Rethinking Refrigeration in the GMC

When I first got my GMC I thought, "gosh, what about the darn electric refrigerator and electric hot water heater?" In fact I used both of them as methods to "talk down" the price of the rig. The dealer was not aware that it did not have a propane water heater or a propane refrigerator. In late October, in Montana, I got a very good deal on a rig he had been keeping on his lot for over a year and a half.

Being a long time "dry camper" with lots of experience with normal RV refrigerators and hot water heaters, I figured the electric ones in the GMC had to go. The more I examined the real issues involved the less convinced I was that I needed to replace either of those units. I had to change my thinking and also do some changes in the original systems, but the basic "all electric" concept remained sound in my mind.

When the GMC was conceived it was to be a "traveling machine" more used to travel from place to place than to sit in one spot. The hot water heater and the refrigerator show that influence. Both are electric units with no propane involved at all. The 50 amp 120/240 volt power cord with which the all GMC built units were equipped, was very rare at the time, and is still not the normal power supply except in large coaches, even today.

As a concession to the electric hot water heaters, the GMC coaches were equipped with engine assist to heat the domestic water with excess engine heat. To heat water when stationary the generator had to be run, or the coach hooked up to grid power at a campground or home.

The original refrigerators on the all GMC built units were Norcold dual voltage electric units. When plugged into grid power they automatically used that source, when that was disconnected they switched to the coach 12 volt power supply system.

<u>Refrigerator types</u>

There are two basic kinds of refrigeration, compression and absorption. A compression refrigerator is one which has a motor that drives a compressor. It is used in virtually all household refrigerators, as well as the air conditioners we are all familiar with. They are simple, efficient, reliable and inexpensive but require electricity to run the compressor. From now on I will call them electric refrigerators.

Absorption refrigeration uses an entirely different mechanism for operation and uses heat to operate. That heat may come from a propane flame, an electric heater or even a kerosene flame or high temperature solar heat. They have no moving parts, are silent, are relatively inefficient, and relatively costly to purchase. Since we usually use a propane flame for the heat source I will call them propane refrigerators.

Characteristics of the Two Refrigerator Types

Electric, positive:

1. Rapid cool down from an unused state.
2. Ability to operate well at high outside temperatures.
3 Ability to operate off level.
4. Relatively low heat output that must be dissipated from the coach.

Electric, negative:

A. Some compressor noise.
B. Very heavy drain on coach batteries when dry camping.

Propane, positive:

A. Noise free.
B. Can operate for days and weeks with little or no electric input (newer propane refrigerators use some 12 volt energy for ignition and control functions).

Propane, negative:

A. Take several hours (up to 6) for initial cool down.
B. Operate marginally at high outside temperatures. This is very annoying to many people who camp and travel in hot climates.
C. Some people have safety concerns when propane is used while driving.
D. If 12 volt power rather than propane is used while driving, they place a heavy demand on the engine alternator.
E. Considerable heat must be dissipated to the outside or marginal cooling will result.
F. When operated on 120 volts the heater requires almost 10 times the watts each hour compared to electric refrigeration. Thus they are much less energy efficient.
G. Off level operation for significant time will damage the cooling unit.

Overall: electric refrigerators are generally superior to propane except for their energy needs when dry camping. Dry camping is the primary reason that propane refrigerators are almost universally used in new RV's. However, it is worth a look at just how individuals use their camping vehicles before dismissing electric refrigeration.

Concentrating on the refrigeration needs of a coach there are four different modes to consider.

1. Cool down, loading the rig for a trip.
2. Travel.
3. Parking/camping with hookups.
4. Parking/camping without hookups.

1. For initial cool down grid power may be available so an electric unit is satisfactory. If it is not available, the 12 volt electric mode will cool the box down in around 2 hours (vs. 6 hours minimum for a propane unit) and will not deplete the batteries significantly. With propane refrigerators I normally start them the night before I leave. Not everyone has that option if their rig is not stored at home.

2. For travel, there is always enough 12 volt power available from the running engine. The Norcold took about 8 amps to run in its original condition, and probably had a half on half off duty cycle (depending on temperature) so the actual energy use was the equivalent of a 4 amp full time load. All GMC's had a 80 amp alternator and many have been upgraded to 100 amps or more. Thus no problem providing enough electricity while on the road.

A propane refrigerator with a 12 volt heater will only maintain an already cold box, and generally takes 20 amps full time to do that. That is 5 times the average load that an electric refrigerator takes. There is a great deal of dispute on the advisability of using propane for refrigeration while traveling. I personally have no reservations about it, and have used propane refrigerators for probably 150,000 miles of road travel with not the slightest problem. Others feel it is unwise and dangerous. Your call.

3. For parking and camping with hookups the electric refrigeration works very well. The energy use is minimal and the outside temperature is not a significant factor in whether the refrigerator keeps things satisfactorily cold. Many owners of RV's virtually never camp without hookups and, for them, an electric refrigerator will work just fine. Even plugged in to grid power, a propane refrigerator may not work very well in extra hot weather.

4. For parking and camping without hookups (dry camping) the electric refrigerator has a major problem. The unit must operate on energy stored in the 12 volt coach batteries and that energy source has severe limits. The hotter it gets outside, the more run time and thus more battery depletion occurs. The designers of the GMC figured that the machines would be "hooked up" or traveling and thus did not see dry camping as a large issue. They specified 120/12 volt electric only refrigeration.

Many, if not most, of the GMC's on the road today have been retrofitted with propane refrigerators and the owners are very happy with their choice. They are willing to live with the propane refrigerator's long and slow initial cool down and marginal operation in very hot weather in return for the ability to dry camp without having to worry much about the state of charge of their coach battery. I have propane refrigeration in my other RV's and find it works well most of the time. But, my GMC has the original Norcold refrigerator, and I would like to keep it at this time. Replacement cost is one reason. I was interested in just how severe the battery depletion problem could be. This prompted me to examine how much energy the Norcold requires for operation.

Available Battery Energy

To start, we need to look at what we have to work with. Most GMC's have been retrofitted with two 6 volt "golf cart" batteries in series to give the 12 volts we use in the coach. The most common battery of this type is a Trojan T 105 which has a 225 Amp hr rating at a 25 amp discharge rate. I will use this 225 figure as we seldom discharge our house battery at a faster rate than 25 amps unless we have a large inverter powered microwave, and generally that is a very short term use. 225 Amp hr times 12 volts gives us a capacity in watts of 2700 watt hr. It is not advisable to fully discharge any lead acid battery so I will assume that we will not discharge it less than 80% of its total capacity. That gives us 2700 x .8 = 2160 watt hr of useable energy in storage. To understand how little that is, think of your home electric bill. You probably use 400 to 1200 kWh (1 kWh = 1000 watt hr) each month. Your coach battery will hold about 2 kWh. Even if you filled it and emptied it each day, you would only cycle 60 kWh through it in a month. So, every watt hour is valuable.

How Much Can We Afford to Use On Refrigeration?

Refrigeration must operate 24 hours a day. How long do you want to go without running your engine to recharge batteries, or your generator for the same recharge? Two full days? That is 48 hours so if we used the batteries only for refrigeration we couldn't use more than 2160 watt hr / 48 hr = 45 watts each hour to run our refrigerator. I'll assume you want lights and maybe some heat in the morning, and TV in the evening, so I limit my thinking for the refrigeration to 30 watts each hour. This gives a bit of energy left over for those other things.

Now, this piece is not about batteries. They are a very complicated subject and the capacity I noted above is based on:

1. Published specifications (often inflated or questionable).
2. Age of the battery (they can age very fast)
3. Temperature of the battery (below 40 F is not good)

4. State of charge of the battery. It is very difficult to fully recharge a battery without the best equipment, and the original GMC "buzz box" was not very good.
5. Rate of discharge of the battery (mentioned above).
6. About 4 million other if's , ands, and buts.

This is not an exact science. As the mutual funds are fond of saying "past performance is not an indication of future earnings". We can only use calculations and best engineering judgement here.

Enough of the disclaimers, back to refrigerators.

<u>The Original Norcold Refrigerator and How it Operated</u>.

For the time it was built, the original Norcold was a very efficient refrigerator. Even by today's standards it is not bad. It uses foam insulation and a "swing motor" compressor, invented in Germany and manufactured in Japan. The motor has a piston on a spring which is set to resonate at 60 Hz. It operates on 23 volts AC at 60 Hz. It is not a direct current motor so operation on 12 volts DC requires changing it into 23 volts AC. To operate on 120 volts AC, the voltage must be transformed down to the lower voltage, but the frequency is right. If operated via the 120 volt generator in the coach it is critical that the frequency be very close to 60 Hz or the compressor may be damaged. (that from the original literature) From now on I will refer to the compressor as a 24 volt unit, because it will operate just fine on that voltage which is common for use on electronics here in the US. Why they chose 23 volts as a compressor voltage is beyond me.

To get the 24 volts needed, the original power supply had a transformer to reduce the voltage when on grid power. It also had a relatively crude (by today's standards) inverter to change the 12 volts DC to 11 volts AC, 60 Hz and then that was transformed up to the 24 volts needed by the compressor. The Inverter was a transistorized switch which choped the DC to make a square wave 60 Hz AC. Thus the name "chopper inverter". The transformer was a dual primary unit, which would either take the 120 volts and step it down or the 11 volts and step it up to the final 24 volts needed. Transformers don't like square wave AC very much, producing inefficiency. Also, dual primary transformers can be less efficient than single primary ones.

In addition, there was an automatic switching mechanism to select 120 volts when available or 12 volts when it was not.

When examining all of this, I found that while the compressor and insulation of the original box of the refrigerator were fairly good in efficiency and operation, the power supply was not very good. The two problems were the original "chopper inverter" and the dual primary transformer. On grid power of 120 volts they are not critical, but on 12 volts DC they are both important. So, my goal was to look at both of them and see if improvements could be made. I did not try to improve the insulation of the box itself. That is very difficult.

By fortunate coincidence I was in an RV lot not long after I got my GMC and saw a Palm Beach there which, of course, I had to investigate. They were fixing it for resale and were replacing the original Norcold electric refrigerator with a propane one. The Norcold was going on the junk pile. I asked for it, and got it for free. It may have had a minor problem, or maybe they were just replacing it, but at any rate it worked fine on 120 V AC when I got it home. Now I had a test unit, and didn't have to remove the one from my coach for testing. Yea! A few quick tests showed me that they are both very similar, so I think my data will fit most all Norcold units originally supplied in the GMC's.

I have a home with a very high thermal mass, so I keep it at a constant 72-73 F 24 hours a day all winter. I set the test refrigerator up and let it come to a very stable temperature of 35 F in the box and 10 F in the freezer part. All of my tests then have the same constant inside and outside temperatures, no matter when I did them. This gives me confidence that the results are consistent, test to test. The exact numbers are not necessarily what you will get in a coach when the outside temperature varies from hour to hour and day to day. (another disclaimer).

I have a very accurate Brand 120 volt digital watt meter. It will measure instantaneous power use from 1 watt to 1800 watts. It also measures watts used over time to give kWh (energy) used for any device plugged into it. It samples both voltage and current many times a second and integrates them, no matter how the waveform varies or the current or voltage drift. It also shows hours of time connected, so by dividing the kWh used by the hours connected I can find the average watts consumed each hour. Even though a device like a refrigerator is on and off, I can find the average use, not just the instantaneous use.

Now, if you have followed me this far, remember I would like the refrigerator to use not more than 30 watts each hour so the batteries don't take a beating too fast.

<u>The tests</u>

Each of these tests were done at least twice, and each test lasted from 8 to 24 hours. The results were very consistent from test run to run. Also I found that the compressor has a label which states it requires 60 watts, and that is confirmed in the original operating book.

Test 1. For a baseline, I ran the refrigerator on 120 volts AC grid power, and used the original Norcold power supply with the dual primary transformer.

Results:

Compressor running watts:	77 to 82
Average watts (on and off time included)	37.2

Comments: note that the compressor is running at 17 to 22 watts higher than the specifications of 60 watts.

Test 2. To see if the dual primary transformer was a problem, I substituted a single primary transformer, 120 volts in and 24 volts out. It was a bit under rated for the load, but transformers are very forgiving especially in non continuous operation such as a refrigerator. The primary was run through the original refrigerator box temperature control switch, so it was not energized until the box called for cooling. This test used grid power.

Results:

Compressor running watts:	64 to 67
Average watts (on and off time included)	30.1

Comments: Note that the compressor running wattage is somewhat lower than in case 1. I have no great explanation for that. The compressor sounds a bit quieter, and the compressor case temp feels about the same. Does the original transformer operate the compressor at a higher voltage and thus watts go up? Does it run fewer hours, but on average, take more energy each hour? Conversely, does the new transformer operate the compressor at closer to it's rated wattage of 60 watts but run it longer? I don't know, but the final result is that the watts used each hour is decreased from 37.2 to 30.1, which is a 19% reduction. The only change was the transformer.

Test 3. For this test I used the original dual primary transformer but powered the 120 volt side with a modern 12 volt DC input, 120 volt AC output "modified square wave" inverter. The specific inverter is an xantrex XPower 400, a 400 watt inverter I purchased at Costco for $25. I connected the inverter to a deep cycle 12 volt battery, which was kept fully charged by a small battery charger. I monitored the 120 volt output of the inverter which is the input to the transformer only. I did not measure the input to the inverter as I have no way to integrate the DC voltage and current over the time that the compressor is on and off. Thus the watts used by the refrigerator are AC watts and are directly comparable with those in the two tests above.

Results:

Compressor running watts:	52 -55
Average watts (on and off time included)	31.8
Average watts including 85% inverter efficiency:	37.4

Comments: Note that the compressor running watts has been reduced from either test one or two. The average watts used each hour is less than test 1, but not as low as test two which used the single primary transformer running on grid power.

No inverter is 100 % efficient, so that has to be taken into account. I could not measure the actual wattage input to the inverter over time. However, most of these inverters are in the range of 85 to 90% efficient, so the 31.8 watts / .85 efficiency comes out to 37.4 watts each hour used from the battery. So by just using a more modern inverter with the output fed to the original 120 volt plug of the refrigerator alone increased the overall efficiency and thus reduced the battery usage.

Test 4: This is the one that shows the lowest energy use on 12 volt operation. For this test I ran the single primary transformer from test 2 on a the modern 12 volt DC input, 120 volt AC output, inverter from test 3. Again I monitored the 120 volt output of the inverter which is the input to the transformer only. Thus the watts used by the refrigerator are AC watts and are directly comparable with those in the three tests above.

Results:

Compressor running watts:	49-52
Average watts (on and off time included)	28
Average watts including 85% inverter efficiency	33

Comments: This is a number that I feel is quite good for the energy use of a 29 year old refrigerator. It is one that I can live with. Note that the compressor running watts is lower than either of the previous two tests. I cannot really understand why but it must have something to do with the waveform of the "modified square wave" inverter and the interaction of that with the single primary transformer and unusual swing motor compressor. The actual watts used each hour is also lower than the same transformer on grid power. The refrigerator still runs well and keeps the same temperature. The compressor case seems the same temperature.

As in test 3 the inverter efficiency needs to be included in the calculations. Assuming an 85% efficiency, the 28 watts / .85 efficiency comes out to 33 watts, still not a bad figure and close to the original goal of 30 watts each hour.

One additional note on inverters. I had another small inexpensive inverter that I made a test with. The compressor sounded funny, the compressor running watts was over 80 and the average watts each hour was in the range of 59. This was totally unacceptable and I terminated the test. So, not all inexpensive inverters are created equal. Beware.

<u>The test I could not do</u>

The one test that I really wish I could have done is to determine exactly how much energy the original chopper inverter and dual primary transformer required for 12 volt operation. Because I have no equipment similar to the Brand meter I used for the above AC tests to integrate exact DC voltage and current over time I can only make educated estimates and I am reluctant to do that. But, with that disclaimer, here it goes.

The input current for the original setup I have measured is about 7.8 to 8.1 amps at about 12.5 volts, which is 97.5 to 101 watts. Remember this is the old chopper inverter and original transformer combination. The problem is determining the run time. This requires me to monitor, with a watch, the on and off cycles over many hours. I have done a little of it, but not enough to have great confidence in what I say now. But it looks like about half time (on half hour, off half hour) compressor operation. That combined with the above guesstimate of input wattage would say that the original unit required around 50 watts each hour. If I am right, then the reduction to 33 watts using a new transformer and inverter would result in about a 33% efficiency increase and thus a one third reduction of battery energy used.

Some of you may want a specific "how to do the modifications" information, to reduce the energy use on 12 volt operation. The simplest thing you could do is to unplug your Norcold from the 120 volt outlet and plug it into a more modern inverter. That alone would decrease the energy requirements and almost anyone could do it. The inverter can go in behind the refrigerator, or under it. The 12 volt power supply is already available there and is sufficient. You need to be able to turn the inverter on and off, and plug the refrigerator into grid power when hookups are available

If you want to change the transformer and remove the original power supply altogether you will need a single primary 120 volt to 24 volt transformer, rated about 3 amps at 24 volts output. If you are willing to try this modification, and can find a transformer, you probably can figure out the wiring modifications needed to make it work. I am a bit reluctant to spell the specifics out in detail, because the novice could mess things up and possibly damage the refrigerator, or do some unsafe wiring practices. I already had a suitable transformer in my junk box and have not looked for sources for another.

Photos of my test equipment, the original power supply, the new transformer, compressor, and wiring are in the GMC photos site. The captions on the photos may help you if you want to do the modifications that I have done.

Back to the original question? Can one live with an electric refrigerator when dry camping? First, how long do you want to stay in one place without running the generator? Is two days OK? Second, since the hot water heaters in most GMC coaches are still electric, how often and how long do you run the generator to heat hot water? Can you also assume that the batteries can be partly recharged when you are doing that? This will extend the refrigerator run time longer. Third, how much are you willing to run the generator? Personally, I hate the darn things, be they my own or someone else's, but an hour or two during the late morning is not too bad in my book. Just not at night, please. Another thought is to buy a Honda EU1000i generator which is very quiet, and run it longer hours to recharge your house batteries. I have such a generator in addition to the original Onan.

You do need to have a good three stage battery charger or converter/charger. The Todd or Progressive Dynamics 40 to 60 amp units (with the charge wizard) fill the bill and can also operate on a small Honda if you have one. The original "buzz box" converter/charger is not very good if you want to recharge your coach batteries quickly. When driving the engine alternator does a good job of battery recharge.

<u>What about solar power?</u> There is no question that you could reduce your generator run time with some solar panels. Here at home I have a very large stationary solar system that I use for reducing my grid power load in the summer time and as a backup system for the common grid failures we have all year around. It has been in operation for 10 years now, and works very well.

However, in the winter months here in the North, the sun is very low in the sky and not available often for long time periods. Solar simply does not produce much useable energy. If out in the GMC in the summer, I want to park in the most shady spot I can find in a cool National Forest campground. The shade kills most solar panel output. So, although it works for some, in some climates, it is not a viable option for me.

<u>A Final Note on Replacement Electric Refrigerators</u>.

The Norcold was a good unit for it's day, and with modifications is not all that bad today. But if you want to stay with an electric refrigerator that is a direct size replacement three are available. Norcold, Dometic (Tundra), and Nova Kool all make units which fit. The literature I have seen is a bit hard to interpret as to energy use, but they seem to remain in the 28 to 30 watt per hour range. A bit better than my tests on the old Norcold, but not dramatically different. Of course

I don't have any to test directly in comparison with the one I have. I would love to have one to make a direct comparison with the old Norcold. All of the new electric units seem to be in the $900 to $1100 range, about the same as a propane refrigerator.

There is a great temptation to just go out and buy a small 120 volt electric refrigerator from one of the hundreds of stores that carry them and plug it into an inexpensive inverter and go. $200 will get you something that may look great and a wonderful bargain vs. the prices for the RV specific electric refrigerators mentioned above.   Watch out here. Small does NOT mean energy conserving. Look at the yellow hang tag required in all refrigerators sold today. It will list the yearly consumption in kWh. If you take that number and divide it by the number of hours in a year (8760) you will have the average watts per hour it consumes. Or to put it another way, the 30 watts each hour in my budget above means that the hang tag had better have a number less than 262 kWh a year. I have not yet found one that low, even the little "dorm cube" refrigerators. 40 watts each hour comes out to 350 kWh a year, and some are in that range, but are not nearly as large as the original Norcold unit.

I hope that this gives you something to think about, no matter what refrigerator you now have. Propane is great, but don't write off electric refrigeration without some careful thought.

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