the size of your eutectic plates according to the load of the box. Of course, this isn't possible, but there is a simple alternative, making up extra eutectic solution as needed and dropping it into the box to take up space and to add to holdover capacity.

There is a simple way to do this: Take salt water, fill a plastic jug 90 percent full (leaving the rest for expansion), and place it in the fridge. Salt water freezes around 30 degrees Fahrenheit and provides 1,100 Btu of storage per U.S. gallon (3.8 liters)

For best results, place the jug directly against the cold plates for efficient heat transfer.

Testing Your Box

If you have an existing box and want to get a handle on the heat load, there's a simple test you can do. Start off with a block of ice, and leave it in the box until an equilibrium point is reached in temperature.

Leave the ice in for another six hours or so. This will remove the latent heat build-up in the insulation so that you are ready for your test.

With latent heat removed and box temperature stable, remove the ice and any liquid from the bottom of the box.

Then insert a known quantity of ice into the box. Close the door, and wait 24 hours. Note the ambient cabin air temperature during the 24-hour test.

At the end of the test period, remove the ice and check the quantity left, or measure the amount of water in the bottom of the fridge.

The amount of ice that has melted will tell you how many Btu it took to maintain the box for the time period tested.

Let's say that at the end of the period there were two U.S. gallons of liquid in the bottom (about 15 pounds). We know that frozen freshwater stores 1,140 Btu per gallon, so if two gallons melted the heat load would be 2,280 Btu (2 gallons times 1140 Btu/gallon).

This gives you a start.

To interpolate to new conditions, try the following: If you did the test on a fall day and the ambient temperature was 60 degrees Fahrenheit and the box temperature averaged 40 degrees during the test, there is a 20-degree temperature differential. Assuming that the ambient would be more like 80 degrees in the tropics this would double the temperature differential. Since heat load is proportional to temperature differential and we are looking at doubling the differential, the heat load would double as well.

If the box is to be used as a freezer, multiply the heat load shown for the fridge by between 1.5 and 1.7.

If you then go back to some of the comparison tables for various thicknesses of insulation, you can get a handle on how good a job your existing insulation is doing. If the boat is more than a few years old, and the insulation was not properly sealed, the odds are you're in for a rude surprise. It is not unusual to find that insulation values are less than half of what is predicted when new.

Upgrading the Box

Sometimes it is not that difficult to remove fridge tops and install new insulation. One of the keys is how easily the top itself comes off. Frequently it is possible to remove fiddle-rail plugs and then take the fiddle rails off without damaging them. If this can be accomplished, getting the top off is usually pretty easy.

The first question then is replacement of existing insulation. If the thickness is limited, and you want a really efficient system, I'd call Glacier Bay about some of their new super insulation panels. The custom panels are available with a fiberglass lining and by getting the correct sizes you have the basics of a new box. Run some fiberglass tape in the corners, put on a bit of gelcoat, and you are ready to roll with a highly efficient box.

Alternatively, you can install new PU or isocyanurate foams, being careful to seal all exposed edges.

AIR-CONDITIONING

We had done plenty of tropical cruising without air-conditioning and didn't feel the need to even consider the topic, until the time came to build *Intermezzo II*.

Then, from the viewpoint of resale it seemed like a good idea, so we learned something about the basics and put a simple system aboard, never intending to use it ourselves. But when we found that Fort Lauderdale was to be home base for a year, our outlook changed. Tied up on 15th Street behind an 8-story condominium that blocked any breeze in the summer, the air-conditioning was a lifesaver! Since that time we've installed air on many boats, as well as having built boats, including *Sundeer,* without.

Do You Need Air?

It is easy to define whether or not air is worth considering: A prime candidate — summer cruising areas where sand fleas or mosquitoes combine with high heat and humidity. Shutting the boat up or blocking airflow with screens, with humidity in the 80-to-90-percent range and temperatures in the 90s, will not make for happy crewmembers. Many areas, such as the Bahamas in the summer, are lovely cruising grounds, with the preceding caveat. Air-conditioning opens many of these areas to consideration, when without it you wouldn't even think of going. On the other hand, if insects aren't a major problem, if you can swing head-to-wind on your own hook, and if your boat has awnings, good hatches, vents, and interior fans, you can skip the rest of this section and go on to something more interesting. After all, we and lots of our friends have done nicely without air-conditioning in places like the Marquesas Islands and Papua New Guinea during the summer.

The principles of air conditioning are very similar to those of refrigeration, which we've already covered. The main difference comes in compressor design, type of freon employed, and the fact that air is blown over the evaporator coils to cool it down (as opposed to freezing a holding plate).

Capacity Requirements

If you want to consider air, the first question is how much. Realistically define your needs. A small system will do the job if the boat is well insulated, you're prepared to use awnings when it's really hot, and you can accept a worst-case interior temperature of 80 degrees Fahrenheit. On the other hand, if the deck is solid fiberglass without insulation, you don't want to bother with awnings, and 68 degrees is a maximum allowable temperature, it will take two or three times the capacity. Next, you must decide how much of the interior will be maintained at optimum temperature — the whole interior or just the saloon? What about sleeping cabins?

A marine air-conditioning contractor will look at your project from the worst possible angle and will propose a commensurately large system. The bigger system will take more space, more power, and more bucks. This is fine if you really need it, but most boats with air-conditioning have more capacity than warranted. Defining needs for the contractor will help him develop the right system for you.

There are some very generalized rules of thumb to roughly calculate capacity. Assuming you want a 20-degree temperature difference (i.e., it's 90 degrees outside, and you want 70 degrees below), and you're working without awnings, calculate the cubic feet of interior volume and multiply this by a factor of 17 to obtain basic Btu capacity. Then, add an additional factor for window area and/or deck hatches — about 150 Btu's per square foot. Kick in another 500 Btu's per body. To be truly scientific, add another couple of thousand Btu's for mealtime heat from the galley.

Direct Expansion

The most common system uses a centrally located compressor with remote evaporators. Liquid freon is pumped from the compressor to the evaporators, where cool air is generated. Two evaporators are usually the most that can be connected to a single compressor. At least one of these evaporators must always be on, and there's a minimum fan speed that has to be maintained; otherwise the evaporator coils will freeze, sending liquid freon back to the compressor with dire results. The same result can occur with a dirty evaporator filter. Air flow is blocked and liquid freon heads for the compressor. Most boats over 45 feet have two direct expansion compressors.

Recently, Marine Air has introduced rotary air-conditioning compressors. These are about 1/3 more efficient on power and much quieter. Instead of the low-frequency vibration of reciprocat-

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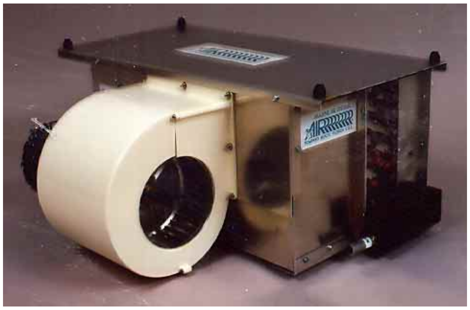

A direct-expansion system is the most compact way to air condition the interior — refrigerant passes through an evaporator coil, over which air is blown and cooled. However, take care to get air cleanly into and out of the evaporator. Make allowance to drain condensation. Filters ahead of the evaporator (supply side) need to be accessible for checking and changing.

As the boat gets larger and/or need for capacity increases, chilled-water systems begin to make sense. There is a centralized plant from which chilled water is pumped to evaporator coils set around the boat. The hoses are small in diameter. However, the evaporator coils end up about 40 percent larger as the water temperature is higher than that of direct refrigerant.

ing compressors, which is so hard to mask, these compressors have fewer, faster moving parts, and can be used in the interior without too much discomfort to the ears.

This can be a big advantage in installation cost and allows for more zonal control of cool air than was previously possible. It may be the wave of the future.

Chilled Water

In larger systems it starts to make sense to use a heat exchanger at the compressor to cool water and to pump the cold water around the boat to various evaporators. This way, an infinite amount of stations can be turned off and on at will and can run at any fan speed. The obvious advantage is flexibility, both in temperature control by zone, and in directing capacity where needed, in the saloon in the day, for example, and in the staterooms at night. Also, because the chilled water isn't as cold as the direct-expansion freon gas, the evaporators are larger and use a slower speed but higher volume of air. This is quieter and feels nicer.

If more than 16,000 Btu is called for, two compressors may be utilized on the same heat exchanger. Both compressors can be used, providing some flexibility on power requirements and backup. This also reduces starting loads on the generator.

Before you race out to order a chiller system, there are a couple of negatives. The evaporators are around one-third larger, meaning more lost storage space. The cost, both in equipment and installation, will be 30 to 70 percent higher. Finally, the plumbing associated with the system is bulkier and more complex. Still, if you want the best and are willing to devote the necessary space, this is the way to go.

If you choose this route, be sure the plumbing is carefully laid to eliminate bends and depressions, which tend to make air bleeding difficult. Then, insist that each air-bleed valve (and there will be lots of them) has good access.

Reverse-Cycle Heating

By the use of a simple valve at the compressor, the direction of freon gas is reversed, causing the compressor to pull heat out of the water and put it into the boat. With 50-degree water you can generate just about full capacity in the heating mode. For Florida winters or autumn in New England or the Chesapeake, this is a nice feature. All direct expansion and some chilled-water systems have this feature.

Evaporator Installation

The evaporator is a bulky piece of gear, to which you need good access. There also has to be provision for a clean run of condensate drain hose — a 16,000-Btu system will generate 5 or 10 gallons a day of condensation during the Florida summer.

It should be mounted as high as possible, since cool air drops after it leaves the coil. There must be a good supply of air as well as exhaust, and the supply should be picked up down low, where cool air is sitting. Obviously, there will be some ducting, either down to the pickup or up from the evaporator to the exhaust grill.

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The larger the duct, the more efficient the system. Also, having some duct between the evaporator and the grill reduces fan noise level. Ducts can be either light plastic tube or fabricated in light plywood. Exhaust ducts, with cooled air, should be insulated for best results.

You may want to install the evaporator where the air can be directed to several locations at once or at different times. Thus one evaporator can do multiple jobs, simplifying the system.

There will be an air filter on the intake side, which ought to be easy to change.

The supply and return air grills become major aesthetic issues. The return air is always mounted high. This means it is readily visible, something that is less than ideal. We always try to minimize the impact by matching surrounding surfaces.

Compressor Installation

Air-conditioning compressors are pretty reliable, so when the fight comes for which gear gets the most accessible spot, put this compressor at the bottom of the list. The water pump that supplies cooling water, however, must be extremely accessible. Even with the magnetic-drive pumps now commonly in use, you can expect to be doing some maintenance work on the pumps periodically.

Using the Fridge Compressor

If you have an automotive-style fridge/freezer compressor, there's no reason why it can't be used to run your air-conditioning as well. The Schmidts used this approach on *Wakaroa*, and it served them well, eliminating the space and cost of an AC-powered special compressor.

If you consider this route, the system won't be quite as efficient, and your evaporator will have to be sized for freon 12, as opposed to freon 22, which is normally used in air-conditioning. You'll also have to use a good oil separator to be sure the compressor isn't starved for oil by the evaporator.

Electric Loads

Here's where the equation starts to get tricky. If air is going to be used at anchor, and if the genset has to handle it, you have to decide how much other gear will be running when the air is on. This will dictate the size of the genset as well as your shore-power system.

In a smaller boat, if you can stay with a 16,000-Btu compressor (or smaller), then 110 volts can be used. The typical running load will be about 15 amps, so on a simple, small genset and a single shore-power line you can have air and one galley accessory. At dinner, if you need more electricity, the air can be shut down for a while.

Or, if you have a large inverter and engine alternator, the smaller compressor can be run from the engine, whether powering or on the hook.

As your needs grow, however, the electrical loads multiply to the point where there must be a genset aboard. Odds are, there will only be a separate shore-power cord for air.

Remember our comments about starting loads? Well, those really apply to air-conditioning compressors! They take a big kick to get going — about 3 1/2 times their running current is required for "lock rotor starting." This affects shore and generator requirements. Hence there's an advantage to having several smaller compressors. They can be started one at a time, reducing total starting loads — although the cumulative running loads will be the same.

Duty Cycle

The air conditioning–equipment vendors get nervous when you talk about running their equipment 100 percent of the time. While this can be done for long periods, it eventually leads to premature wear and system failure. They really like to see the system sized for a 50-percent cycle on just half the time. If your cruising will be mainly in hot weather and the air is likely to be used a lot, it will save money in the long run to keep a modest duty cycle.

But if the air is only used occasionally, it makes sense to let the compressor work full-time on that rare occasion when it's really hot out and you're too lazy to set up the awnings.

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