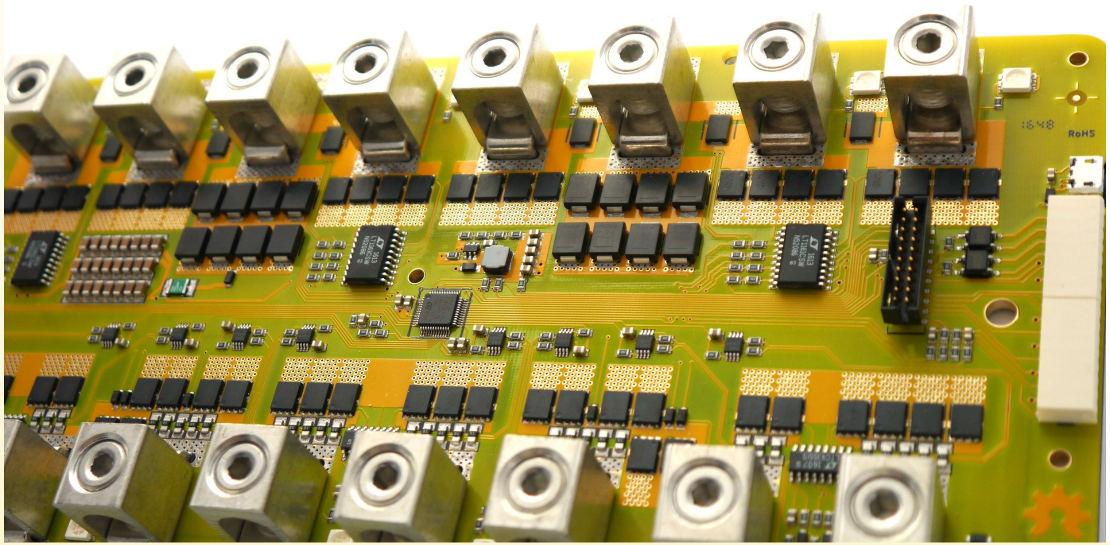
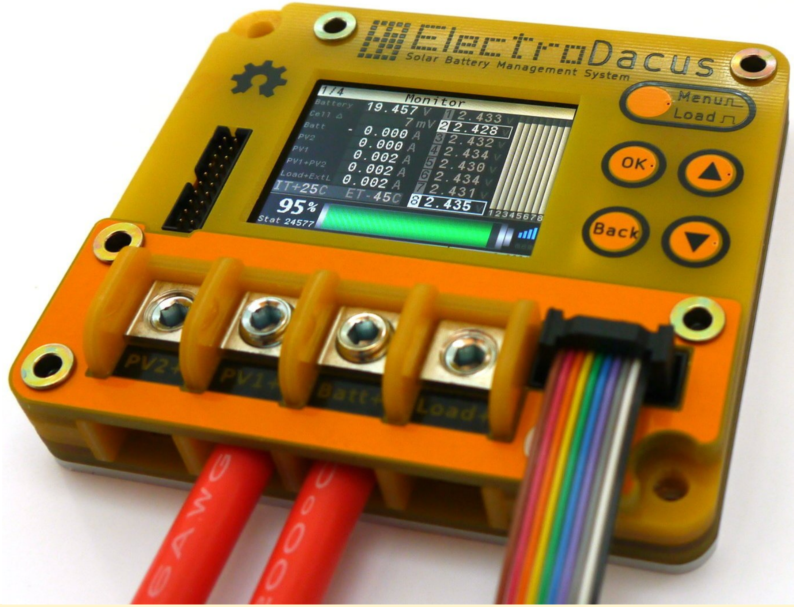
Off-grid Net Zero house energy solution with Digital MPPT thermal controller + SBMS

v0.1

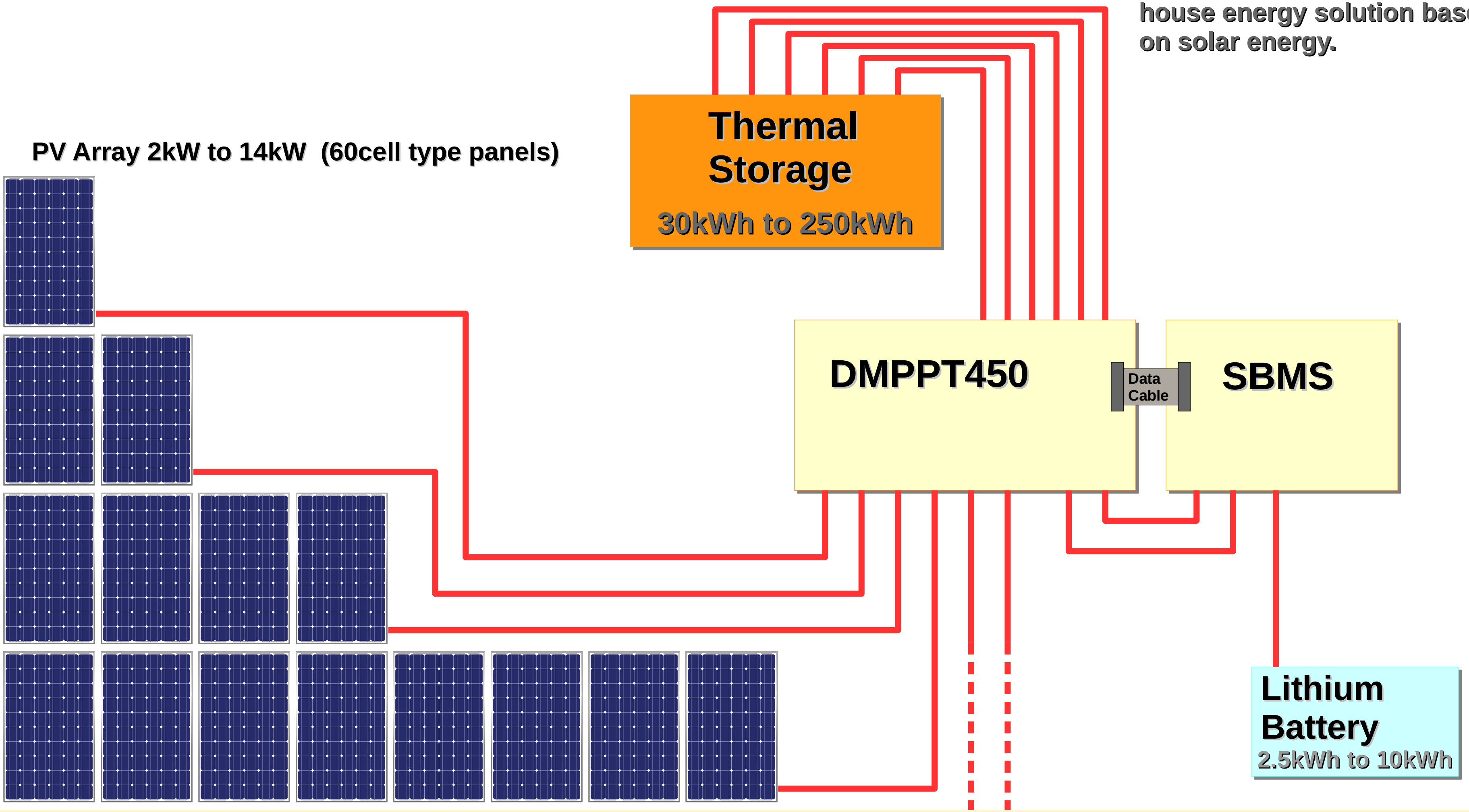
DMPPT450 prototype board



SBMS100

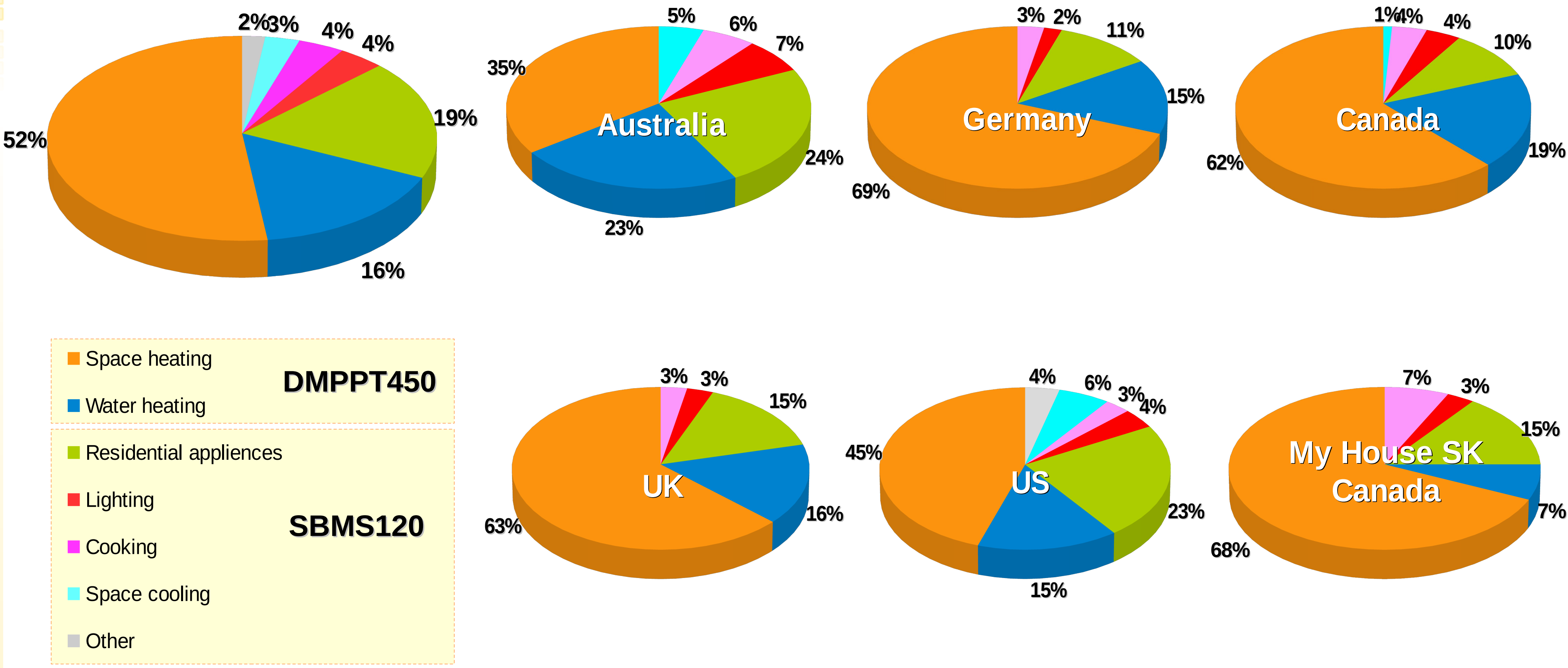


Simplified Diagram of a complete house energy solution based just on solar energy.



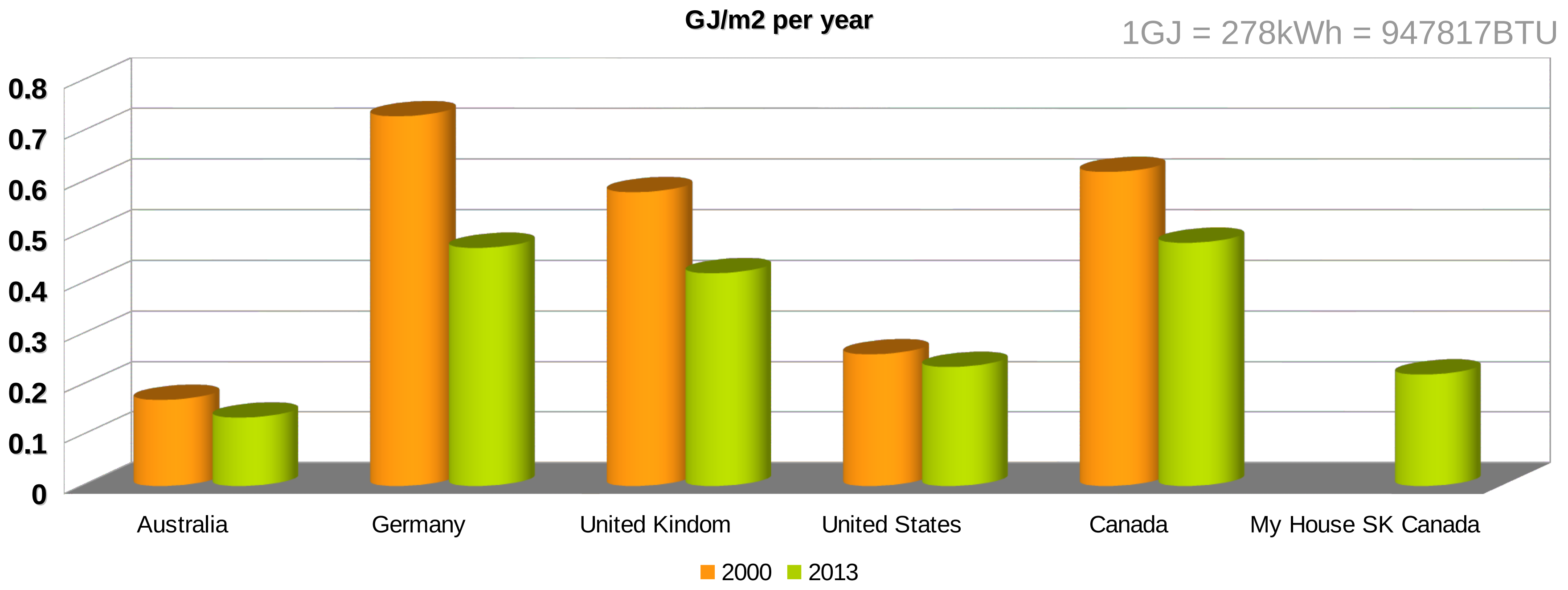
Residential energy use IEA countries

(International Energy Agency)



Graph's are based on data from the IEA Energy efficiency indicators see: http://www.iea.org/publications/freepublications/publication/EnergyEfficiencyIndicatorsHighlights_2016.pdf

Energy Intensities by end-use per floor area per year



Graph is based on data from the IEA Energy efficiency indicators paper see http://www.iea.org/publications/freepublications/publication/EnergyEfficiencyIndicatorsHighlights_2016.pdf
The data represents the amount of energy consumption per floor area and as expected warmer countries show in general a lower energy needed since less energy is needed to keep the temperature inside residential buildings at comfort level.
An average of all residential building was used that includes everything from a small detached house as mine to large apartment buildings and larger buildings can be more efficient since the floor area is larger as ratio to outside exposed area.
My house located in southern Saskatchewan Canada is a small 65sqm (~700sqft) single story house that is at least 3x better insulated than a typical new house build here and this together with the fact that the house is also 3x smaller will than average house will make the house require about 9 to 10x less energy than an average house at this location. You need to keep this in mind when you look at the heating energy requirement example provided here for my house.

www.ElectroDacus.com

Heating options comparison sized for my house needs

	PV solar heating with DMPPT450	Thermal Solar	Natural gas
Energy source	39 x 260W PV panels 0.8USD / Watt for panels + 0.15USD cables and connectors 0.95USD/Watt used for calculation	6x SunRain TZ-58 1800 30R Solar Hot Water Retrofit Kit - 2 Collector x 3 {see Link2 and Link3}	5000kWh/year * 25years (1m3 = 10kWh) 90% * (0.01052+0.00632) = 0.01684 / 0.9 = 0.0187 USD/kWh + 17.03/month (I used current price 2.77 USD/GJ (0.0187USD/kWh) price was 6.46 USD/GJ (0.0426USD/kWh) in 2008) {see Link1}
Total rated power [Watt]	10140	13200	Basic Monthly Charge ($/month) \| Delivery Charge ($/m3) | Commodity Rate
Energy production in Canada Calgary or Regina [kWh / year]	14747	13002	17.03 | 0.0632 | $0.1052/m3 $2.77/GJ
Collector total surface area [m^2]	63.96	31.44	
Cost total for energy source [USD]	**9633**	**11516**	**7447**
Heating device or furnace cost [USD]	445	0	2000
Heating device electricity usage pumps/fans cost [USD] (2kWh/day (6 month heating) for 25 years at 25cent/kWh)	0	2281	2281
Thermal mass storage for solar options min 150kWh [USD]	2000	2000	0
Heat exchanger	0	0	215
Heating radiator / in floor cable or pipe [USD]	460	625	625
Circulation pumps for in floor heating [USD]	0	360	360
Accessories fuse / pipe fittings ... [USD]	300	300	300
Solar cover for thermal solar collector {see Link4}	0	1752	0
Total system cost [USD]	**12838**	**18834**	**13228**
Advantages:	The most cost effective heating solution in most cases. Most reliable since there are no moving parts just electricity and wires. In combination with offgrid electricity can save money by reducing the battery capacity. (up to $4000 savings over the life of the system because of reduced battery capacity needed). Huge unused electrical energy available in summer months that can be used for something. No need for an electrical connection can work completely independent. Will not need any maintenance over system life time. Can most probably work for much more than 25 years used in this example.	Takes ~2x less area compared to PV solar panels.	Requires the lowest initial investment if house already has a natural gas connection. No need for thermal mass storage since gas is always available.
Disadvantages:	PV panels take ~2x more area when compared with thermal solar. Needs thermal mass for energy storage.	More expensive. Unreliable compared to PV solar. Need to cover the unneeded panels in the warmer months. Needs an electrical connection to work. Needs thermal mass for energy storage. Possibly needs repair and maintenance cost.	The most expensive if is a new house or old without natural line gas connection. Price of natural gas can fluctuate over time. (using the cost of natural gas from 2008 will make this much more expensive). Less reliable than PV solar. Needs an electrical connection to work. Will possibly need repair and maintenance so additional expense.

* System sized for my small house 65sqm(~700sqft) that is in a cold but relatively sunny climate (Regina Saskatchewan Canada). Solar data for PV are from PVWatts online calculator and for thermal solar are based on last table on Link3 both are for Calgary that has identical temperature and solar radiation as Regina.

** DMPPT450 + SBMS120 can offer a complete house energy solution for a net zero energy house.

Link1: http://www.saskenergy.com/residential/resrates_curr.asp

Link2: https://nlsolarheating.solartubs.com/solar-hot-water-retrofit-kit-2-collector-p-246.html

Link3: http://www.solartubs.com/solar-evacuated-tube.html

Link4: https://nlsolarheating.solartubs.com/solar-cover-for-30-tube-vacuum-solar-collectors-p-13.html

PVWatts results for my location.

Below are the results of the PVWatts calculator for a 10kW PV array at my location. All settings are default except for the DC System size 10kW and the array tilt that is set at 60° in order to get the best output in winter when is mostly needed in my case.
My location is fairly decent for solar (not the best but also not the worst) and excellent for solar energy. Also based on the same data available here (you can download a csv file with daily solar data) I build a graph that you can see on the next page.

Solar data are from PVWatts online calculator.

PVWatts® Calculator

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

My Location | regina sask | » Change Location | HELP | FEEDBACK | ALL NREL SOLAR TOOLS

RESOURCE DATA | SYSTEM INFO | RESULTS

Go to system info

RESULTS

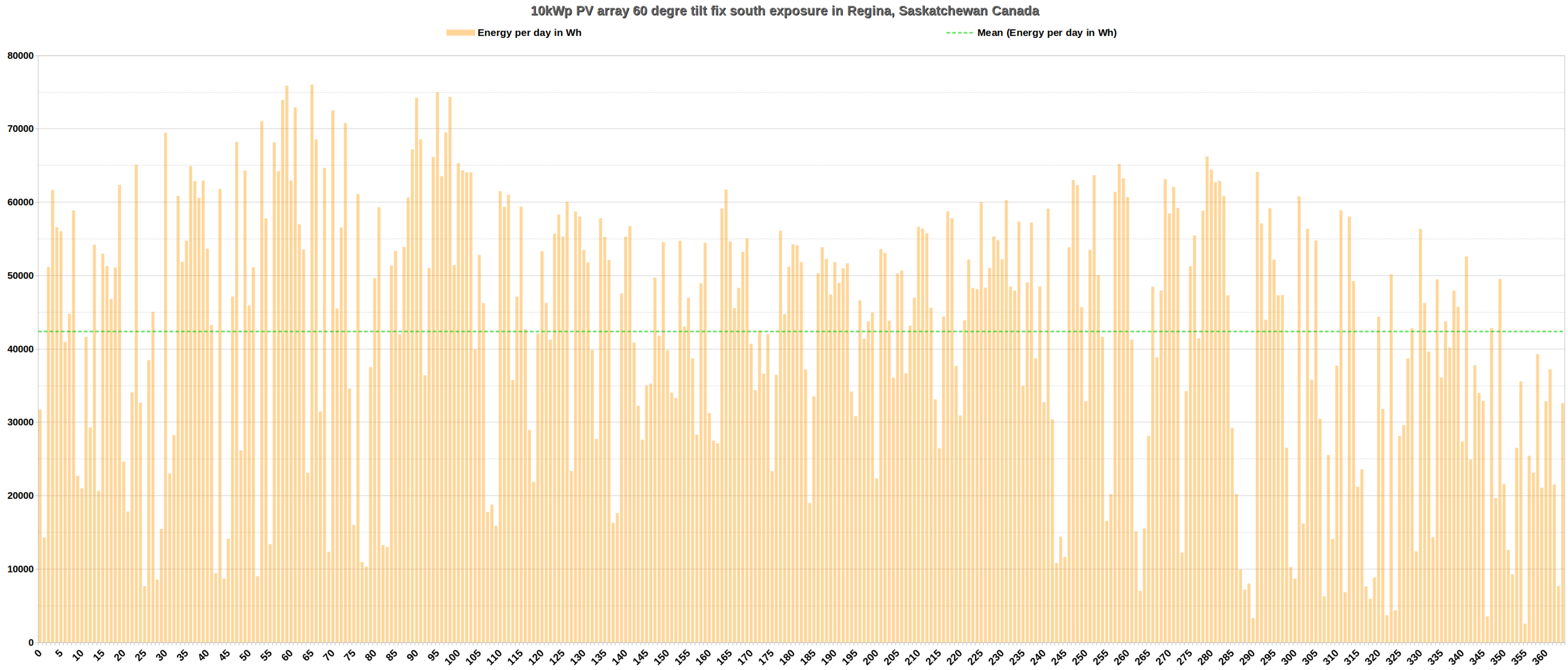
Print Results

14,747 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	4.13	1,165	N/A
February	5.07	1,251	N/A
March	5.18	1,399	N/A
April	5.94	1,464	N/A
May	5.40	1,334	N/A
June	5.33	1,247	N/A
July	5.67	1,329	N/A
August	5.89	1,404	N/A
September	5.17	1,219	N/A
October	4.63	1,191	N/A
November	3.23	848	N/A
December	3.22	896	N/A
Annual	4.91	14,747	0

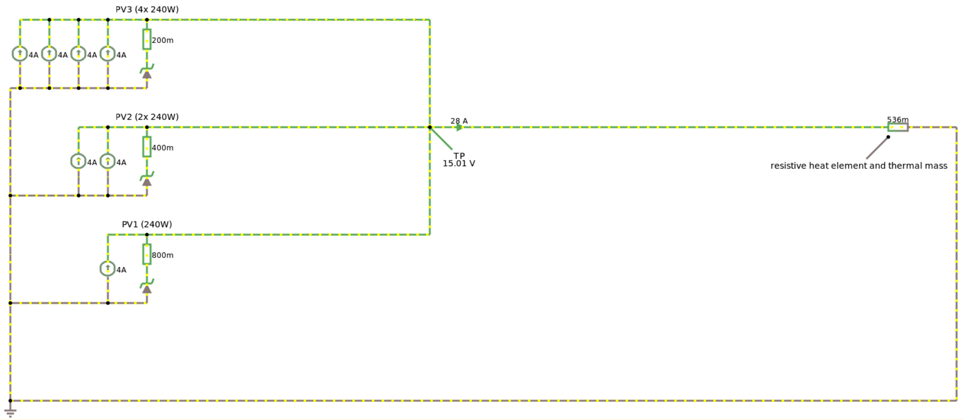
Location and Station Identification	
Requested Location	regina sask
Weather Data Source	(INTL) REGINA, SASKATCHEWAN 2.5 mi
Latitude	50.43° N
Longitude	104.67° W
PV System Specifications *(Residential)*	
DC System Size	10 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	60°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1
Economics	
Average Cost of Electricity Purchased from Utility	No utility data available
Performance Metrics	
Capacity Factor	16.8%

Solar data are from PVWatts online calculator.



DMPPT advantage over a fixed value resistive heat element.

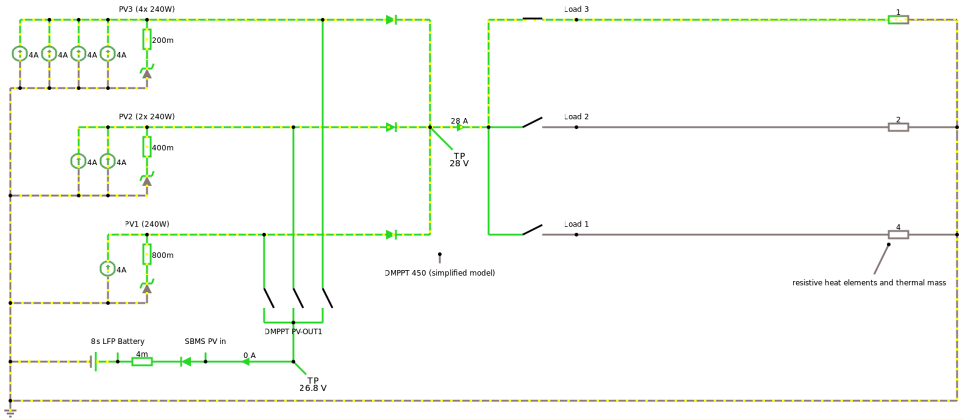
Below you see a simple example with fixed resistive heat element on the left and a simplified 3 output DMPPT that should explain the large advantage gained with an DMPPT.
There is an array made out of 7 large 240W PV panels with STC spec of 30V max power point voltage and 8A max power point current that receive about half of the STC power from the sun in this test and so the max power point current will be about half at 4A from each panel.
The fixed 536mOhm resistor is selected to give overall the best result so is calculated for full STC power 30V / (7 x 8A) = 0.5357Ohm and as you can see when solar output is at half the STC (that can be because of clouds or because sun is at an angle on the panels maybe earlier in the morning or later in the afternoon) the efficiency is quite low at 50% and will continue to drop as the amount of sun drops.
With the DMPPT example in order to keep things as simple as possible only 3 outputs are used *(instead of 6 outputs on the real DMPPT450) and the 3 restive heat elements are selected so that when all in parallel the value will be very close to the value of the single resistor 0.536Ohm but in order to keep things simple rounder numbers where selected as seen 1,2 and 4 Ohm.
As you see significantly higher efficiency is achieved even with this simplified 3 output DMPPT.
If you want to play with the different combination and better understand how DMPPT works you can download this simplified 3 output DMPPT simulation circuit on your drive here http://electrodacus.com/DMPPT450/DMPPT450.txt and then open that file in this free to use online simulation tool http://www.falstad.com/circuit/circuitjs.html
For typical efficiency of the DMPPT450 in a typical sunny and cloudy day as compared to fixed resistive heat element see the graph in next page.



PV MPPT 4A x 7 x 30V = 840W
Load 28A x 15.01V = 420W

Efficiency = 50%

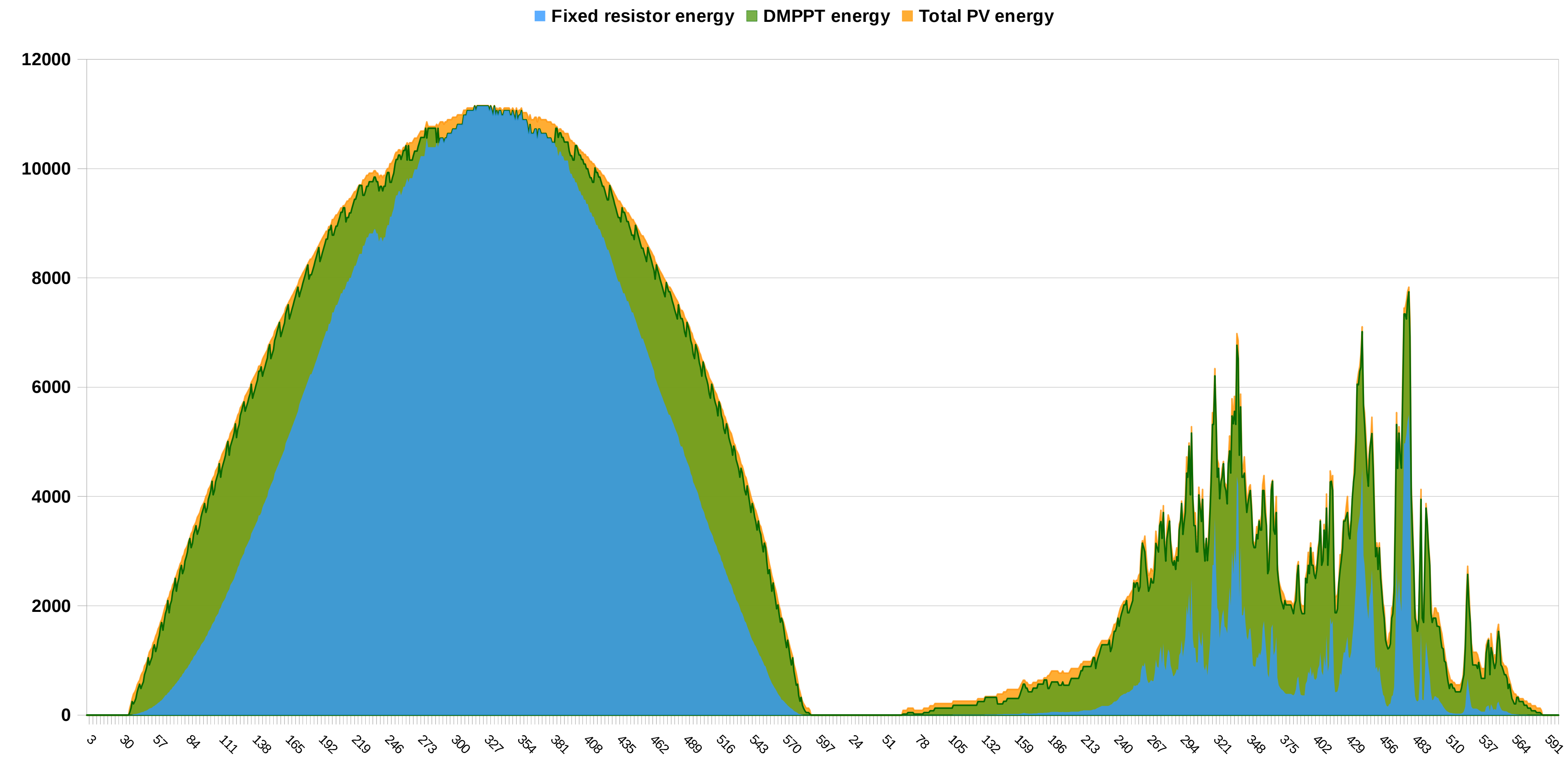
1/2 solar power with fixed resistor



PV MPPT 4A x 7 x 30V = 840W
Load 28A x 28V = 784W

Efficiency = 93%

1/2 solar power with *DMPPT

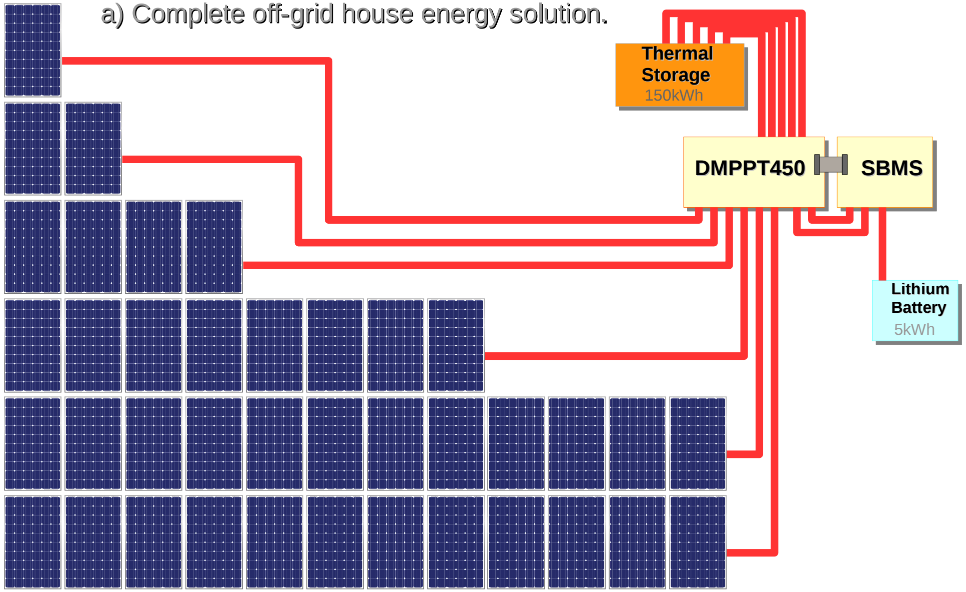


	PV Energy Wh	Energy fix resistor Wh	Efficiency fix resistor	Energy DMPPT Wh	Efficiency DMPPT
Day 1 sunny	68658	54909	80.0%	67151	97.8%
Day 2 cloudy	18119	5764	31.8%	16934	93.5%

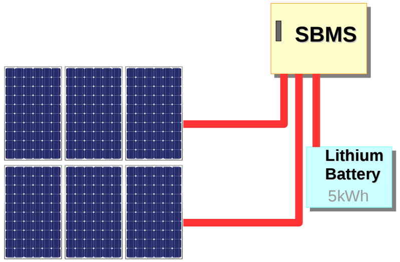
DMPPT advantage when both heating and off-grid electricity is needed.

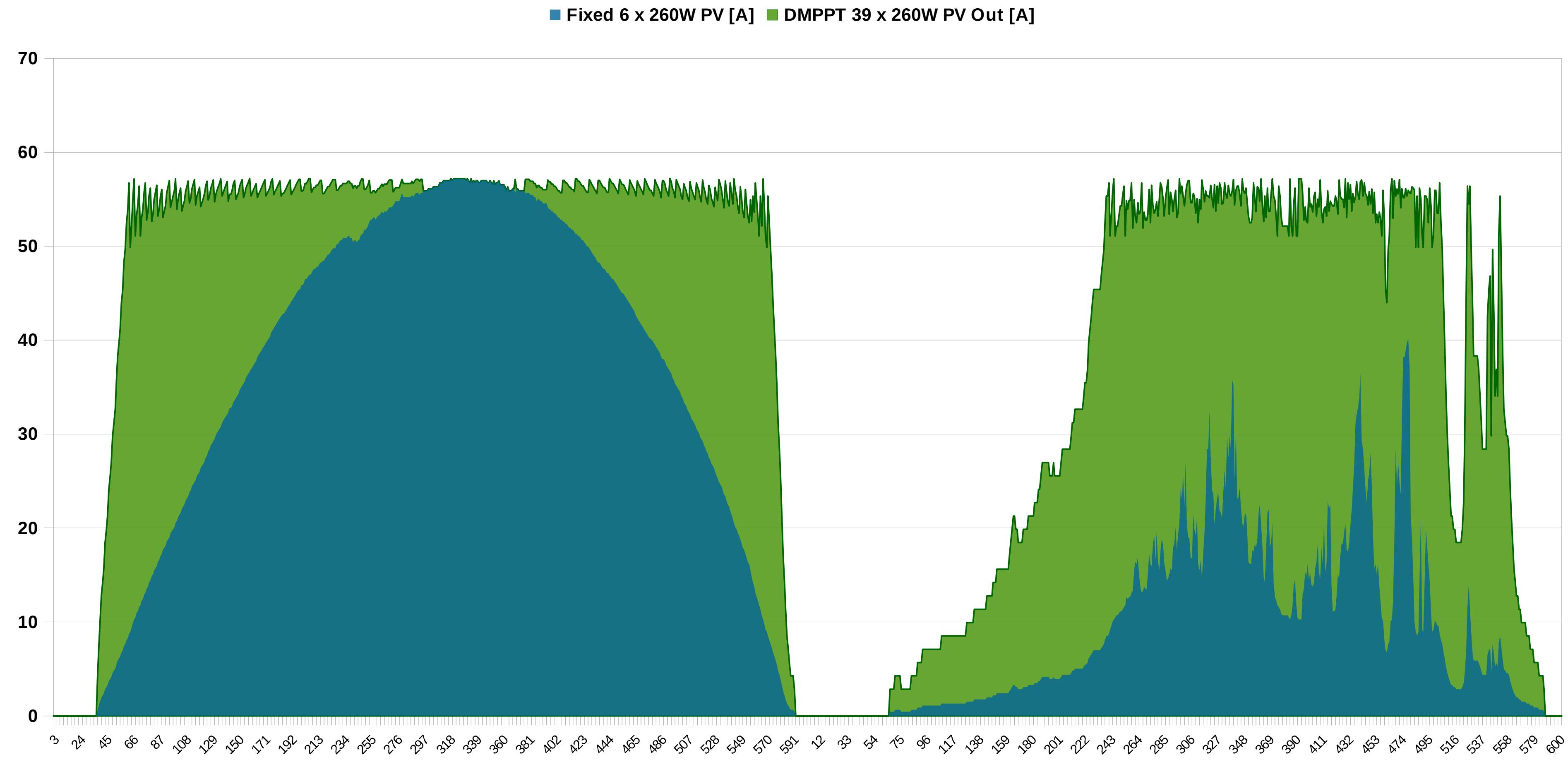
Below you can see a) 39x 260W PV panel array exactly as I will be using for my off-grid house. Lithium battery has priority for charging and as many as needed from the 39 panels will be redirected to battery charging and all the energy not needed for electrical appliances and battery charging will be stored in the much larger and less expensive thermal mass.
The 5kWh LiFePO4 battery will cost around $2000 (at the current price of $400/kWh) and in real use case scenario that will have a cost amortization over the life of the battery of about 25 cent/kWh while the much larger 150kWh thermal mass will cost around or even less than $2000 (so less than $14/kWh) and if just 25 years life is considered the cost amortization will be well below 0.5cent/kWh so extremely low compared to electricity storage in Lithium battery and ideal for heating and or cooling (cooling is more complex will need the use of custom build peltier cooling devices).
Solar PV panels have a cost amortization of 2.4cent/kWh (based on acquisition cost of 80cent/Watt, 25 years amortization period and amount of sun at my location).
So based on this thermal mass storage is the most cost effective 0.5cent/kWh so the use of that needs to be maximized next is solar PV solar at about 2.4cent/kWh and last as the most expensive in therms of cost amortization is Lithium battery storage so that needs to be kept as small as possible (but all 3 are needed for a cost effective complete energy solution).
Having the large PV array for heating will allow much more electricity use with the same battery size compared to just b) simple PV array and Lithium battery as seen in the graph on the next page.
In winter with solution b) at my location you can expect to use around 100kWh/month while with a) 200kW/h are possible for electric appliances all the rest will be used for heating.
So if you want 200kWh with solution b) at my location in winter then PV array will need to be double 12x 260W panels and battery will also need to be increased to 10kWh.

a) Complete off-grid house energy solution.



b) Off-grid electricity only.





	DMPPT 39 x 260W PV Out [Ah]	Fixed 6 x 260W PV [Ah]	DMPPT gain vs Fixed PV
Day 1 sunny	**496**	**352**	**41%**

	DMPPT 39 x 260W PV Out [Ah]	Fixed 6 x 260W PV [Ah]	DMPPT gain vs Fixed PV
Day 2 cloudy	**330**	**93**	**255%**

Thermal storage solutions.

Thermal storage is an important part of the solar PV heating solution but the thermal storage can be done in many different ways and using different storage materials so below I will give a few example so that you can make your calculations based on your own needs.

Almost any solid or liquid can be used for thermal storage but the most common is water and concrete or sand/stone.

a) Water can usually be considered free so the cost in this case is related to storage and I selected in this example a very common 206 Litres (55 Gallon) HDPE barrel than can be had new for about 60 USD or used/recycled for much less.

The water has the highest heat capacity of any liquid and is 4185.5 J/(kg·K) where 1 Joule is actually 1Watt-second to transform this in Watt-hour you just need to divide this by 3600 the number of seconds in one hour. So heat capacity of water is about 1.16Wh/(kg·K) and since water density is about 1 then 1kg of water is the same as 1 litre of water and a delta of 1 Kelvin is the same as a delta of 1 Celsius the calculation of amount of energy stored in that barrel of water is quite simple.

Say that usable temperature range in that HDPE barrel is 20°C to 55°C so usable temperature delta is 55°C-20°C = 35°C then

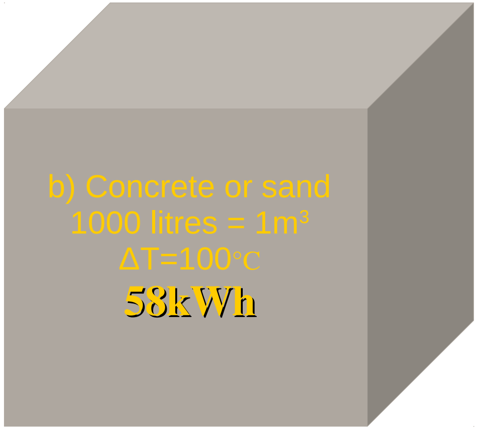
206 litre * 35°C * 1.16Wh/(litre·°C) = 8363.6Wh = 8.364 kWh this is a large storage capacity for a small cost and almost infinite cycle life so I hope this shows why thermal storage is so important in a solar setup.

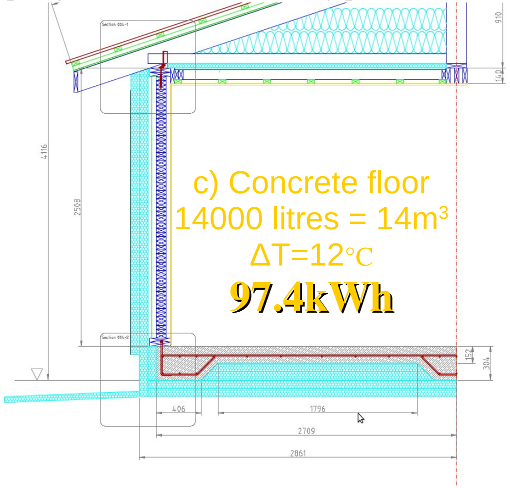
b) Second example is based on a generic 1 cubic meter of concrete or sand (they will have about the same storage capacity) 880 J/(kg·K) this looks bad compared to water by weight but since the concrete has higher density 2400kg/cubic meter things are not as bad by volume about half compared to water at 0.58Wh/(litre·°C) (one cubic meter = 1000 litres)

The amount of energy you can store in that cubic meter of concrete depends how large is the usable temperature delta.

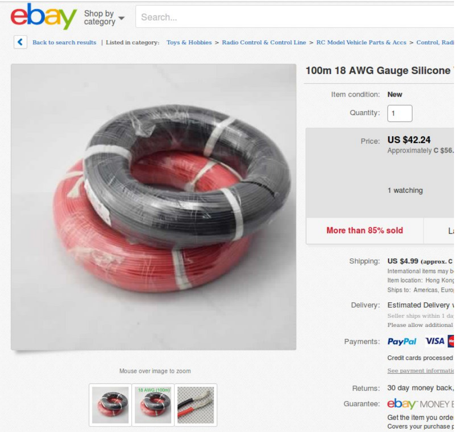
If the concrete is actually a floor used for storage as in my house then max delta is probably just 10 to 12°C but if this is a cube maybe thermally insulated and used in a separate space then you can have maybe a temp delta as high as 80 to 100°C or even higher then 1000 litres * 100°C * 0.58Wh/(litre·°C) = 58kWh

c) My house already integrates a 14 cubic meter concrete floor so 14000 litres * 12°C * 0.58Wh/(litre·°C) = 97.4kWh of storage capacity at no cost since is already part of the house structure.



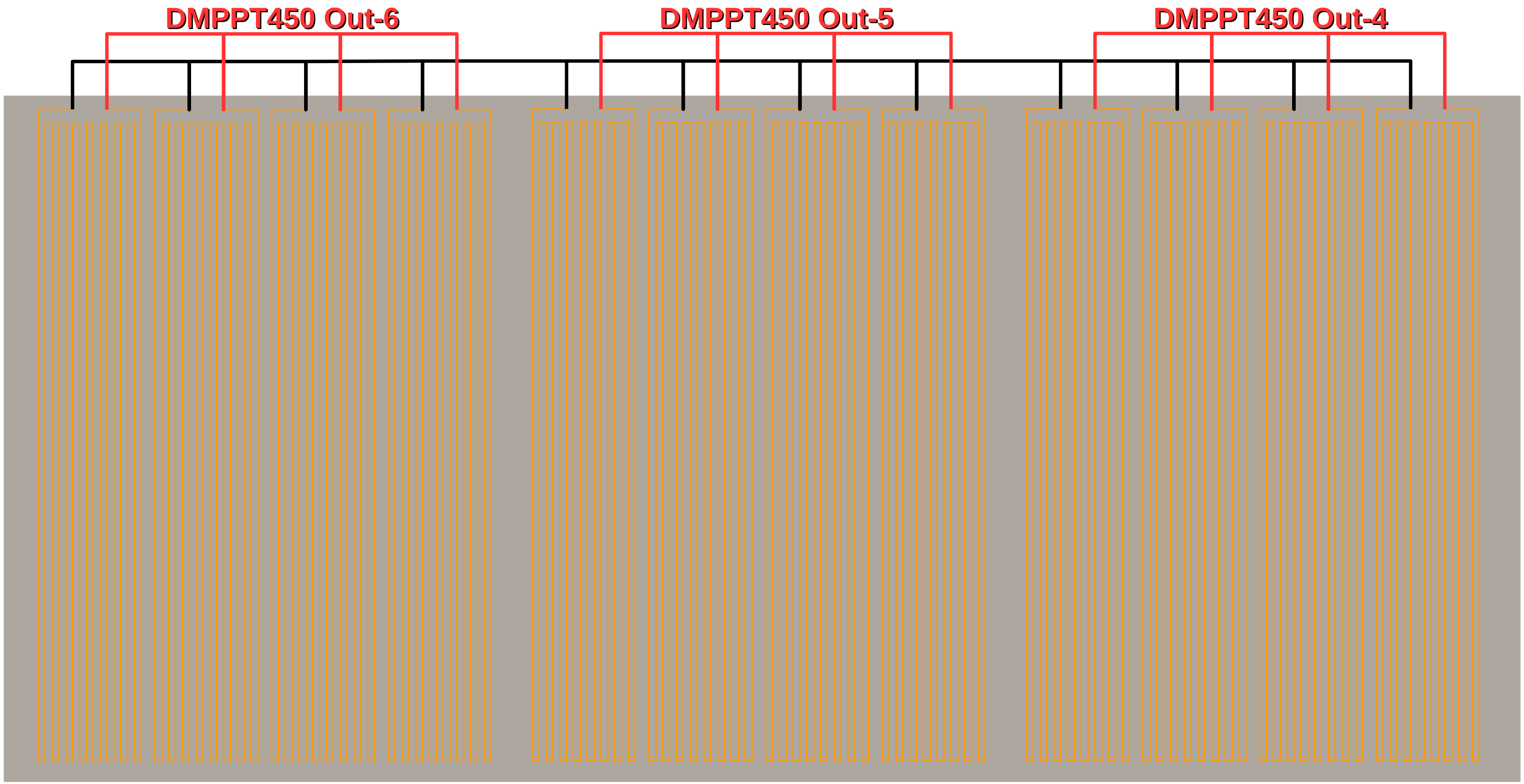


So you may be asking how do you transfer the energy to thermal mass and ansewer is simple if all you want is heating (yes cooling possible with peltier modules but more complex and maybe I will get in to more details about that in another paper).
Simplest will be the case c) where thermal mass in the house concrete floor thermally insulated from the outside as it is done on my house since then all an be solid state and not much else is needed other than some simple copper wires acting as restive heat elements embedded in the concrete floor.
The entire floor in my case will be covered with ceramic tiles (it is not as of the time I write this) and the copper cable for heating will be embedded under the ceramic tiles.
Probably almost any type of copper cable will work but my recommendation will be using one of the following 150°C to 200°C silicone isolated cables, enamelled copper wire or Teflon isolated copper wires.
Personally I will be using 200°C rated silicone insulated cables since they are easily available and relatively inexpensive. The cable thickness can be somewhere in the range of $0.3mm^2$ to $0.8mm^2$ (#22 AWG to #18 AWG) since that will give the best length vs resistance at around 30V DC max power point of 60 cell PV panels and at a good cost.
I already got #18 AWG 200°C cable since I got a good deal and I will be using that for my house and in this example.
This #18 AWG 200C cable is rated for a max of 24A in free air and while this will be embedded in concrete where thermal conduction will be much better I do not want to exceed that so since max power point voltage is around 30V the worst case in winter may be higher 33 to 36V possible and the cable resistance is about 21mOhm/m for this cable.
36V/24A = 1.5Ohm so cable will need to be 1.5Ohm/0.021Ohm/m = 71.4m.
At this worse case scenario 36V x 24A = 864Watt I have about 12W/m of cable but more realistic or typical will be about 32 to 33V max power point in a cold winter day for current generation 60 cell PV panels so 33V/1.5Ohm = 22A and 33V x 22A = 726W so about 10W/m of cable.
For the concrete floor I will be using a total of 12 of this 71.4m loops 726W x 12 = 8712W and since my usable floor space inside the house is around $57m^2$ then I will have about $8712/57m^2 = 153W/m^2$
From this ($153W/m^2$ and 10W/m) I can calculate what will be the spacing needed for this cable 1/(153/10) = 0.065m so the distance between two wires will need to be around 6.5cm.
But if the math above is confusing (for sure my fault) no worries since I will provide a tool to simply calculate all this based on your requirements.
Total length for this heating cable will be 12 x 71.4m = 856.8m (rounded to 900m) and total cost will be around 425USD including shipping as you can see in the below eBay screenshot. I think the price is very reasonable so it makes no sense to try and save something here (this should last the life of the house).



Thermal storage example for my house simplified diagram.

As mentioned in the anterior page there will be 12 resistive heat loops and they are grouped in 3 zone each with 4 parallel groups and each of this 3 groups is connected to one of the DMPPT450 output. The other 3 outputs of the DMPPT450 will be connected to another smaller thermal storage for domestic hot water and to preheat the air getting out of the air heat recovery unit. Those other 3 outputs together will have a lower power than one of this single 3 outputs used for the floor heating/floor thermal mass storage.



In order to maximize the usage of the DMPPT450 the total heat power that is desired will need to be split between the 6 outputs in the following way.
Say you want a 11.25kW output and you have you panels with a 33V max power point in your average winter temperature so about 341A max current.
The way you will want the outputs setup will be as the last 3 outputs (Out-6,Out-5 and Out-4) all equal say with x then the other 3 outputs (Out-3,Out-2 and Out-1) will be 1/2x , 1/4x and 1/8x respectively in order to maximize the max power point.
So total of all outputs will be 3x + 1/2x + 1/4x + 1/8x = 3.875x and then x = 341A / 3.875 = 88A. Then first 3 resistive elements will have 33V/88A = 0.375Ohm and you seen in my example that is made of groups of 4 resistive loops each 1.5Ohm in parallel so 1.5Ohm/4 = 0.375Ohm and all this are embedded under ceramic tiles on the large floor thermal storage made of concrete and with a capacity of 97.4kWh.
The next 3 outputs will have 0.75Ohm (so can be made of two of those 1.5Ohm loops in parallel) next will be 1.5Ohm and last will be 3Ohm
This setup will allow for 31 power steps (32 if you include zero) and you can see below how with just 6 outputs you get 31 levels (the SW engineers will get this relay easy) and understand why this is called a Digital MPPT.
As you can see in the graph at page 10 this 31 levels are more than sufficient since up to around 98% efficiency can be obtained and increasing the number of steps will only increase HW complexity with very little gain so this in my opinion is the optimum level.
As SW people will notice the number of steps can be increased to 63 since there are 6 outputs so number of combination is 2^6 = 64 but then the max output power will need to be lower since each output is capable of max 100A and if you want 63 levels for slightly more efficiency 99% instead of 98% then max total output power will be limited to 196.875A x 33V =6496W compared to recommended 31 levels and 3 equal outputs where max is 387.5A x 33V = 12787W.

	Resistive heat elements [Ohm]		Resistance level Ohm	Current level [A]
1	0.375	1	0.097	341.00
1	0.375	2	0.100	330.00
1	0.375	3	0.103	319.00
1	0.75	4	0.107	308.00
1	1.5	5	0.111	297.00
1	3	6	0.115	286.00
		7	0.120	275.00
		8	0.125	264.00
Total resistance	0.096774	9	0.130	253.00
		10	0.136	242.00
		11	0.143	231.00
		12	0.150	220.00
		13	0.158	209.00
		14	0.167	198.00
		15	0.176	187.00
		16	0.188	176.00
		17	0.200	165.00
		18	0.214	154.00
		19	0.231	143.00
		20	0.250	132.00
		21	0.273	121.00
		22	0.300	110.00
		23	0.333	99.00
		24	0.375	88.00
		25	0.429	77.00
		26	0.500	66.00
		27	0.600	55.00
		28	0.750	44.00
		29	1.000	33.00
		30	1.500	22.00
		31	3.000	11.00
mppv [V]	33			

Summary.

Hope this document was able to explain what DMPPT450 is all about and how this together with the SBMS can be a complete house energy solution.
I'm extremely enthusiastic about the Digital MPPT thermal controller and if this is not a success has only to do with my inability to explain it's functionality :)
Follow the progress on my google+ https://plus.google.com/+electrodacus where you can also post questions or contact me directly electrodacus@gmail.com