Doing a Load Analysis: *The First Step in System Design*

Benjamin Root

It's not that we really care about electricity. We don't even care about the appliances that the electricity powers. Our wants and needs are even more basic than that. We want to read after dark, hear good music, and learn about what is happening in the world. We want water on demand and unspoiled food. We don't need the electricity like we don't need the drill. What we need is the hole.

Electricity is merely a tool used to meet our needs and wants. When planning a renewable energy (RE) system it is important not to lose sight of what our needs actually are. Only once our needs are defined can we then begin to design an RE system to meet them. We must analyze each need and determine how much energy it takes to meet that need. Long before we start comparing prices on photovoltaic modules we must first create a list of needs called a "load profile." This article will first discuss some important considerations in choosing appliances to meet certain needs. Then we will go through a step by step discussion of the various elements in a load profile.

Why Do a Load Profile?

RE systems are expensive. Costs to produce one's own electricity from renewable sources average between $0.25 and $1.15 per kilowatt hour (kWh). This is many times the price of buying power from the electric utility. Off grid, it is a waste of money to use more energy than we need to and a waste of money to produce energy that is not used.

If done correctly, your load profile's average daily kWh figure can be quite accurate. Careful load analysis can assure that we size our RE system appropriately.

Which Loads are Appropriate Uses for Electricity?

Most of us need to eek out as much functionality from as little energy as possible. For example, electricity is an expensive way to produce thermal energy. The electricity needed to provide space heating is generally cost prohibitive. Passive solar, wood heat, and propane furnaces are all much more practical. Domestic hot water heaters and cookstoves are also best powered by passive solar, wood, or gas.

Certain loads can be powered by electricity or by other sources. Refrigeration is a good example. Propane refrigerators are available but have their own set of pros and cons. In an energy efficient home the electric refrigerator (even the energy efficient kind) is usually the largest single load. Many RE systems use electric well pumps, but wind-powered mechanical pumps have effectively provided domestic water for generations. These choices are ours. Do we need a 1,200 watt hair dryer or will a towel do just as well? Is using candles or kerosene for light really a smart (or safe) alternative to compact fluorescents?

Some needs are surprisingly appropriate for use with renewable energy systems. Power tools, microwave ovens, toasters, and other kitchen appliances can draw a lot of power and are often mistakenly considered to be too much for an RE system. Actually, these appliances are used for short periods of time and the energy consumed is rather small.

Why Pay Extra for Efficiency?

It might sound like we must do without certain luxuries in order to live with a renewable energy system. This is not the case! RE systems can provide the same amenities that our city cousins enjoy. The trick is to carefully choose how these luxuries are implemented. The most cost effective way to produce one's own energy is to first reduce one's needs for that energy. Richard Perez has a saying that sums it up quite well, "Every watt not used is a watt that doesn't have to be produced, processed, or stored." When buying grid power we can dip into a limitless supply and pay as we go. But with RE systems the cost of the energy is the up front cost of expensive system components. Choosing energy efficient appliances is cheaper than renewable energy system components.

For example, compact fluorescent light bulbs have improved immensely. The light is natural colored, flicker free, and very efficient. A 15 watt compact fluorescent produces the same amount of light as a 60 watt incandescent bulb—at one fourth of the power consumption. They cost about $22 but last 10,000 hours, about ten times longer than a standard incandescent bulb. More important is the money saved by power that doesn't have to be produced. Saving 450 kWh of electricity, at $0.65 per kWh (a hypothetical middle ground cost for RE based on a well designed photovoltaic system with generator back-up), over the bulb's lifetime translates to about $292 dollars. More than enough savings to cover the $7 price difference between one compact fluorescent and ten incandescents!

Refrigeration is another good example of energy efficiency paying for itself. It is often the largest load in a RE-powered home. A sixteen cubic foot Sun Frost fridge may cost $2,500 but uses only about 540 watt hours each day. A typical major brand, non-efficient fridge may cost only $600 but will use 1,500 watt hours per day. Assuming $0.65 per kWh for an RE system, the electricity to operate the non-efficient fridge for ten years costs about $3,558. The electricity to operate the Sun Frost for ten years costs about $1,281. The difference is $2,277 worth of renewable energy system components that never need to be purchased, and more than covers the $1,900 difference in price.

"Every watt not used is a watt that doesn't have to be produced, processed, or stored."

A good rule of thumb says that for every extra dollar spent on energy efficient appliances, three dollars will be saved in energy system components. It becomes obvious that before one dollar is spent on photovoltaic panels, wind generators, or hydro turbines we must streamline our electrical demands.

Are Phantom Loads Really a Big Deal?

If you read many *Home Power* articles then you know phantom loads are one of our biggest pet peeves. Phantom loads use electricity while providing nothing in return. A phantom load is any appliance that consumes power even when it is turned off. While they may seem small they use power twenty-four hours a day. A 4 watt phantom load can cost about $22 a year on an RE system, a lot for an appliance that is supposed to be off.

Any appliance with an electronic clock or timer is a phantom load. If we want a clock we should use one that is mechanically wound, battery powered, or even electrical. But a clock in an appliance keeps the appliance's entire power supply "alive" just to tell us the time. Very inefficient.

Appliances with remote controls remain alive while waiting for the "on" signal from the remote. Any appliance with a wall cube is also a phantom load. A wall cube is a small box that plugs in to an AC outlet to power appliances. Wall cubes consume 20 to 50% of the appliance's rated power even when the appliance is off.

"One human One Light"

Most modern TVs, VCRs, stereos, computers, Fax machines, and other electronics are phantom loads. They may contain a transformer, much like a wall cube, that stays alive even when the appliance is off and consumes between 50 and 200 watt-hours per day. They may also contain a filter or line conditioner, to clean up incoming power for the sensitive electronics inside, consuming 8 to 40 watt-hours per day.

Modern televisions have an "instant on" feature so we don't have to wait for the picture tube to warm up. We might as well call these TV's "always on."

The most direct way to overcome phantom loads is to unplug the appliance when it's not in use. A more convenient technique is to use a switched plug strip. These short extension cords with multiple receptacles allow us to cut all power to multiple appliances with one flip of a switch.

Use care when shopping for appliances that will run on a renewable energy systems. Models that are not phantom loads often have the fewest bells and whistles but are the least expensive.

For more information on detecting and avoiding phantom loads see *HP* 55, page 36.

How to Do a Load Analysis

On page 41 is a load profile form. It is available as a Microsoft Excel spreadsheet on the Home Power web site (http://www.homepower.com). Every appliance in your household that receives regular use should be logged onto this form. When completed you will have an accurate estimate of your average daily kWhs used. This is the foundation on which to build an RE system.

You may be planning for a future RE system at a home that is not yet completed or fully inhabited. Is is important to estimate your future loads as accurately as possible. Try to be realistic about your lifestyle and energy usage habits (Americans watch twice as much TV as they think they do). Be aware of possible appliance purchases in the future, like for growing families. Remember obscure loads such as well pump, satellite dish, garage door opener, etc. The accuracy of the final estimate is dependent on the accuracy of your initial data.

In a load analysis we evaluate a variety of parameters for each appliance. By combining this data we will be able to see this appliance's impact on your energy needs as a whole, and in comparison with other appliances. What follows is a discussion of each parameter (vertical column on the form) and how to obtain the data.

Column A: Appliance
Simply, what appliance are you testing?

Column B: Number
How many of these appliances? An example of multiple identical appliances is lights. There is no need to list every light bulb in the house separately. Richard Perez has a super analogy of one light for every member of the household. Imagine each person has a light that follows them around the house as they move. This is just an analogy, and until technology improves, it is up to each person to throw the switches to get their light to follow them. Ideally then, a three person family should be able to enter 3 in this column for personal lighting. Lights of different wattages should get separate entries. A light on a timer in the driveway should get its own entry, as should a night-light that stays on all night in the hall.

"Every dollar spent for an efficient appliance saves three dollars in renewable energy system components."

Column C: Load Voltage
At what voltage does this appliance operate? RE systems are moving away from 12 Volt systems. Modern RE-powered homes often run on 24 or even 48 Volt systems. Some DC appliances are available for 12 Volt, less so for 24 Volt. Most inverter-powered AC appliances run at 110 Volts (117 Volts rms) but we must not forget about the indispensable 220 volt power tool.

Column D: AC or DC
Does this appliance operate on inverter power or directly from battery power? Inverters consume power by just being on. However, many renewable energy system users are finding that the advantages of constant ac power easily offset inverter losses. Here at Home Power we run all our communications equipment directly on DC for emergency reliability reasons.

Column E: Inverter Priority
Does this appliance spend a large amount of time on? The purpose of this column is to get a feel for the normal operating wattage of the inverter. If an appliance spends a good deal of time on or if we want to be sure that this appliance will always have access to inverter power, then we consider it to be an inverter priority load.

Any appliance that turns itself on and off must be an inverter priority load because we cannot control its access to the inverter. Some loads are operated infrequently and we can decide what other appliance we will allow to operate at the same time. These loads are not inverter priorities.

Later, when we are designing our RE system, this column will help us choose the size of our inverter. It will also help determine the inverter's average operating efficiency.

Column F: Run Watts
How much power does the appliance consume when in use? The most accurate way to determine this is to measure current through the appliance then multiply by 117 volts if it's an ac appliance. If the appliance is DC, multiply the measured Amps by the system voltage to determine Watts. Measuring Amps involves getting an ammeter in series with the load. *HP* 33 page 82 illustrates an effective little gismo for breaking into ac wiring to measure amperage.

Another technique for measuring amps, if your meter has limited amp capability, is to use a shunt. A shunt is a small resistor of known value. It, like an ammeter, must be placed in series with the load being tested. Once in place, measure voltage across the shunt, then use Ohm's law to determine the amperage. If you don't want to buy a shunt then make one out of #10 wire. One foot of #10 copper wire has a resistance of 0.001 ohms. Set your voltmeter to the millivolt scale and measure the voltage drop across the makeshift shunt. For more information on using wire as a shunt see *HP* 6 page 35. To review Ohms law see *HP* 52 page 64.

Electrical appliances display their power use data on a plate or sticker. The noted watt value represents a worst case scenario, the most power that the appliance will ever draw. We generally don't listen to the stereo with the volume all the way up (punk rockers aside), or juice marbles in the blender. If you want accurate numbers you should measure actual watts. If you can't measure then derate the sticker wattage by about 25%.

Column G: Hours per Day
How much is the appliance used each day? In some ways this information is easy to figure: The radio plays

A Appliance	B Qty.	C Volts	D AC DC	E P Y/N	F Run Watts	G Hours /Day	H Days /Week	I W-hours /Day	J Percent of Total	K Surge Watts	L Ph-L Y/N
Espresso Maker (example)	1	117	AC	N	1350	0.20	7	270.0	6.8%	1350	N

Total Daily Average Watt-hrs [ ]

Inverter Priority Wattage [ ]   Max. ac Wattage [ ]   Max. ac Surge Wattage [ ] every morning for forty-five minutes while you get ready for work. The washing machine takes twenty minutes to complete a cycle. Other appliances are more tricky, for example the three light bulbs for your three person family. You need to guess how much time each day that each light is on.

Some appliances turn themselves on and off automatically. Refrigerators start up when the temperature inside gets too warm. They run until they are cooled down to certain temperature when they turn themselves off. This is called a “duty cycle” and can be estimated by direct observation. Just pay attention to how often that fridge comes on and how long it stays on.

When determining energy use, the time element of column G is interconnected with the power element of column F. We can ignore duty cycle by using a recording ammeter and a stopwatch. Simply divide total amp-hours consumed by the number of hours tested to obtain a constant amps rating. Multiply amps times appliance voltage (column E) to get watts (column F). Then use 24 hours per day in column G.

“If you want a clock, then buy a clock.”

Column H: Days per Week
Do you do wash every day? Do you only watch TV on Saturday mornings? This helps determine average energy use per day.

Column I: Average Watt-hours per Day
Number (Column B) x Watts (Column F) x hours (Column G) x days (Column H) ÷ 7 days per week = average watt-hours per day for this appliance.

$$B \times F \times G \times H \div 7 = I$$

This amount tells us, on average, how much electricity is consumed each day by this appliance. The total at the bottom of this column tells us how much electricity we use on an average day.

Column J: Percentage of Total Electricity Use
Just for your information, what percentage of total electrical use does this appliance represent? Column I ÷ the total sum of column I for all appliances.

Column K: Starting Surge in Watts
Does this appliance have a starting surge? How much? Any appliance with a motor has a starting surge. This means that before the motor is up to operating speed it is drawing more than its rated operating power. This is especially true if the motor is starting under load. Refrigerators, well pumps, and most power tools have starting surges. Motors surge between three and seven times their rated wattage.

Other appliances that may have starting surges are TVs, computer monitors, and any appliance with an internal power supply. These loads have large capacitors that charge themselves when the appliance is first turned on. They can surge up to three times their rated wattage.

Because they are relatively short—in the millisecond range—starting surges don’t make much of a difference in the amount of energy that an appliance consumes. Starting surges are important, however. Inverters must be sized to handle the starting surge of ac appliances. Battery banks must also be sized to handle the voltage depression caused by a high amp surge. Voltage depression can cause an inverter to shut down even if the inverter itself is large enough to handle the surge.

Measuring the starting surge of an appliance requires a meter with a peak hold (maximum) capability.

Column L: Phantom Load
Does this appliance consume power even when turned off? Home Power is ruthless with phantom loads! Our offices are totally controlled by plug strips. No phantom load is allowed to haunt the system. Column L will do three things. First, it reminds us to check each appliance while doing our load profile. Second, it reminds us later that this appliance is a phantom load and must be dealt with as such. Third, if for some reason this appliance is allowed to operate as a phantom load, we will remember that a separate entry must be made in the load table to reflect its energy usage (whenever the appliance is not in use).

The Completed Load Survey
You have combed your house testing loads. You have estimated future loads and maybe even made purchase decisions based on this load survey. But what does the table really tell you? The total at the bottom of column I.is most important. This number represents the average daily electricity that your household uses. This is also the amount of power that your RE system must generate daily.

Some days you do wash and some you don’t. Some days you run a lot of power tools. Some days the sun shines and some it doesn’t. There are inefficiencies in batteries and inverters. There are a lot of other variables involved in system design. However, average daily kWh is the basic need that must be met. All system design starts here!

Other information in this table (inverter priority wattage, max ac wattage, and max ac surge wattage) will become useful during system design. Do you install 220

Examples

Here are load tables for two example households. Both of these homes provide the same functionality, meeting the same needs and luxuries for their inhabitants. The only difference between these two homes is the efficiency of the electricity use.

Home 1 represents the use of some inefficient appliances: a name brand refrigerator and incandescent lights are used. Also, the inhabitants of this home ignore the phantom loads, allowing them to run constantly. Notice that each phantom load has its own entry on the load table representing the power used by that appliance when turned off.

Home 1 uses an average of almost 7.4 kWh of electricity each day. At 65¢ per kWh this adds up to about $4.80 per day for electricity!

Home 2 represents a more efficient use of electricity: Compact fluorescent lights and an efficient refrigerator. Also, phantom loads are completely eliminated by the use of switched plug strips. These are the only differences between Home 1 and Home 2. However, Home 2 only uses an about 4 kWh per day of electricity. At 65¢ per kWh this is about $2.53 per day for electricity.

The $2.27 daily difference between Homes 1 and 2 is substantial. Over $828 dollars saved each year can easily pay for the expense of efficient appliances.

Remember, the accuracy of the final energy use estimate is only as accurate as the data within the load analysis table.

Home 1 (inefficient)

Appliance	Qty.	Volts	AC DC	P Y/N	Run Watts	Hours /Day	Days /Week	W-hours /Day	Percent of Total	Surge Watts	Ph-L Y/N
Incandescent Lights	4	117	AC	Y	60	5.0	7	1200.0	16.3%	0	N
Refrigerator RCA 16 cu. ft.	1	12	AC	Y	141	10.0	7	1410.0	19.1%	1300	N
Blender	1	117	AC	N	350	0.1	2	10.0	0.1%	1050	N
Microwave Oven	1	117	AC	N	900	0.3	7	225.0	3.1%	1200	Y
Phantom Load-Microwave	1	117	AC	Y	4	23.8	7	95.0	1.3%	0	
Food Processor	1	117	AC	N	400	0.1	5	28.6	0.4%	1200	N
Espresso Maker	1	117	AC	N	1350	0.1	7	135.0	1.8%	1350	N
Coffee Grinder	1	117	AC	N	150	0.1	7	7.5	0.1%	200	N
21" Color Television	1	117	AC	Y	125	5.0	7	625.0	8.5%	570	Y
Ph/L-TV	1	117	AC	Y	20	19.0	7	380.0	5.2%	0	
Video Cassette Recorder	1	117	AC	Y	40	2.5	7	100.0	1.4%	80	Y
Ph/L-VCR	1	117	AC	Y	15	21.5	7	322.5	4.4%	0	
Satellite TV System	1	117	AC	Y	60	2.5	7	150.0	2.0%	1600	Y
Ph/L-Satellite Sys.	1	117	AC	Y	22	21.5	7	473.0	6.4%	0	
Stereo System	1	117	AC	Y	30	8.0	7	240.0	3.3%	60	Y
Ph/L-Stereo	1	117	AC	Y	3	16.0	7	48.0	0.7%	0	
Computer	1	117	AC	Y	45	6.0	3	115.7	1.6%	135	Y
Ph/L-Computer	1	117	AC	Y	3	21.4	7	64.3	0.9%	0	
Computer Printer	1	117	AC	N	120	0.3	3	12.9	0.2%	360	Y
Ph/L-Printer	1	117	AC	Y	3	23.9	7	71.7	1.0%	0	
Power Tool	1	117	AC	N	750	0.5	3	160.7	2.2%	2250	N
Radio Telephone (receive)	1	12	DC	N	6	24.0	7	144.0	2.0%	0	N
Radio Telephone (transmit)	1	12	DC	N	20	1.0	7	20.0	0.3%	0	N
Phone Answering Machine	1	117	AC	Y	6	24.0	7	144.0	2.0%	0	N
Washing Machine	1	117	AC	N	800	0.5	4	228.6	3.1%	100	Y
Ph/L-Washer Timer	1	117	AC	Y	8	23.7	1	27.1	0.4%	0	
Clothes Dryer (motor only)	1	117	AC	N	500	1.0	4	285.7	3.9%	1500	Y
Ph/L-Dryer Timer	1	117	AC	Y	8	23.4	7	187.4	2.5%	0	
Sewing Machine	1	117	AC	N	80	2.0	1	22.9	0.3%	400	N
Vacuum Cleaner	1	117	AC	N	650	0.5	4	185.7	2.5%	1950	N
Hair Dryer	1	117	AC	N	1000	0.2	7	200.0	2.7%	1500	N
Ni-Cd Battery Charger	1	117	AC	Y	4	15.0	2	17.1	0.2%	25	Y
Ph/L-Batt Charger	1	117	AC	Y	2	19.7	7	39.4	0.5%	0	
Total Daily Average Watt-hrs								**7376.8**			

Inverter Priority Wattage 599 — Max ac Wattage 1350 — Max. ac Surge Wattage 2250

Home 2 (efficient)

Appliance	Qty.	Volts	AC DC	P Y/N	Run Watts	Hours /Day	Days /Week	W-hours /Day	Percent of Total	Surge Watts	Ph-L Y/N
Fluorescent Lights	4	117	AC	Y	15	5.0	7	300.0	7.7%	0	N
Fridge Sun Frost 16 cu. ft.	1	12	DC	N	48	11.3	7	540.0	13.9%	1300	N
Blender	1	117	DC	N	350	0.1	2	10.0	0.3%	1050	N
Microwave Oven	1	117	AC	N	900	0.3	7	225.0	5.8%	1200	Y
Food Processor	1	117	AC	N	400	0.1	5	28.6	0.7%	1200	N
Espresso Maker	1	117	AC	N	1350	0.1	7	135.0	3.5%	1350	N
Coffee Grinder	1	117	AC	N	150	0.1	7	7.5	0.2%	200	N
21" Color Television	1	117	AC	Y	125	5.0	7	625.0	16.0%	570	Y
Video Cassette Recorder	1	117	AC	Y	40	2.5	7	100.0	2.6%	80	Y
Satellite TV System	1	117	AC	Y	60	2.5	7	150.0	3.8%	1600	Y
Stereo System	1	117	AC	Y	30	8.0	7	240.0	6.2%	60	Y
Computer	1	117	AC	Y	45	6.0	3	115.7	3.0%	135	Y
Computer Printer	1	117	AC	N	120	0.3	3	12.9	0.3%	360	Y
Power Tool	1	117	AC	N	750	0.5	3	160.7	4.1%	2250	N
Radio Telephone (receive)	1	12	DC	N	6	24.0	7	144.0	3.7%	0	N
Radio Telephone (transmit)	1	12	DC	N	20	1.0	7	20.0	0.5%	0	N
Phone Answering Machine	1	117	AC	Y	6	24.0	7	144.0	3.7%	0	N
Washing Machine	1	117	AC	N	800	0.5	4	228.6	5.9%	100	Y
Clothes Dryer (motor only)	1	117	AC	N	500	1.0	4	285.7	7.3%	1500	Y
Sewing Machine	1	117	AC	N	80	2.0	1	22.9	0.6%	400	N
Vacuum Cleaner	1	117	AC	N	650	0.5	4	185.7	4.8%	1950	N
Hair Dryer	1	117	AC	N	1000	0.2	7	200.0	5.1%	1500	N
Ni-Cd Battery Charger	1	117	AC	Y	4	15.0	2	17.1	0.4%	25	Y
Total Daily Average Watt-hrs								**3898.4**			

Inverter Priority Wattage 325 — Max. ac Wattage 1350 — Max. ac Surge Wattage 2250 volts worth of inverters or do you run your single 220 vac load on your generator? Do you want an inverter that can run your ac well pump at the same time as the washing machine? What happens when someone turns the microwave oven on too? If you run the fridge and the well pump on DC, can you get away with a smaller inverter? These kinds of questions will come up during system design. Being able to refer back to a complete and detailed load profile will help with the answers.

Access:

Ben Root is still trying to remember to turn off his stereo at night while writing and doing graphics for *Home Power* at Agate Flat.

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