Keeping your food COLD

By Michael Hackleman

Solutions to refrigeration when electricity is scarce

Many readers of this magazine live in remote settings and generate their own electricity, often through solar, hydro, wind, or generator machines, storing the electricity generated in batteries. In such a scenario the electricity produced is dear and needs to be used efficiently. Since refrigeration is a major consumer of electricity in a home, the essence of this article is efficiency. The goal: gaining the most refrigeration for the least amount of energy consumption.

Over the years, I've helped design the energy systems for a variety of places and situations, and visited many others. Invariably, I'll find a stock refrigerator squatting in some corner of the kitchen. If it's an electric one, it's obvious that the house must have a grid (electric utility) connection. Or a large inverter. Or there's a standby generator someplace nearby. If it's a gas unit, there's a corner with a few five-gallon bottles that rotate between the gas line at home and the gas line at the nearby LP (liquified propane) station.

Refrigerators *are* complex gizmos, and it *is* understandable that most folks don't want to mess with them. However, ranging from simple to involved, there are nearly 30 changes I can list (see opposite page) that will reduce the energy consumed by refrigeration.

Refrigerators are fairly low-wattage devices. In the standard household, they *nibble* energy whereas tools, motors, and other important electric appliances, such as stoves, water heaters, air conditioners, toasters, and blenders, gobble it up. Where's the problem? While refrigerators don't consume energy at a very high rate, they *do* work the equivalent of an eight-hour day. In consequence, they may easily consume, in a day, week, or month, the lion's share of available electricity.

What can you do? Quite a bit.

The first thing is to understand how refrigerators work. Ever wonder how they "make" cold? Heat is absorbed in the interior (where you put the food and ice trays), transferred by a suitable refrigerant such as Freon or ammonia, and dissipated outside, usually at the back of the refrigerator (see Fig. 1).

The second thing to know is that, while "heat pumps" are generally very efficient, refrigerators are not shining examples of that fact. Can the situation be remedied? Faced with the same question a few decades back, I began an exhaustive study of the problem. It soon became clear that I was dealing with more than just poor

Things to consider when considering refrigeration

(This numbered list tracks the article)

Operation practices

1. Minimize frequency/duration of open door
2. Check the door gasket
3. Don't overload the refrigerator
4. Correctly set the dial thermostat
5. Re-examine refrigerator's contents weekly
6. Evaluate the refrigerator's size

Siting

7. Maintain clearance around refrigerator
8. Design alcoves properly
9. Consider alternative refrigerator sites

Design changes

10. Trade in frost-free units
11. Insulate the refrigerator
12. Re-locate the HDC (heat-dissipating coils)
13. Build a hybrid refrigerator/water heater
14. Use a horizontal refrigerator

Power conversion (electric)

15. Use a 110-volt AC standby generator
16. Use an inverter
17. Modify the motor-compressor unit
18. Replace the motor-compressor unit
19. Use a battery charger

Power conversion (gas)

20. Convert to the correct fuel
21. Modify for AC or DC

Purchasing a new refrigerator

22. Buy & convert an old 110-volt AC model
23. Buy an RV or PV-type unit
24. Find and buy a gas refrigerator
25. Build a solid-state refrigerator

Refrigeration alternatives

26. Build and use a root cellar
27. Learn canning for foodstuffs
28. Dehydrate your food
29. Control your food supply

design, engineering, or construction of the refrigerator. What about operator abuse? Improper siting? A mismatch between the power available versus the power required? Also, what about alternatives to the refrigerator?

In the following sections—**Operation**, **Siting**, **Design changes**, **Power conversion**, **Purchasing a new refrigerator**, and **Refrigeration alternatives**, I will detail the answers I found. Wherever possible, I will describe specific situations and solutions. Don't expect me to tell you exactly what to do. Your situation is unique. Ultimately, only you are qualified to identify problems and apply appropriate solutions.

Are the issues I'll discuss worth the effort of change? Obviously, much will depend on which ones you'll identify as troublesome and choose to rectify. However, some of the these solutions, which were applied to a stock refrigerator matched to a low-voltage DC wind (power) system at a remote retreat in the California Sierras in the early 80s, reduced the energy consumption from 150 kWh per month to a mere 30 kWh. Today you may purchase high-efficiency refrigerators which will match or beat these numbers.

Operation practices

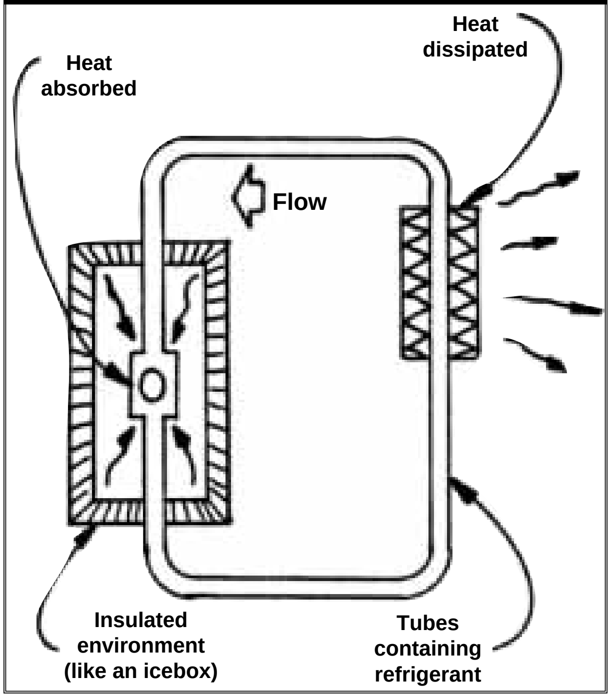
New refrigerators usually come with an operator's manual. A proud new owner may even read it from cover-to-cover. After that, it's put away and, eventually, lost. That's too bad. A poorly operated refrigerator is an inefficient one.

This section is devoted to proper refrigeration operation. Apply this information and you will easily *halve* your refrigerator's present consumption of energy—gas or electricity.

1. Minimize both the frequency and the duration of door opening(s). Cool air, and the energy it takes to make it, are lost every time you open the door of an upright refrigerator. Before you open the door, decide what it is you're after. And, if it's breakfast, lunch, or supper you're fixing, get everything you need at one shot; one long opening is less wasteful than item-by-item door openings which "fan" cold air out and warm air in.

2. Check the door gasket. The gasket which seals the door against the main body of the refrigerator keeps heat out and "cool" air in. How do you know whether it is, or is not, sealing? Open the door, place a sheet of paper against the face of the seat, and close the door. Does the gasket hold the piece of paper in position when you let go of it? Does it offer some resistance to your pulling the

Figure 1: Basic refrigerator functions



sheet out? If not, the seal is not adequate.

Sometimes the problem is just a dirty gasket or seat face; clean both well and re-test. Or the door may be misaligned. Does it seal at the top but not at the bottom? If not, loosen the hinge bolts and have someone push the door firmly against the refrigerator body as you re-tighten them. If that doesn't work or there's no adjustment for the door hinges, you may have a warped door. Here, the only solution is to find a new refrigerator door. Or another refrigerator.

More often than not, the source of the problem is the gasket itself. After years of hot and cold, open and close, the rubber gets tired, old, brittle, and torn. This is replaceable; check with the manufacturer about a new one. If it's an old refrigerator, you may want to consult with an appliance store or a refrigeration man about a new gasket. The price is not cheap. In early 1982, a replacement gasket for our own refrigerator cost $50. Shell it out, though; makeshift gaskets are impossible to clean and require frequent replacement.

3. Don't overload the refrigerator. Packing a refrigerator full of foodstuffs is an invitation to poor performance. In order to cool quickly and effectively, sufficient space must be left around the individual food containers or packages to permit heat to escape and be absorbed by the refrigerant. Also, allow foods to cool before placing them in the refrigerator; hot foods only make the refrigerator work harder and longer. If you're rushed, food will cool more quickly if the container is placed in room temperature water in the sink for 5-10 minutes before inserting it in the refrigerator.

4. Correctly set the dial thermostat. Different foods have different refrigeration needs. This ranges from frozen to something just below room temperature. Recognizing this need, manufacturers provide an operator control, the dial thermostat, which will adjust the interior temperature over a 15-30 degree F temperature differential. There are numbers on the dial; they range from 1 to 10, with an 0, or "off" position. The higher the number you set, the *lower* the temperature in the refrigerator's interior.

This dial adjusts cooling by adjusting the "duty cycle" of the refrigerator. Therefore, a low (number) setting asks for mild cooling. Here, the motor-compressor unit (the device which actually performs refrigeration) is "on" infrequently and for short durations. A higher setting of the dial calls for lower temperatures. Consequently, the motor-compressor will be "on" more often, and for longer periods of time.

If you want to minimize your electric bill, it's up to you to correctly set the dial thermostat. Of course, you've no way of knowing just how low a number (how high an interior temperature) you can select which will keep things from spoiling. Or do you? The dial must be presently set to some value right now which *does* the job or you'd have turned it up higher, right? So, decrease it one number and wait a few days. If all's well, lower it by one more number. Repeat until you begin to notice that it's not doing the job as you wish it to—the time it takes to cool things, the butter's soft, etc. Then kick it back to the previous number and give it a day or two to fully recover.

5. Re-examine the refrigerator's contents weekly. A refrigerator doesn't *prevent* spoilage; it *delays* it. It doesn't matter what section the food occupies; even frozen foods have a very short lifespan (six months?). Sure, the food may be digestible and even palatable, but it definitely has less nutritional value, and it may taste or look funny. A periodic review is a good policy.

6. Evaluate the refrigerator's size. If your present refrigerator seems too small, clean it out and stop putting non-perishables in it. You may be surprised to find out that it *is* the right size. And, if you think your refrigerator is adequate, apply the same treatment; you may discover that it's really bigger than what you need. Don't rule out the possibility of getting a smaller one. In the long run, the energy saved will pay for the swap.

Siting

Often, very little attention is given to the siting of a refrigerator—beyond convenience, the availability of space, or the firm belief that it's got to go *somewhere* in the kitchen.

At least some consideration *should* revolve around the specific needs of the "coolworks." The coolworks is my own term for the refrigerator's machinery—electrical and mechanical—which performs the magic act of refrigeration. More specific names are given to these component parts: motor-compressor, heat-dissipating coils, expansion valve, refrigerant and plumbing, thermostat, interior light, and electrical wiring (see Fig. 2).

In the interest of good looks, compactness, and transportability, a number of design factors have been severely compromised in domestic refrigerators. By far the most flagrant violation is the positioning of the heat-dissipating coils (or HDC). These are designed to dissipate the heat which is pumped out of the refrigerator's interior—principally through convection. Unfortunately, they're *not* aesthetically pleasing enough to put anywhere but out of sight—behind the refrigerator or below it. Siting of the refrigerator, then, may aid or impair the proper functioning of the HDC.

7. Maintain clearance around the refrigerator. Note how far the HDC project from the back of the refrigerator, and maintain at least that distance—more if you can spare it—between the HDC and the wall. This will assure an adequate passage of air past the HDC during refrigerator operation. If you pull out the refrigerator for a periodic cleaning, take care to maintain the correct distance when it's shoved back in.

For the air to get to the HDC and back out again, you must also maintain adequate clearance below and above the refrigerator. The manufacturer allows for this in the design, but space directly beneath the refrigerator can become clogged with dustballs, stray toys, and other unmentionables that are swept or have crawled under it. Sweep the space under the refrigerator. If it's too close a fit to get at from the front, make some allowance so the refrigerator may be pulled out for cleaning.

8. Design alcoves properly. Flush-fitting (recessed) refrigerators look good but prevent proper airflow to the HDC without good design. In some instances, a strip of fancy grillwork directly below and above the refrigerator in the wall partition will assure, respectively, a good inflow and outflow of cooling air. Or, if this doesn't appeal to you, install a vent in the floor or lower wall, and another at the top of the wall *behind* the refrigerator so that waste heat exits the house. Either way, maintain the proper clearance between the back of the refrigerator (and its HDC) and the wall.

9. Consider alternative refrigerator sites. The heat pumped out of the refrigerator has to go somewhere. If your refrigerator is unmodified, that heat is dumped into whatever room it's sitting in, usually the kitchen. No big problem in winter as the extra heat is always appreciated, but unacceptable in summer. After all, it's a shame to do such a good job of insulating your home to keep out the summer's heat and get stuck with the heat that's dumped into the kitchen from the refrigerator.

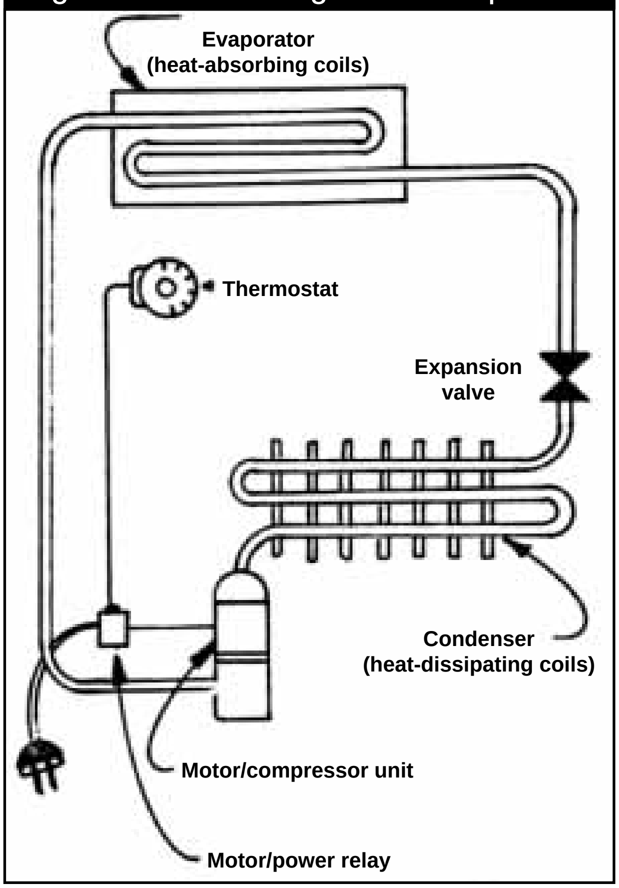
Insignificant, you say? Even the smallest upright refrigerator is working at about one-third the capacity of a 1,200-watt floor heater—for six hours in each 24-hour period. A larger refrigerator, particularly the frost-free variety, *equals* the output of that heater. That's a truckload of Btu (British thermal units). How do we get around this problem?

One way is to locate the refrigerator outside. Admittedly, this is rarely practiced. Unless it was sited in a cool, shady spot, it could use *more* electricity during the summer months. Remember, the larger the temperature difference between the inside and the outside of the refrigerator, the more energy it takes to keep things cool.

On the other hand, you could put the refrigerator into a cool place—a well-insulated pantry, a root cellar, etc, and *decrease* the temperance difference (between the inside and outside of the refrigerator) to aid in efficient refrigeration. This starts out as a good idea, but the HDC will increase the temperature of an enclosed space during operation. A pantry might tolerate it but it would be self-defeating in a root cellar.

One idea is to cut an opening in a north-facing wall and slightly recess the refrigerator in it. This way, you have access to its contents, but the back of the refrigerator, HDC included, dissipates its heat outside.

Figure 2: Basic refrigerator components



Design changes

Refrigerators are pretty good at what they do, but, alas, they are handicapped by design compromises. Ninety-five percent of manufactured refrigerators suffer the same disadvantages. However, look on the bright side. If most of them experience the same problems, each "solution" we find will fit almost any refrigerator. As well, most of these problems are only "delivered" ones—the way the package arrives at our house—and *not* intrinsic to the principles of refrigeration. Some are a matter of knowledge and judgement, and others require some handiwork by the owner.

10. Trade in frost-free units. Newer, so-called "modern" refrigerators incorporate a frost-free circuit. This is supposed to liberate the busy housewife from that all-too-frequent defrosting. How does it do it?

There are only two things you really need to know here. One is that it involves some heater coils in the refrigerator's walls, and, two, it takes as much (if not more) electricity to perform this job as it does to run the motor-compressor. This is why frost-free refrigerators, in normal operation, consume 2-3 times as much electricity as refrigerators of the equivalent size consume *without* this feature.

Defeating this circuit *seemed* like a relatively straight-forward process to me. I unplugged the refrigerator, removed the back plate, disconnected the wires leading to the frost-free heater coils (noted by the handy schematic inside the back cover), replaced the plate, and plugged the refrigerator back in again. All better, yes? For five minutes maybe. Then it stopped cold. Or, more appropriately, stopped making cold. The frost-free circuit, in that refrigerator, was integral to the design and components used in the frost-free refrigerator. So, my advice is: don't fool with it. A working frost-free refrigerator has more trade-in value than one that isn't working. And that's what you want to do—trade it in. Make certain that the new one has no such feature. In the end, you use less energy at the cost of fitting an occasional defrosting into your lifestyle.

11. Insulate the refrigerator. The refrigerator is insulated from the environment. In truth, no matter how thick the insulation is, heat will pass through it, get inside, activate the thermostat and coolworks, and get pumped back out. However, the thicker the insulation, the harder it is for heat to get in and the less the refrigerator's motor-compressor has to run. Ergo, the less energy it uses.

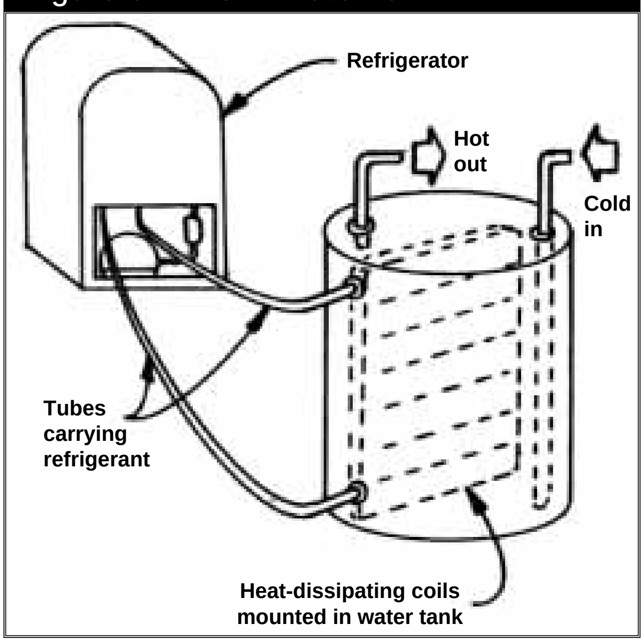
Just how much insulation should the refrigerator have? Without getting absurd, as much as we can afford—in terms of space or money. The manufacturer's answer to this question? As little as they can get away with. Don't be too hard on them, however. A bulky refrigerator doesn't have as much sales appeal as a slim-and-trim one. Any amount of insulation you're able (or willing) to add will make, on its own, a very significant contribution to the refrigerator's efficiency. Here's an idea, then, that has an excellent cost-benefit ratio.

If space around the refrigerator isn't a restriction, you can use just about any type of commercial insulating material you desire. If you're cramped for space, your best bet may be polyurethane foam sheeting; it has the highest R-value (resistance-to-heat-transfer rating) per inch of material thickness. A 2-inch thick "jacket" will give you an R-11 insulating value. If you can double it, you're up to R-22. The bottom, sides, and top of the refrigerator lend themselves very well to insulating in this manner. If you're concerned about appearance, consider covering the foam with some wood-faced paneling or rough-sawn siding that is stained and sealed to match your kitchen decor.

Insulating the refrigerator door may be a problem if it's contoured, as many are. If you can accept the challenge, cut the foam sheet to fit and attach it. Since the door is movable, the insulation must be, too. Be certain, therefore, that it will move freely for as far as the door must swing. Since there are normally no refrigerant-carrying tubes or electrical wires in the door, sheet-metal screws may be used to secure the insulated cover. Check! If there's a light in the door or an ice-making tray, don't risk it. Or, if it's a hassle, don't bother. Refrigerator doors usually have more insulation than the side walls or bottom anyway.

Construction-grade sheets of rigid polyurethane insulation are available at local lumber, building material, and hobby supply firms. Alternative insu-

Figure 3: HDC in water tank



The heat-dissipating coils (HDC) may be mounted in a tank of water.

lating materials are also available. If it's foam, check around for the best buy, however; prices vary from place to place. If you plan to cover the foam with paneling, cut the foam to size and tape it at the corners. There's a temptation to use sheet-metal screws to hold it to the thin metal walls of the refrigerator but you should, at all cost, refrain from drilling holes into the exterior walls. While the thin tubes carrying the refrigerant are spaced pretty far apart and the probability of hitting one is quite small, how unlucky can you afford to be.

Think of this insulation as a 'jacket," meaning removable, if need be, in order to move or service the refrigerator. Caution: Unless you perform a modification of the refrigerator which involves the removal of the HDC (heat-dissipating coils—see #12 below) and/or the motor-compressor unit (#17 or #18 below) from the immediate vicinity of the refrigerator body, you must *not* place insulation in such a way as to interfere with the free-flowing movement of air to, from, and around these components.

12. Re-locate the HDC (heat-dissipating coils). Traditionally, the HDC are mounted behind the refrigerator, within an inch or two of the back wall. Considering the minimal amount of insulation that's crammed into the refrigerator wall, and the kind of heat the HDC can generate, this is downright irresponsible! Coupled with the problems of getting sufficient cooling air to the HDC and an almost certain interference with adding insulation to the back of the refrigerator (where it needs it the most), it makes a lot of sense to remove and altogether relocate the HDC.

Sounds formidable, doesn't it? However, after some initial investigation, I discovered that physically separating the heat-dissipating coils from the refrigerator housing wasn't all that involved. In fact, it's done all the time. Supermarkets routinely install the motor-compressor and HDC on top, or at the rear, of the building. Refrigerant tubing runs from these units to the freezer or refrigerated-air, food-display cases inside. It's a toss-up whether you really *need* to also separate the motor-compressor, as it's usually not all that noisy, nor does it generate that much heat. But I was advised by a refrigeration friend to keep it in close proximity to the HDC, if possible.

The actual changeover is easily accomplished if you've any handyman skills. If worse comes to worse, you can get the local refrigeration technician to do the job for you. Get a quote first; it may not be worth a couple of hundred dollars to you. And even if you do most of the work—disconnecting the motor-compressor and HDC, re-locating it, and running new refrigerant lines, etc.—you'll eventually require the services of a refrigeration technician to inspect the work, bleed the lines of air, and recharge them with the appropriate refrigerant.

All refrigeration technicians can get a system functional, but only a few can get it operating efficiently. Additional tubing lengths may require a different charge—a fine tuning—to make the changeover worthwhile. Ask the technician if he can do this. It's important.

If you move the HDC, you can now locate the refrigerator (box) inside the house, pantry, or root cellar without the normal concern for the heat the unit will give off. It won't generate any. Another major benefit of this modification is that it permits trouble-free recessing of the refrigerator in flush-fitting alcoves.

The HDC (and associated "coolworks") should be mounted outside, perhaps, on the shady side of the house. Protect it from the elements—rain, snow, etc.—and the fingers of curious children. Additionally, if you live in cold climes and there's *any* chance that the outside temperature will fall *below* the inside temperature of the refrigerator, you should "shelter" the motor-compressor and HDC from air currents. Apparently, this condition confuses the heat pump and refrigeration may stop. Removing the fan blade from the compressor pulley (if it exists) also works. Just don't forget to replace it when the cold snap is over.

13. Build a hybrid refrigerator/water heater. What's that? It's a refrigerator which has had its HDC removed and placed in a tank of water. Why would we want to do that? Answer another question first. What are two ways to tell if a refrigerator is working correctly? First, put your hand inside; feel all that cold? And, second, snake your hand around the back of the refrigerator and feel the heat-dissipating coils. Hot, aren't they? We don't get one without the other in a heat pump. Just as its name implies, a heat pump moves heat from one place to another. But it sure is a shame to waste that heat, right? So why not put it to work?

Answer another question. Year-round, what's the one thing in the standard household that might make use of this relatively low-level (but constant) heat source? The water heater, of course!

And what happens when you put the HDC in a tank of water? Naturally, the water gets heated. So how about a refrigerator that also works as a water heater. Right away, you'll run into a problem when you try to interface a stock HDC in a water heater: the HDC is way too big. My first reaction to this dilemma was to reverse the situation. That is, size the tank to the HDC. I used a 55-gallon drum. However, at 30 psi water pressure (a gravity system, at that), the barrel bloated up like a lungfish and damn near gave me cardiac arrest. I thought it was going to explode.

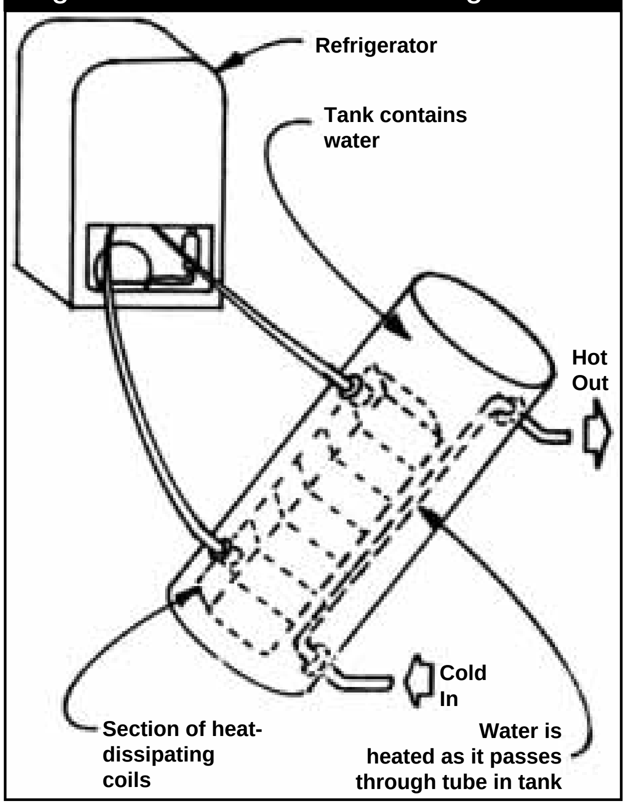
I cautiously tried it the other way—sizing the HDC to the water tank, and this worked much better. Since water is so much faster than air at conducting away the heat, only a portion of the HDC's original area was needed. Quick work with a hacksaw reduced the HDC to a long, narrow section which easily fit inside a steel tank that, hereafter, was to be a water heater (see Fig. 3).

After hearing of my modification, a refrigeration technician recommended what he thought would be a simpler process for most people. Add a small length of tubing between the compressor and HDC and insert this into the tank. Since this is the "hottest" portion of the line, it accomplishes the same end while eliminating the "chop and fit" on the HDC. I wish I'd heard that *before* I did mine.

Why didn't I just install the smaller section of HDC in the water heater tank I was presently using? Well, besides some rudimentary problems associated with doing it *without* damaging or destroying the water heater, there's another very important reason *not* to do this. Those heat-dissipating coils are, in fact, circulating refrigerant. Older units may still use ammonia and newer ones have Freon. In the event of a leak, they'd end up in your water. Unpleasant, at least; dangerous, at best. Since there is no simple way to prevent a tube from leaking the stuff into your water tank, use what's called a "double heat-exchanger" (See Fig. 4). That is, the heat-dissipating coils go into a tank filled with water and *another* coil of tubing connects directly to your hot water line. The water in the tank, then, stores the heat, transferring it to the water circulating through the coiled tubing when you want to use some. It's a lot simpler than it sounds.

There's one major condition attached to the hybrid refrigerator; you must use the hot water that's produced. When the water in the tank is its coolest, the refrigerator is operating at good efficiency. This efficiency decreases as the water temperature increases. So, for some function or another, *use* that heated water.

Figure 4: Double-heat exchanger



A double-heat exchanger is a safer installation.

Want some facts and figures? A medium-sized refrigerator will have a rating around 2,000 Btu/hour. At a duty cycle of 30%, this amounts to a steady 750 Btu pumped away as waste each hour or, in a 24-hour period, some 18,000 Btu. If the water in the tank housing the HDC is initially at 60 degrees F, we'd need 480 Btu for each gallon of water raised to the temperature of 120 degrees F. Assuming only 50% efficiency, we'd get 15-20 gallons of hot water each day. That's peanuts to some folks and blessing to others. What about you?

Hotter water *is* possible, but I'd advise against anything more than 105-120 degrees F. Otherwise, the refrigerator will be working nearly as hard as it would *without* the hybrid setup. Remember our goal: use the waste heat *and* cut down on the electricity consumed by the refrigerator.

Is the hybrid refrigerator/water heater worth the effort? For a conversion, I'd say no. There's too much involved; too many "if's." For special applications and investment in future technologies, yes! The refrigerator/water heater symbiosis is a natural technology, transferring heat from an unwanted place to a welcome one. It uses heat that's otherwise wasted and, in the process, saves the energy—electric, gas, wood, solar, etc.—consumed in water heating. Also, the efficiency of the refrigerator can increase dramatically, as water conducts heat away from the HDC faster than air. This boosts a further savings in electricity since the motor-compressor unit runs for a shorter period of time.

14. Use a horizontal refrigerator rather than a vertical one. This technique is used with chest-type and open supermarket freezers. Just as warmed air will rise, cooled air falls. And *very* cold air sinks like a rock. True, if there's any kind of air movement, some of this cold air is going to "slop" out onto the floor and even absorb some of the warmer air above the freezer-case. But "horizontal" cooling works well. The same cannot be said for vertical coolers—the ones traditionally containing milk, pop, beer, etc., enclosed by sliding glass doors. Open them and cold air spills out in huge amounts. Just like with vertical refrigerators.

Why, then, are refrigerators built with vertical doors? Two basic rationales have prevailed: electricity is dirt cheap and wasting energy for convenience is okay.

An upright refrigerator is not as easily converted to work in a horizontal position. You can't just turn your own refrigerator over on its back. First, it would soon stop working. And, how would you place food in it. I no longer recommend converting an upright refrigerator to a horizontal position. Too many variables and too much work for an uncertain product.

If you're ready to go this far, and can't purchase what you want, opt to build the refrigerator from scratch. This is frequently done in marine environments where the shape of a sailing ship's hull will not accommodate a box-like shape. Instead, the refrigerator's coolworks are built around a low-voltage compressor unit and a holdover plate that can be "pumped down" (made cold) inside an odd-shaped, well-insulated compartment. If the access door is on top, so much the better.

People complain about difficulties in accessing food in chest-type freezers. Resolve this issue in some way that is acceptable by everyone using it. Several lightweight trays that will hold frequently-used goods can be lifted out—in the same way many toolboxes are designed—for access to lower levels of foodstuffs.

Power conversion (electric)

The standard household refrigerator in the United States is designed to operate at the 110-Volt, 60-cycle AC (alternating current) supplied by the local utility company. Obviously, if you're not using utility electricity, the "stock" refrigerator isn't going to work "as is" with DC (direct current, as from batteries) at lower Voltages. What do you do? You either match the system to the refrigerator, or the refrigerator to the system. Here are a variety of possibilities.

15. Use a 110-Volt AC standby generator. Auxiliary generator units—small gas engines driving AC generators—exist for use in areas remote from utility power. Or as a backup unit whenever utility power is interrupted. Or as *the* energy source in a survival situation. Portable units, ranging in power from 1,000-6,000 watts (and higher) supply precisely the right kind of electricity needed by the standard refrigerator, eliminating any need for modification. The only pre-requisite is that the standby generator have a power rating equal to, or greater than, the refrigerator's rating.

This idea has some justification; it may take time to set up another way of powering a refrigerator and this keeps things cool in the interim. It's also great for emergencies since you're likely to require a standby generator for special power applications, i.e., radial arm saws, arc welders, etc.

Unfortunately, while the parts work well together, as a system the idea stinks. Powering a refrigerator on a continuous basis from a standby generator has little merit. A unit sized large enough to handle power tools would waste gas powering a refrigerator. Also, refrigerators are basically "demand" devices, operating intermittently throughout the day, adjusting themselves to varying food loads, external temperature variation, and operator mis-use. A once-a-day "charge" of refrigeration from a standby generator isn't going to help food stay fresh, and staggered use of the standby generator throughout the day for refrigeration alone will be a short-lived solution.

Contrary to popular opinion, standby generators are complex. Most folks don't possess the skills or knowledge to keep them on-line even if they *do* have the money to buy all the necessary spare parts. They are noisy. They are as unwelcome as mosquitoes. Mufflers will help, but they reduce—not eliminate—the noise. Also, the more effective the muffler, the more inefficiently the engine operates and, alas, the more fuel consumed per kWh of electricity.

A standby generator *does* have its place in every homestead. However, the inherent mismatch between it and the standard refrigerator (specifically) and most other electricity-consuming devices (generally) relegates its role to backing up *other*, renewable energy sources like PV (photovoltaic), wind generators, and small-scale hydroelectric units.

16. Use an inverter. An inverter is a device which transforms DC (direct current, like that supplied from batteries) into 110-Volt, 60-cycle AC (alternating current, like that supplied from the utility company or standby generators). This *is* convenient; we can match a battery system to a stock refrigerator. Additionally, inverter manufacturers make models for a wide range of DC voltages. You can get a unit to work with 12-, 24-. 32-, or 110-Volt (DC) battery arrays. It's a quick fix for anyone who has battery power (smart) and a 110-Volt AC refrigerator (convenient), but lacks the time to mess around with other alternatives.

As with any "fix," there's a price-tag. The inverter does nothing to reduce the amount of electricity consumed in refrigeration. Instead, a portion of the inverter's output must be reserved for the refrigerator. Of course, it is possible to "schedule" the time the inverter is used to power the refrigerator. This inverter is special, too; only inverters designed to handle inductive (reactive) loads can be used with refrigerators. As well, the inverter must have a load-sensing feature. Without it, it will be "on" and drawing some power even when the refrigerator is "off." Finally, inverters of whatever type—rotary, electronic, etc.—are complex mechanisms. They're *not* consumer serviceable. Consequently, the final system is no longer simple nor inexpensive. Inverters which can power a refrigerator may cost 1-3 times the cost of the refrigerator itself.

But, once an owner/user evaluates the cost of that proportion of solar array, and battery and inverter capacity devoted to a 110Vac, 60-cycle refrigerator over the long term, the cost of a low-voltage, high-efficiency refrigerator (see #24 below) doesn't seem so high.

17. Modify the motor-compressor unit. If the power source is batteries—at 12-, 24-, 32-, or 110-Volts DC—one of the best ways to match them to a refrigerator is to remove the AC motor that drives the compressor and replace it with one of the correct DC Voltage. This is a difficult undertaking if the motor and compressor are "hermetically sealed" (built as one unit - see #18 below), but older refrigerators have a motor separated from the compressor by a belt (and pulley) or a star-coupler. If this is the case, the entire assembly should be removed from behind (and underneath) the refrigerator. Next, remove the AC motor and pull the fan blade off its shaft.

Select the DC motor carefully. It must generally match the old motor's HP (horsepower) and RPM (revolutions per minute) ratings. DC motors have conservative ratings when compared with AC motors. For this reason, you may select a DC motor which has a HP rating ¼th to 1/3rd smaller than the AC motor you pull off. Look for a HP tag on the AC motor. No luck? Find the motor's wattage rating. Or multiply the Amp (A) rating by the voltage (Volts, or V) rating of the refrigerator. The resultant is wattage which, when divided by the value 750, will give an approximate HP rating. This value is usually less than 1 horsepower, and as long as ¼ HP.

Small variations in motor RPM ratings—between the old AC motor and the new DC motor—aren't significant. If the values are close, bolt it up. Larger variations in RPM ratings must be adjusted. Vary the ratio of pulleys in the belt-drive to achieve a match. If a star-coupler was originally used, either go to a pulley drive (and match RPM with the correct ratio of pulleys) or find a motor of correct RPM rating.

Other factors? Change the light bulb in the interior to one of the correct Voltage. Change the motor relay to its DC equivalent (see Fig. 5). Leave the old thermostat alone. It should work fine. Now's a good time to think about sticking the motor-compressor unit, along with the HDC (see #12 above) elsewhere (outside?). You may not have a choice. The modified motor-compressor unit may not fit back into its original refrigerator space. If you've cut the refrigerant lines, reconnect the lines and re-charge them with new refrigerant (or have this done). Finally, insulate the refrigerator in the area once occupied by the motor-compressor unit.

18. Replace the motor-compressor unit with another that matches your system. If the motor-compressor unit is the "sealed" type (where the motor and compressor are an integral, non-separable part), replace it.

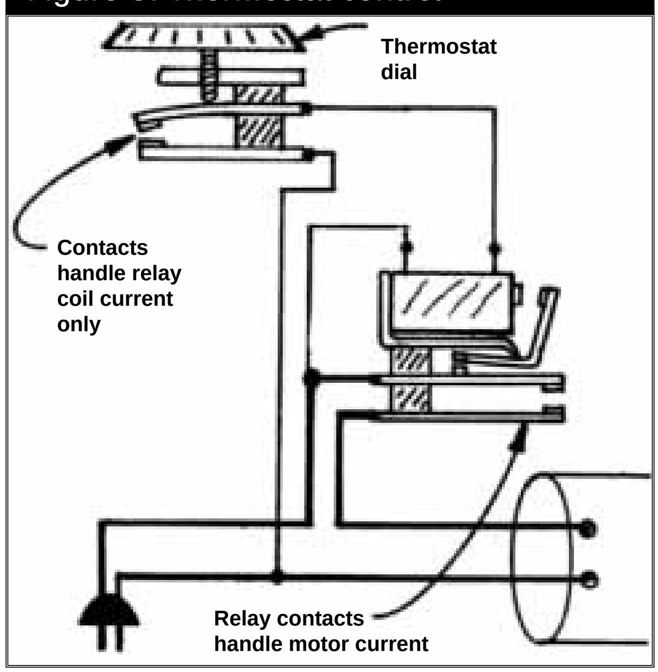
There are two ways to proceed. One is to scout around for a motor-compressor unit of equivalent rating which *is* separable, buy it, strip off its motor, and add one with the correct DC voltage. Get some help. A refrigeration technician will be of great assistance. Plus he or she may have a junked unit of precisely this type out in back. If the only thing wrong is a burned-out motor, what could be better? And, if you affect energy-saving modifications with your refrigerator, you may look for a motor-compressor of a *lesser* rating. That is, when you do it better, you don't need a unit designed to compensate for all of those losses.

A second possibility is to replace your refrigerator's motor-compressor unit with one designed specifically to work at lower DC voltages. For example, 12-volt motor-compressor units exist in the RV (recreational vehicle) and PV (photovoltaic) industry. Or check out surplus outlets. A 24-volt system can make use of a military 28-volt motor-compressor. Folks using 32-volt systems, on the other hand, should check marine and railroad supply houses; many boats and trains still use this standard DC voltage. And 110-volt DC equipment (i.e., a universal motor) is readily available through many farm equipment and surplus sources.

The other components—light bulb, power relay, thermostat, etc.—in the refrigerator get the same treatment as those where a refrigerator's motor compressor unit is only modified (see #17 above).

19. Power the refrigerator with a battery charger. Once a refrigerator has been converted to low-voltage DC operation (or if it's originally designed that way), it is ready to use the energy of the sun, wind, and water all around us. Another source of energy is the battery charger—whether it is plugged

Figure 5: Thermostat control



A standard thermostat can control a relay to handle any load or motor.

into the utility grid or a standby generator. A battery charger transforms 110-volt, 60-cycle AC into lower DC voltages. This is handy in an emergency.

There are two prerequisites of a battery charger for this job—the correct (final) DC voltage and a wattage rating (the product of the output voltage and output amperage) equivalent to, or greater than, the refrigerator's power rating.

Power conversion (gas)

Servel-type (gas) refrigerators are designed to accomplish refrigeration with a small gas flame as the power source. Naturally, these operate on a principle that's very different than ones equipped with a motor-compressor unit. The fuel that is used also varies. Natural gas, propane, and butane are commonplace fuels, while an occasional kerosene-fueled unit may be found.

While refrigerators based on liquified fuel are dependent on oil supply and economy, they can be a real blessing for remote sites. Add in the advantage of a high-density fuel (and a 300-gallon propane tank) and you have an attractive alternative to the electric refrigerator.

Gas refrigerators don't lend themselves very well to relocation of their heat-dissipating coils, upright-to-horizontal conversions, or hybrid (refrigerator/water heater) adaptations. This is due, in part, to the sheer number and complexity of components in the gas refrigerator. However, the owner of a gas refrigerator is not altogether restricted. After all, there are other sources of heat than a flame.

Note: The three conversions suggested in this section apply specifically to Servel refrigerators, with which the author has experience. Other makes of gas refrigerators will make use of the same principles described herein, but specific component parts and processes will vary. A copy of the master Servel Service Manual, which covers all models, is available for $10 from me at Box 327, Willits, CA 95490.

20. Convert the unit to the correct fuel. Since a stock Servel-type refrigerator can utilize any one of three fuels—natural gas, propane, or butane—with the change of only a few small parts, you must consider the possibility that the unit you own is *not* set up for the gas you intend to use.

If your unit operates poorly or not at all, this is immediately suspect. However, the BTU differences between these fuels can be slight enough that you could operate the refrigerator on the wrong gas and never know it. Using the wrong parts, the refrigerator will run too rich or lean, waste gas, and force more frequent refills.

How can you tell if the unit does need conversion? Easy. Conversion involves three things: the orifice (jet), the turbulator, and an adjustment (maybe). The first thing you do is locate and remove the burner assembly from the refrigerator. Next, find the jet (that's the orifice in gas lingo), unscrew it, and extract the turbulator.

Does it have one groove or two grooves? One groove is used with LP (liquified propane) and two grooves are used with natural gas (city gas line). So, if you're converting to propane, and you've got a two-groove turbulator, you need a one-groove turbulator.

Since propane is a higher-density fuel (more BTUs per cubic foot) than natural gas, it takes less propane to do the same job. Hence, the burner orifice (jet) must be replaced with one with a smaller diameter (hole). Don't jump to conclusions; even if the correct turbulator is installed, this doesn't mean that the orifice is of the correct size. And vice versa. Check it. It could be expensive (in gas and money) to assume that both were changed at the same time.

Both the turbulator and orifices for the burner assemblies of *all* makes and models of Servel refrigerators are still available. Remarkably, the cost of both parts seldom exceeds $5-8. Obtain them from, or through, your local LP gas office. The Servel Service Manual will prove invaluable here, since the store may not have the cross reference needed to select these components. The manual, then, will help you identify the model you own, and it contains the charts and tables to assist in selecting the correct size of the jet orifice for the fuel you're using. Then, it's a matter of cross-referencing the two.

21. Modify the gas refrigerator for AC or DC operation. The gas flame in the heater box of a Servel refrigerator generates a finite (specific) amount of heat. If you can provide the same amount of heat from any other energy source, the refrigerator will still work. And two convenient sources are 110Vac (utility, generator, or inverter) and 12V DC (batteries, solar modules, mini-hydro, and wind power).

A sealed heat coil is commercially available for use with Servel and other refrigerators (Jeff's Gas Appliance, 549 Central, Willits, CA 95490). It is available for either 110V or 12V electricity and costs about $40. There are several wattage ratings available (depending on model numbers) with the average about 325-375 watts. That's about 3 amps at 110V and about 30 amps at 12V. I didn't know this when I wanted to experiment in "electrifying" my Servel about 25 years ago (see sidebar, Gas-to-Electric Conversion). Hence, I built both coil and control circuitry. [If you buy a 12V heater resistor, you may need a control circuit similar to mine (see Fig. 5). The contacts on most thermostats will not handle the high current at 12VDC.]

The real beauty of this setup—operating a gas refrigerator from electricity— is that it does not interfere with using gas. If you want to use gas again, simply pull out the coil and re-light the pilot. Want to go back to electric? Turn off the pilot and shove the coil back up into the heater tube. Conversion from one to the other should require only a few minutes. A few extra notes are in order. First, don't be tempted into leaving the electric coil in the heater box during operation with gas. It won't work. Second, during gas operation, exhaust fumes are given off by the flame, and these are channeled through a vent tube to the top of the refrigerator. (The tube will vent into the room unless routed outside.) Electric heat provides *no* exhaust fumes, but the air it warms will rise and carry away some of that precious electric heat. When you use the electric coil, close off this vent. Aluminum foil will do nicely for a cover—squish it down for a tight seal. I'll leave it to you to figure out a foolproof means of installing/removing the cover as you switch from gas to electric, and vice versa.

What if you don't think you have enough electricity to operate a gas refrigerator part time, much less full time, on electricity? I'd recommend, at least, that you buy the parts for the electric heater coil. In an emergency, even if it's only something as simple as running out of propane, you can always power your refrigerator for a while from a car battery or a 110V source.

It's better to have it (or the parts) and not need it than to need it and not have it.

Purchasing a new refrigerator

Thus far, this article assumes that you *have* a refrigerator, that you'll probably want to keep it, and that it may lend itself to the modifications you deem necessary. Nevertheless, an awkward accumulation of design deficiencies in your present unit, an inherent mismatch between available refrigeration and a low-yield energy site, or ownership of a refrigerator that is simply too large for your present needs are all good reasons to consider purchasing a new one.

If you're in the market for a new refrigerator, it's an ideal time to apply the information discussed in foregoing sections. Two goals are worth pursuing. The first is to find a refrigerator which has the *least* number of design deficiencies *you* consider important. And, secondly, get a refrigerator which has design deficiencies that *you* can change. Applying both, item by item, will help match the new unit to your unique situation with the least expenditure of time and energy on your part.

Be forewarned. You may find little "relief" in the purchase of a new, standard refrigerator. Sorry, while there may be more impetus to make energy efficient changes today, there hasn't been in the past. Manufacturers don't pay your utility bills. For this reason, "newer" stuff isn't always "better" stuff. So, if you're led to this section because of the apparent convenience of purchasing anew, instead of reworking your old unit, don't be shocked if you find yourself reconsidering the modification of your present refrigerator. It may look far more attractive after you've looked at the purchasing options.

22. Purchase and modify an old 110-volt refrigerator. A new refrigerator may, in fact, only be another refrigerator. Even if you want to convert it—say, to low-voltage DC—buying a second 110-volt AC refrigerator may be a wise choice.

Why? I can list four reasons. First, you can continue to use the refrigerator you already have. Modification comes under the heading of experimentation and that consumes time and can result in setbacks; both conflict with the everyday need for refrigeration. Second, if your pocketbook is a wee thin, a "standard" refrigerator is a lot less expensive to buy than one which is brand new, or special-built. Three, since you plan to modify the unit anyway, you don't necessarily need a *working* unit. A refrigerator with a burned-out motor-compressor unit is adequate (if you're replacing it anyway) and *always* cheaper than one which is working. And, fourth, since 110-volt AC refrigerators are so commonplace, you've a wider range of models and sizes to choose from. Hence, it's easier to find precisely what you're looking for.

What questions do you want to ask yourself as you search for a suitable unit? Is it in good shape? Will it fit into that special place in your pantry? kitchen? root cellar? Is it a frost-free type? What problems, if any, was it experiencing when it was last used? Is the door warped? Is the gasket okay? Is it the right size (be very critical here)? Are its shelves (they're there, aren't they?) easily removed? Are the "coolworks" easily removed? Can you buy it for less than $10? $15? $20? Be selective.

23. Purchase an RV- or PV-type refrigerator. With the RV (recreational vehicle) boom a few years ago, a new breed of refrigerator was born. Instead of the "scaled down" gas and electric versions found in homes, this new "type" of unit would operate from as many as *three* different energy sources: gas (propane), 110-volts AC (utility power), and 12-volts DC (car battery).

I like the idea of a refrigerator which can use two or more energy sources. However, the actual product is marred by a number of disadvantages. The first is immediately apparent. These things are *small*. Characteristically, only a few cubic feet of space is available. The second problem is that, designed for portability, the units are really compact. Hence, the HDC are positioned in a tangle of plumbing and, in the few units I've seen, it would be a nightmare to remove the coils. A third concern is lifespan. Considering the intended application of the refrigerator—for weekend and vacation use only—I wonder how the unit will hold up in continuous use. Fourth, like station wagons, anything which tries to be two or more things often compromises each one. So, the units tend to be inefficient in any specific mode. The fifth and final objection is the price. You pay top dollar for the few cubic feet of refrigeration you get.

The booming PV (photovoltaic, or solar cell) industry has also prompted special consideration for efficient refrigeration. Unlike the RV emphasis, refrigerators designed for use in PV systems *must* be efficient because very little power is available. For example, a 17-cubic foot SunFrost consumes less than 0.5 kWh per day on 12VDC. The price of the unit *seems* high—around $1,200-1,500 depending on size. However, when you consider that this unit would take two *years* to consume the energy used by a standard refrigerator in one *month*, it's worth a second glance.

It's hard to imagine shelling out more than a thousand dollars for a refrigerator, isn't it? Still, the cost/benefit ratio of this new breed of refrigerators is quite good. (Sun Frost, P.O. Box 1101, Arcata, CA 95518. Tel: (707) 822-9095)

For anyone able and willing to make their own, well-insulated refrigerator enclosure (as in sailboats), consider purchasing the "coolworks" for one of these super-efficient refrigerators.

24. Find and buy a Servel (or other brand of gas) refrigerator. There are a lot of old gas refrigerators out there, folks. Since electric is still the rage, they're fairly inexpensive to buy. If you only wish to use them on gas, fine. Later, you might consider an electric options (see #21 above).

The biggest problem with buying a Servel is finding one that's in operating condition. Since most are stored in a barn or lying out in the weeds out back somewhere, you can't be sure they'll work until you get them home and hook them up. Sure, the pricetag may be very low. Nevertheless, buying $25 worth of junk is still a net loss of $25. And, since there are a *wide* range of models and sizes (I've yet to see two that were identical), don't count on using a dud for parts.

However, Servel refrigerators may still be found in good condition. Why? Because they were often replaced with electric equivalents *before* they wore out. This is also the reason why they weren't simply hauled off to the dump. So, despite their vintage, they're fairly easy to find. Running an ad is one way to find them. If you're lucky, the local refrigerator man in rural areas is likely to sell and service them, or know where some are. Look it over closely (see the sidebar, Inspecting a Servel Refrigerator) to weed out the poor candidates.

A final comment. Servel refrigerators are neat old "horses," but if you seriously don't need a gas option in a refrigerator, stay away from them. There are many modifications—relocation of the HDC, hybrid refrigerator/water heater, conversion from upright to horizontal orientation, all-around insulation, etc.—that are impossible to perform on them. If these are important to you, look at other options.

25. Build your own refrigerator using a solid-state module. An exciting newcomer to the refrigeration field is the thermoelectric cooling module. Unlike the electric or propane-based refrigerators, this does it all with transistors. No kidding! Only it's just one big, special transistor. And when you apply electricity to it, something amazing happens —one side of the module gets hot and the other side gets cold. It's a heat pump which employs the principle of the Peltier effect. You've got to see it to believe it.

The Peltier module is used in battery-powered coolers at 6 or 12 Volts DC. Power consumption is less than 50 watts. The efficiency is low—about 10-15%—about the same as PV modules. Polarity is important; if the leads are reversed, the unit will cool and heat on (respectively) opposite sides. Some models come complete with a ther-

Gas-to-electric conversion

Many years ago, I fabricated my own electric-option for my Servel. First, I wound a length of nichrome wire around an insulator. I used an old porcelain through-wall (electrical wire) insulator; this supports the nichrome wire, safely dissipates its heat, and allows one of the power leads to be run *through* the coil. Next, electrical wire power leads of an appropriate length were added. I screwed them on. I figured soldered connections would melt with the heat.

Before I installed the electric coil, I rolled a thin section of mica insulator sheet into a tube shape, and inserted it up the heater tube (in the refrigerator) in the portion normally exposed to the gas flame. Since the heater tube is metal, I wanted the mica to keep the nichrome wire from contacting and, thereby, shorting out against the tube wall. I was aware that I would interfere with heat transfer. Next, I inserted the heater coil and bent the trailing wires to help support it.

This worked but I am happy to shell out the 38 bucks for a sealed, ready-to-go heater coil that was designed for this job!

The electric heater coil may be controlled by a simple switch. Turn it on when you want refrigeration and off when everything's cold. It is possible to size the coil's wattage rating for a continuous "on," but since a refrigerator's cooling needs fluctuate considerably through any given 24-hour period, the food will alternately freeze or thaw. During gas operation, I observed that my Servel gas refrigerator was "on" an average of 20 minutes per hour, or *less*. I was unwilling to babysit my refrigerator.

Unfortunately, the thermostat already installed in the unit was designed for gas and not electric operation.

Fortunately, there is a solution. Install a standard thermostat (like those found in electric refrigerators) in your gas model and have it operate a power relay for heater coil operation (see Fig. 5). The power relay should have an efficient coil resistance for the voltage. Also, its contacts must be able to handle the DC current.

Inspecting a Servel refrigerator

When you have found an old Servel refrigerator, it's time for a closer look. Is it all there? It should have a door with a working latch and a decent gasket, trays, gas line, burner assembly, backplate, and thermostat. After you've looked at the innards and *before* you go any further, ask yourself if this unit is of the right size (capacity). If not—it's too big or too small—don't tempt yourself any further; walk away and search elsewhere.

Next, closely examine the back of the Servel, unscrewing and removing the back-plates, as necessary. Ammonia is a great refrigerant but it attacks copper. For this reason, the "coolworks" will use cast iron or steel pipes and fittings. The point? If everything you see is dirty but still painted, chances are that everything's okay. However, if you see lots of rust, this may be trouble.

Unless the unit is connected to a gas line, there's no way you can know if it will still work or not. Even if the owner says it was working when it was disconnected, that does *not* mean that it will work now. I won't tell you what to do at this point; it's your money, so it's your risk. However, you might point this out to the owner; it may help to bring the price down.

Servel refrigerators, even the smaller models, are *very* heavy. A number of strong bodies and a heavy-duty handcart are indispensable when it comes to moving a purchased unit onto a truck bed. Always tape the door shut, as even a working latch can be snagged and the door can open at an inconvenient (or dangerous) moment. If it doesn't whack someone, it will probably damage itself. Also, only jack the refrigerator from the sides, *never* from the front or back. If you can't safely tie it off (in the truck) in an upright position, lay it down on its side. Some old rug parts, blankets, even a sheet will help as it's lifted or pushed onto, or out of, a truckbed. Strap it down tight and drive slowly. Treat it as you would a rare player piano.

Once you've got it home, clean it up, locate the burner assembly, disassemble the jet, and determine whether or not it will require conversion to the gas you intend to use (see#20 above). Can't figure out where the burner assembly is? Get a service manual.

Many a Servel unit has been hauled off to the junkyard after a revival attempt has "failed" simply because the unit was not burped. Yeah, you read it right. Just like a baby—BURPED! In disuse, an ammonia bubble can get trapped in some part of the plumbing and, when re-activated, fail to dislodge. This will prevent cooling.

How do you burp a Servel? Just like a baby, of course. Well, after you've removed the trays and other loose parts, and taped the door shut. Next, lay the refrigerator on its side, and roll it up onto its top, *carefully*. A complete roll to the other side is fine if room permits, but, while it's upside down, thump it, rock it, and jar it. Work that bubble loose. Of course, if the unit has other problems, this won't help. More often than not, however, this *is* the problem and the refrigerator will work after burping it. Folks who laugh at this procedure, claiming their units didn't have the problem, don't realize they may have inadvertently "burped" their unit transporting it over the bumpy road to their place.

mostat for unattended operation; others don't, necessitating manual on-and-off switching.

Correctly applied, each module is capable of freezing up to two cubic feet of space or providing normal refrigeration up to four cubic feet. If greater cooling capacity is needed, additional modules may be "ganged" (paralleled) together. In fact, the 12-volt model is really two 6-volt modules in series. More cooling is available from extra modules but the power consumption also increases proportionally. It's the pricetag, at $150-200 per module, and low efficiency that will prevent widespread use.

The Peltier module was interesting to me when I was looking for a way to piggyback (or hybrid) a refrigerator with a water heater (see sidebar, A hybrid refrigerator/water heater, and Fig. 6). Since water conducts heat away more about a 150 times faster than air, the module's shape is ideal for interfacing the heater and the cooler on which it is stacked. I figured the module's efficiency would be at optimum and the heat normally wasted recovered for a practical use.

The main obstacle in using sold-state modules for refrigeration is finding a source for them. Contact a company which sells the picnic-type units like Koolatron; they may sell the modules separately. In the proper environment—good insulation, small container capacity, essential cooling needs, and a knowledgeable operator—the thermoelectric cooling module is a technology searching for an application.

Refrigeration alternatives

I have gotten so caught up in the various ways of perfecting refrigeration that I have failed to realize that one of the best schemes is to reduce the *need* for it by pursuing alternatives. Anybody who uses a refrigerator seldom considers what mankind did *before* the refrigerator was developed. Some may remember cutting ice from lakes, storing it in well-insulated buildings, and the daily task of transferring small chunks to the "icebox" in the house. But let's go back still further in time.

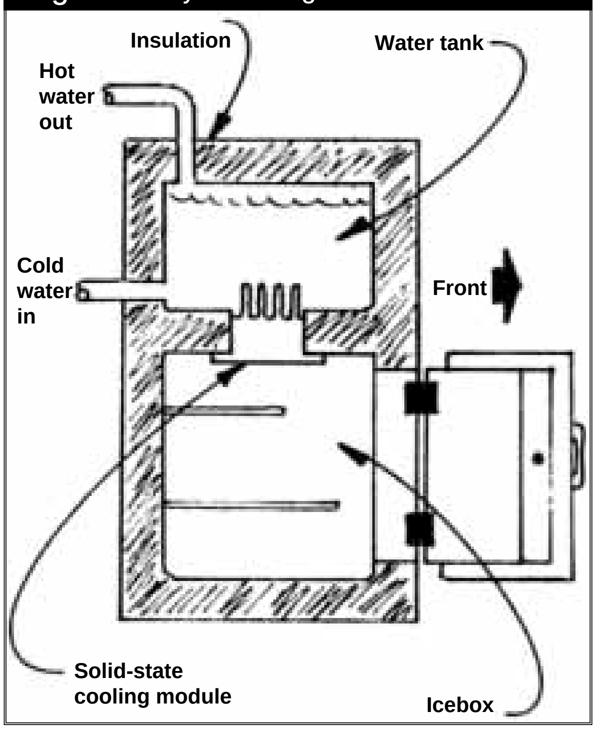
In the pre-icebox era, how *was* food preserved? Basically, people used one or more of four techniques: root-cellaring, canning, dehydration, or controlled supply. Let's look at them one at a time.

26. Build and use a root cellar. The secret to the root cellar is that it's tucked down into the midst of the biggest thermal flywheel we know—the earth. In a 12-hour span, air temperatures may vary as much as 100 degrees F above ground. Several feet into the earth, however, there may not occur a one-degree change. Season to season, the same in-earth spot may vary by only 10-20 degrees F.

Traditionally, root cellars are built under the house. This provides easy access and cuts down on the cost of separate construction. Another important aspect of this design is that the house itself acts as a buffer against surface-side temperature fluctuations. One built separately from a house must be snuggled down a little further in the ground to avoid the influence of temperature variations at the cellar's weakest boundary—it's ceiling and entrance.

What kinds of food can be stored in a root cellar? Garden produce and grains. Vegetables have a natural protection against weather and, when ripe, may be kept for exceptionally long periods merely by keeping them cool. Most types of grain—stored in air-tight, air-evacuated (vacuum or gas-filled) containers, and kept from temperature extremes and direct sunlight—will keep almost indefinitely. It may appear that a root cellar's main function is to protect food from the ravages of summer heat, but this isn't true. Vegetables are just as susceptible to damage by severe cold or freezing. So, the root cellar's moderating influence is also essential during winter months.

Figure 6: Hybrid refrigerator/water heater



A hybrid refrigerator/water heater built around a solid-state module.

Grain and vegetables constitute less than 50% of the average person's daily diet. Also, the root cellar may prove inadequate in light of the cooler temperatures required to preserve other foods—dairy and poultry products, meats, and frozen vegetables. Nevertheless, the root cellar keeps vegetables and grains out of the refrigerator and, in the process, cuts down the size of a unit needed to handle perishables.

27. Learn canning for foodstuffs. Canning involves all types of foods but focuses principally on fruits and vegetables; preserves, pickles, jams and jellies are the end product. However, meat, poultry, and seafood can also be canned. Canning requires no energy in storing the finished product, but it will require a strong heat source and the energy of your own labor to prepare. By comparison, freezing foods predominates now for its obvious advantage in convenience, but its main disadvantage is high energy consumption for the duration of the storage.

Improper processing when canning produces a toxin which causes botulism poisoning. It's the fear of this possibility which turns prospective canners away from this food preservation technique. This is both unreasonable and unfortunate. When tried-and-proven recipes are used and other processes are followed for jar preparation, there is no danger. *Backwoods Home Magazine* has had a number of articles on canning in past issues.

28. Dehydrate your food. Another food preservation technique is dehydration. Involving low-temperature heat, freezing temperatures, or vacuum, this process drives water from foods. As a result, the final product is sealed against the normal pace of decomposition. The final product can be eaten "as is," or reconstituted with water.

The most widely-known example of food dehydration is beef jerky. Although the process is carried out in gas or electric ovens nowadays, the original version involved stretching the thin strips of meat out on sun-baked rocks. In addition to the preparation, the cook had to stick around to fend off animals, birds, flies, and other insects lured by the delicious scent.

A person serious about using this food preservation technique could easily build a solar dryer for unattended drying of bulk quantities of fruit, produce, and meat. The popularity and high cost of dried fruits and meats should be indication enough of what you could do with any surplus dried foods from this inexpensive process.

A hybrid refrigerator/water heater

The thermo-electric cooling module (based on the Peltier effect) is capable of keeping a small, well-insulated compartment 408F below ambient-air temperature. However, touch the "hot" side of the unit after it's been in operation for a while, and you can get burned. Why is the metal hotter than the air temperature? Even with the cooling fan, it's just time for the heat to leave the radiating fins. But, if you piggyback this module—its hot side—into a water tank (after removing the fan and other hardware) things get better (see Fig. 6). Why? Water conducts heat away nearly 150 times faster than air.

In this design, the refrigerator is at the lowest point, the water heater at the highest, and the module is inserted in a hole between them. When switched on, the module "conducts" heat from the lower side to the upper side. In the refrigerator, the cooled air falls and the (relatively) warmer air rises to be conducted out of the refrigerated space. In the tank above, the water in contact with the module will be heated and rise, allowing cooler water to rush downward and, in turn, be heated.

The module iis only capable of conducting a small number of BTUs per hour. In this application, its performance will be significantly better, yet probably not double that of air transfer. Deep insulation, particularly at the cold box/water heater junction, minimizes losses. The rate of energy transfer between refrigerator and water tank may be increased by adding more modules.

The "hot" face of the thermoelectric module is aluminum. After an indeterminate time with exposure to water, it will corrode and may become plated with minerals in the water it heats. For this reason, provide access to the modules for periodic cleaning and make use of galvanic gizmos to minimize the interaction of dissimilar metals. Since tanks of water heat from the top down, add a thermoswitch to the tank to activate a light or buzzer when the water at the bottom of the tank starts to get warm. In other words, it's time to use that heated water. Shower time.

29. Control and "pace" your food supply. A controlled supply means that you keep your food alive—on the hoof or on the vine—until you're ready to use it. If it's ripe, it's ripe; if it's not eaten or preserved, the food will rot, spoil, or become unpalatable. Therefore, in a controlled supply, one staggers the ripening or aging of food so that it comes due as frequently and as reliably as a trip to the store each week.

Meat supplied from domestic animals is another issue. Unlike the relative freedom we may enjoy in picking small or large quantities of vegetables, fruits, or nuts, with animals we're stuck with irreversible "harvests." What portion of it we don't immediately consume *must* be preserved or suffer a loss to spoilage. It wasn't long before raising rabbits for food got to me, and the experience nudged me just that much closer to being a vegetarian. It was the extra effort. When we finally got to the point where there was sufficient food coming from the gardens to maintain our rabbits without the outside purchase of feed, it was also easy to see that we were adding an unnecessary step. In the final analysis, then, the extra energy, water, and grain was too great to justify the meager return.

Last thoughts

A lot of ideas and techniques have been covered in the foregoing sections. While you catch your breath, may I suggest a plan for implementing some of these ideas?

- Seriously consider exactly what it is you want that requires refrigeration.
- Consider one primary and (optionally) one or more secondary power sources for refrigeration. No single source—or the equipment which converts it to useful form—is 100% reliable.
- What conversions, modifications, and replacements appeal to you? Which of these can you perform yourself? Do you have the time, energy, skills, and tools? What will the materials cost? If you need (or want) help, is it available? What will it cost? Is it worth it? Be honest with yourself.
- Are you willing to change some operator habits? Do you need to resite the refrigerator?

Solid answers to these questions will make other options clearer and, hopefully, subsequent decisions easier to make.

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