Lecture 3:
Off-grid solar systems

the sustainability society

a technical interest group of

engineering new zealand

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Chair in Sustainable Energy Systems

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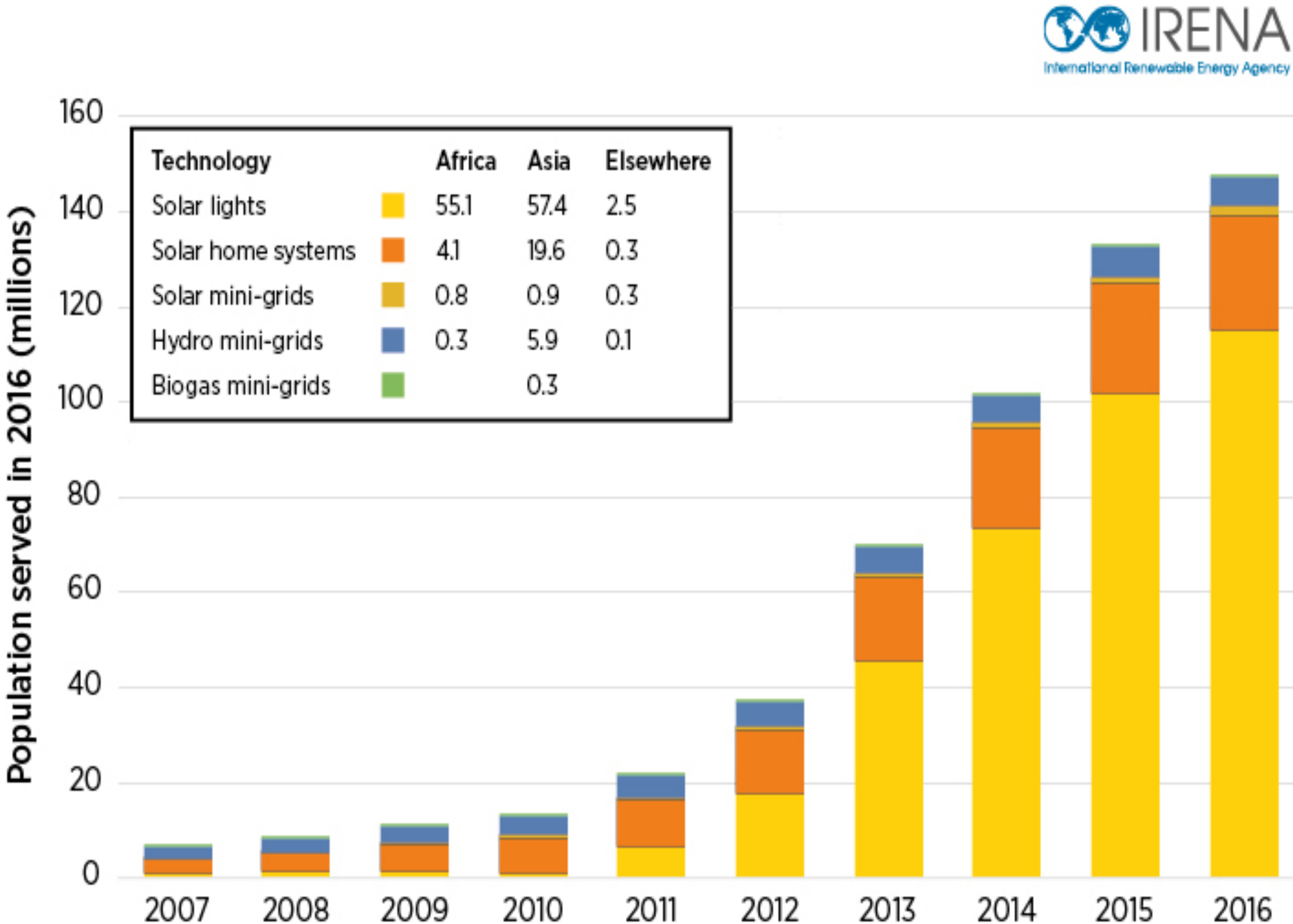
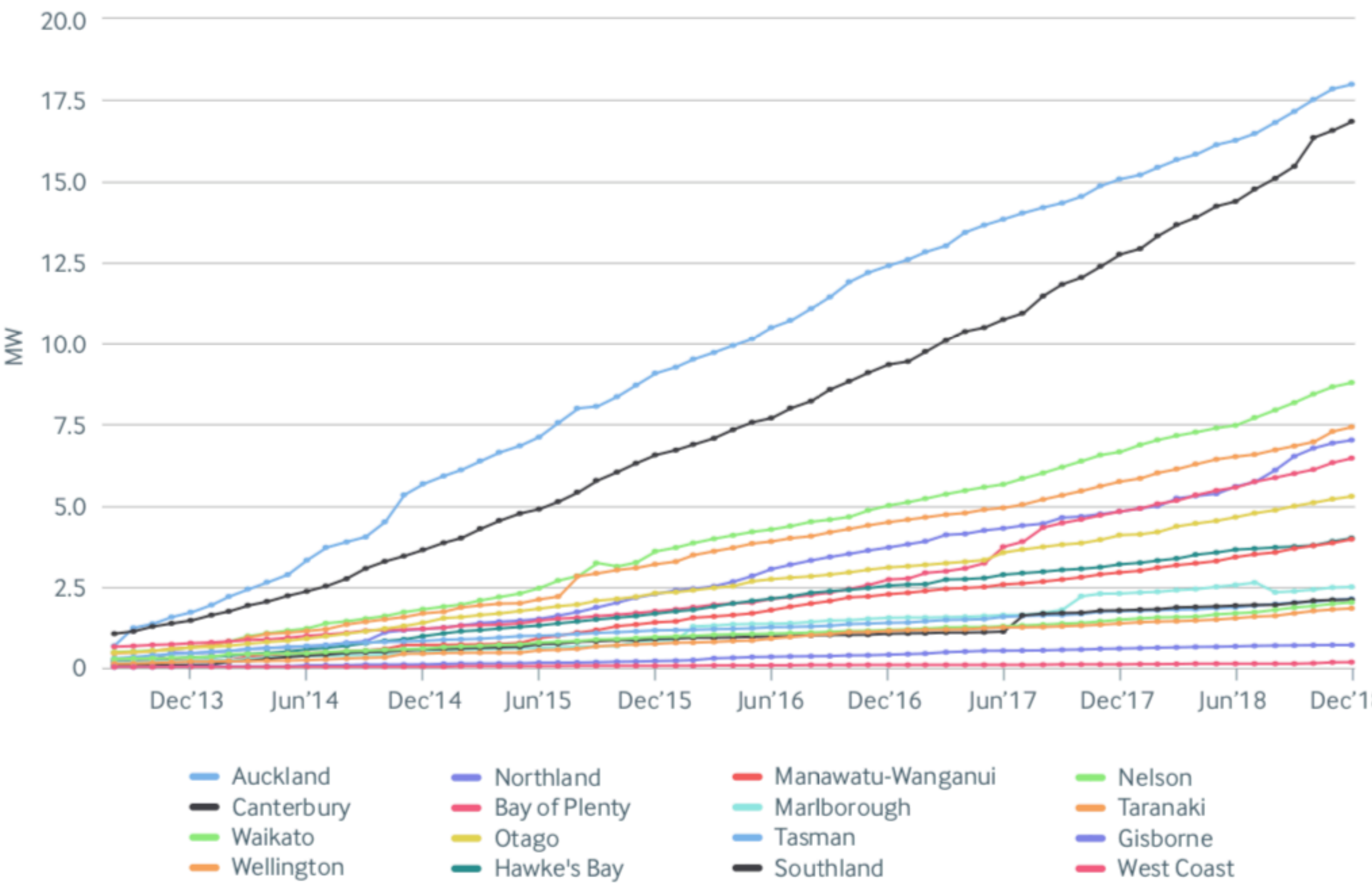
KAITIAKITANGA WHAKAPAPA MAURI

Capital thinking.
Globally minded.


IRENA
International Renewable Energy Agency
Population served in 2016 (millions)
160
140
120
100
80
60
40
20
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Technology
Africa
Asia
Elsewhere
Solar lights 55.1 57.4 2.5
Solar home systems 4.1 19.6 0.3
Solar mini-grids 0.8 0.9 0.3
Hydro mini-grids 0.3 5.9 0.1
Biogas mini-grids 0.3


TRANSPOWER
The sun rises on a solar energy future
January 2019
Te Mauri Hiko
Energy Futures


20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0
MW
Dec'13
Jun'14
Dec'14
Jun'15
Dec'15
Jun'16
Dec'16
Jun'17
Dec'17
Jun'18
Dec'18
Auckland
Canterbury
Waikato
Wellington
Northland
Bay of Plenty
Otago
Hawke's Bay
Manawatu-Wanganui
Marlborough
Tasman
Southland
Nelson
Taranaki
Gisborne
West Coast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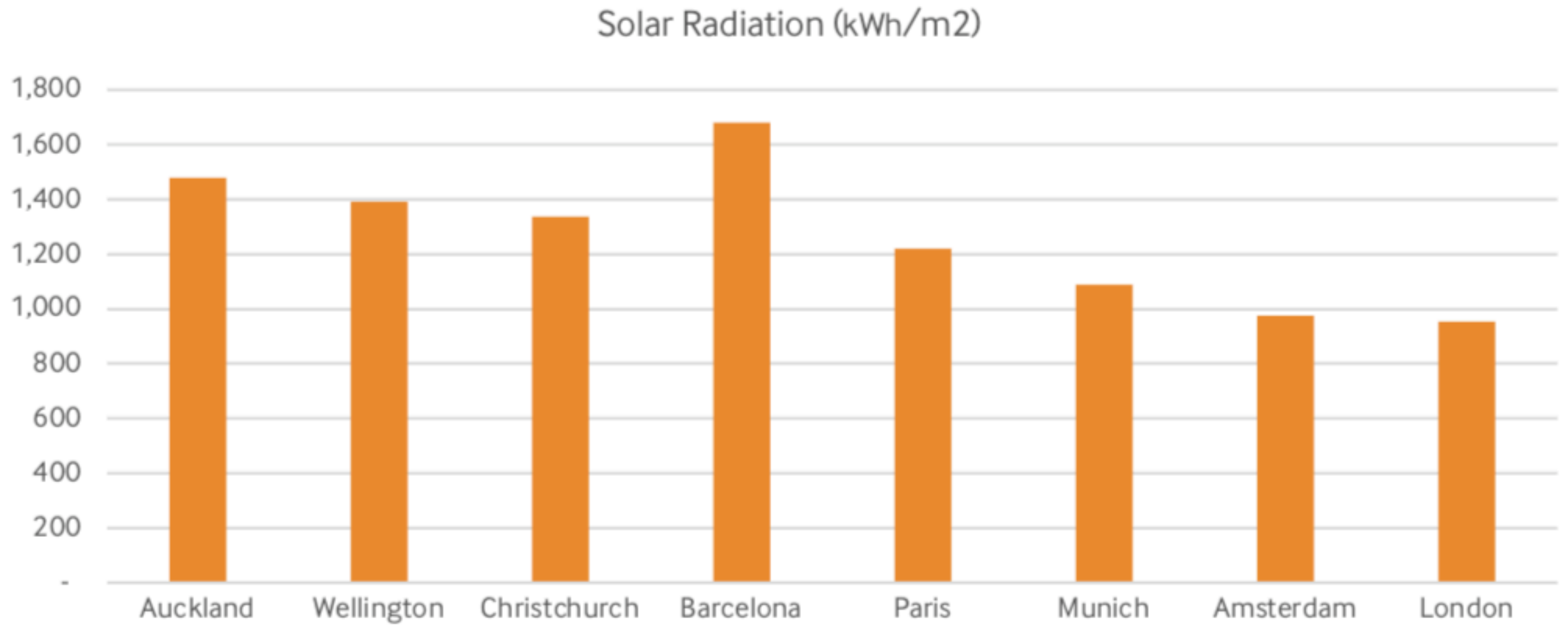
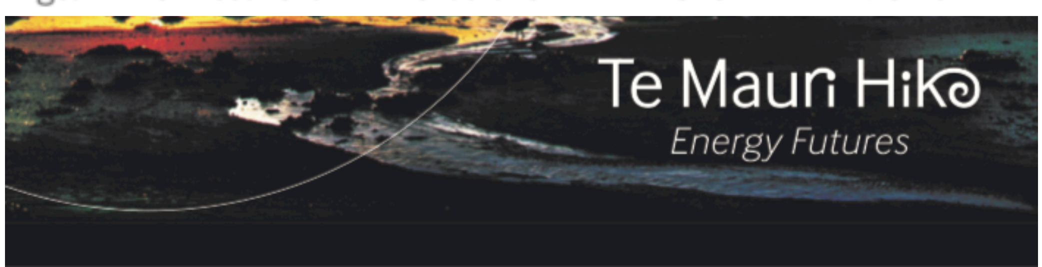

Solar Radiation (kWh/m2)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
-
Auckland
Wellington
Christchurch
Barcelona
Paris
Munich
Amsterdam
London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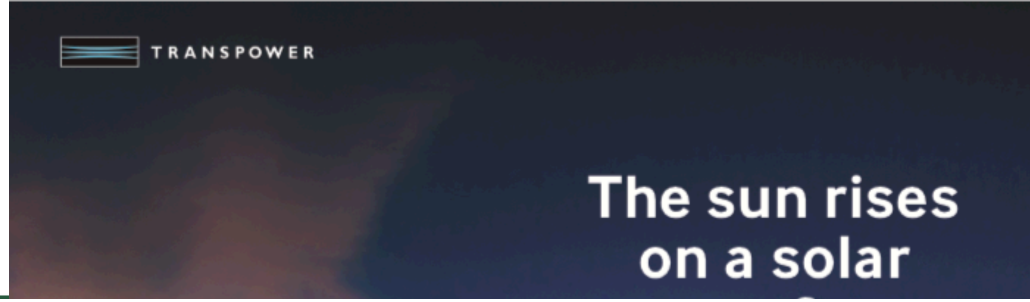
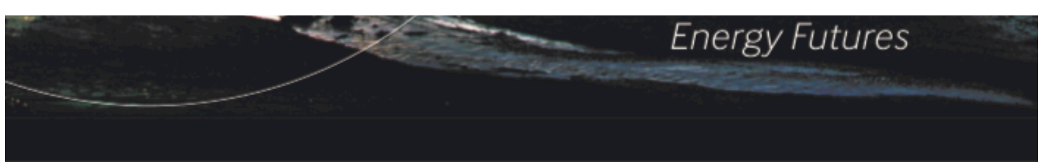

TRANSPOWER
The sun rises on a solar


80%
70%
60%
50%
40%
30%
20%
10%
0%
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Clean NZ
Mass Solar


Energy Futures

Stand-alone solar PV system: 1

- DC ventilation fans, small water pumps such as circulating pumps for solar thermal water-heating systems, and other DC loads that do not require electrical storage.

(a) System 1

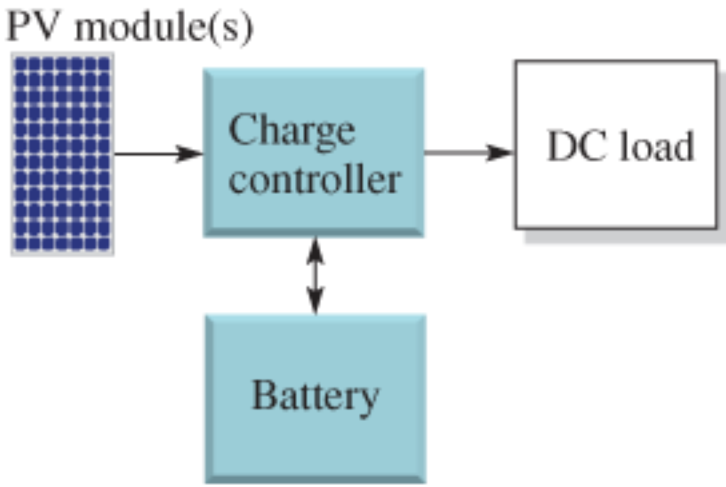
Stand-alone solar PV system: 2

- DC loads that require specific DC voltages, but do not require storage, such as a charging station for certain electric vehicles or DC water pumps. This configuration is also useful for miniature applications, such as calculators.

(b) System 2

Stand-alone solar PV system: 3

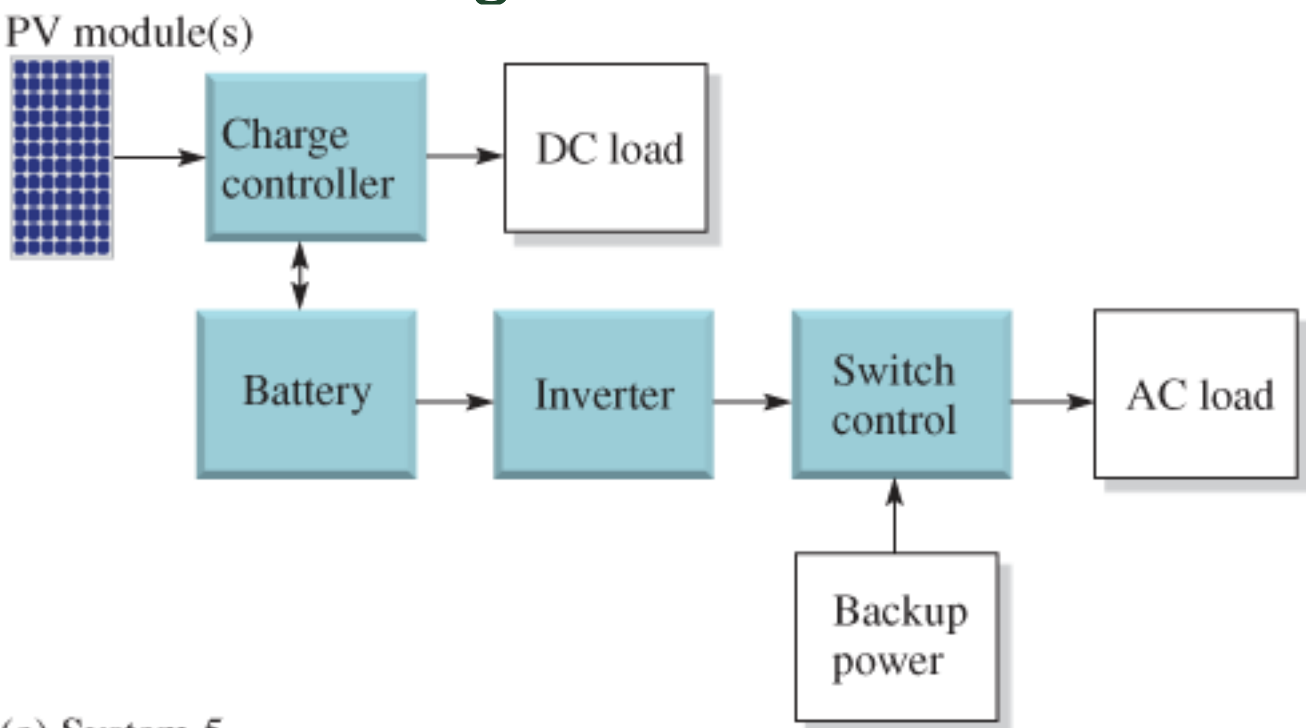
- DC loads that require power even when there is no solar input, such as small yard lights, traffic warning lights, and buoy power, or mobile and remote power for recreational vehicles (RVs) and communication systems.



(c) System 3

Stand-alone solar PV system: 5

- AC and DC systems where there is large seasonal variation in solar input. The supplementary power can be from any other power-generating system such as a wind generator.



(e) System 5

Some notes on the components

- Typically up to 10 kW
- Inverter is a basic battery-based inverter rather than the more expensive grid-tie inverter
- A charge controller must match the rated voltages of the solar array and battery bank (usually 12 V, 24 V, or 48 V)
  - Also the charge controller must have sufficient capacity to handle the current from the solar array

Some notes on the components

- A basic formula for determining the minimum current rating is:
- $I_{CH}=1.56.I_{SC}$
  - I_{CH} is the current rating of the charge controller
  - I_{SC} is the short-circuit current of the solar array

Some notes on the components

- For example, if six 39.8 V, 215 W modules are connected in parallel, and the I_{SC} for each module is 5.8 A:
- $I_{CH} = 1.56 \times 6 \times 5.8 = 54.3$ A

Some notes on the components

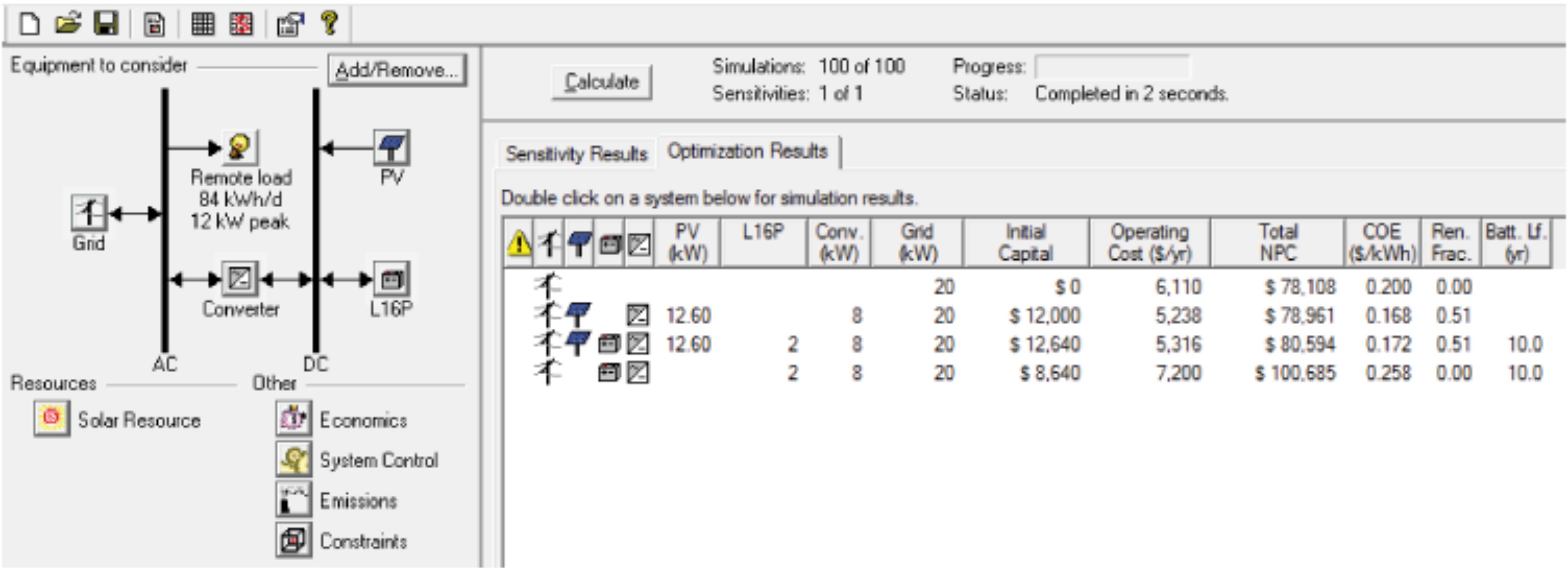
INVERTER SPECIFICATIONS

SPRx HIGH EFFICIENCY INVERTERS	ELECTRICAL SPECIFICATIONS		
Model	**SPR-3300x**	**SPR-3300x-208**	**SPR-4000x**
Maximum AC Power Output	3300 W	3300 W	4000 W
AC Output Voltage (nominal)	240 VAC	208 VAC	240 VAC
AC Voltage Range	211-264 VAC	183-228 VAC	211-264 VAC
AC Frequency (nominal)	60 Hz	60 Hz	60 Hz
AC Frequency Range	59.3-60.5 Hz	59.3-60.5 Hz	59.3-60.5 Hz
Maximum Continuous Output Current	13.8 A	15.9 A	16.7 A
Current THD	< 3%	< 3%	< 3%
Power Factor	> 0.9	> 0.9	> 0.9
DC Input Voltage Range	195-600 VDC	195-600 VDC	195-600 VDC
Max DC Current	18.5 Adc	18.5 Adc	22.1 Adc
Peak Power Tracking Voltage Range	195-550 VDC	195-550 VDC	195-550 VDC
Peak Inverter Efficiency	95.3%	94.6%	95.7%
CEC Efficiency	94.5%	94.0%	95.0%
Night Time Power Consumption	< 1W	< 1 W	< 1W
Output Overcurrent Protection	20 A	25 A	25 A

Some notes on the components

- To determine the power that a solar module array must provide to achieve maximum power from the SPR-3300x inverter:
  - $P_{IN} = P_{OUT}$/peak efficiency = 3300/0.953 = 3463 W
  - $P_{IN} = P_{OUT}$/CEC efficience = 3300/0.945 = 3492 W

HOMER Legacy



PV (kW)	L16P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
			20	$ 0	6,110	$ 78,108	0.200	0.00	
12.60		8	20	$ 12,000	5,238	$ 78,961	0.168	0.51	
12.60	2	8	20	$ 12,640	5,316	$ 80,594	0.172	0.51	10.0
	2	8	20	$ 8,640	7,200	$ 100,685	0.258	0.00	10.0

Sizing the stand-alone system

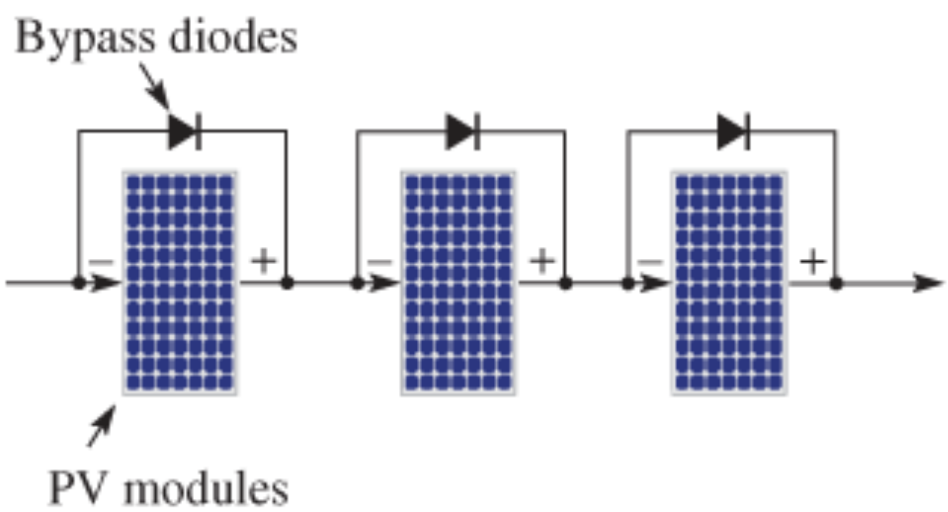
- Conduct a load requirement analysis
- Evaluate the site
- Develop the initial system concept
- Determine the PV array size
- Evaluate cabling and battery requirements
- Select the components
- Review the design

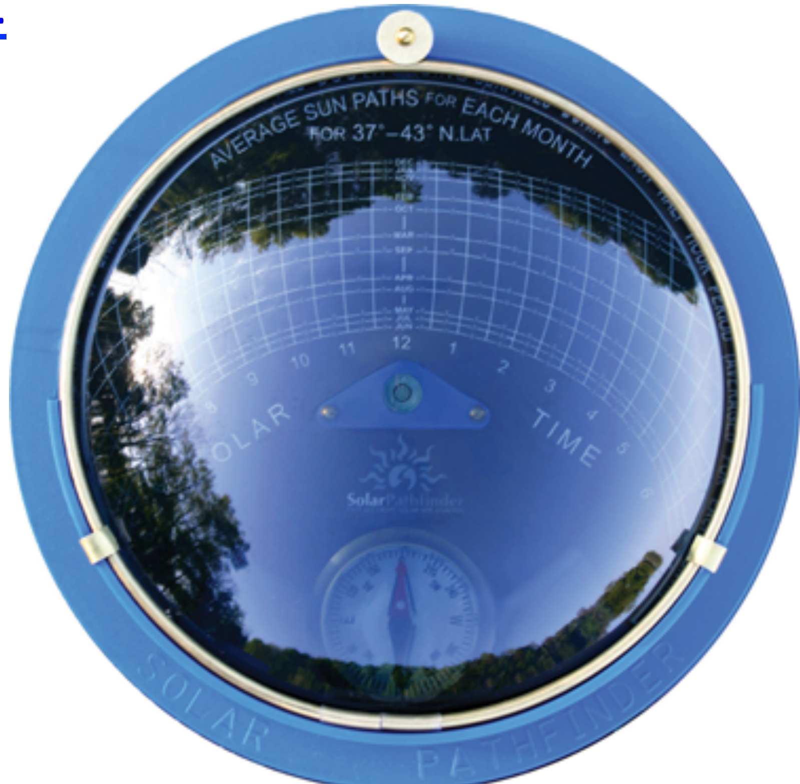
Conduct a load requirement analysis

AC Load Description	Quantity	Power Rating (W)	Time on per Day (h/da)	Energy Used (Wh/da)
Refrigerator	1	450	8	3,600
Washing machine	1	500	0.5	250
TV	2	100	3	600
Lights (incandescent)	4	60	6	1,440
Lights (fluorescent)	5	30	10	1,500
Toaster oven	1	1,500	0.5	750
Microwave oven	1	1,000	0.4	400
Ceiling fans (medium speed)	3	25	10	750
Computer	2	125	4	1,000
Printer	1	400	0.25	100
Miscellaneous loads	1	200	2	400
			TOTAL 5 =	**10,790**

Evaluate the site

- https://solarview.niwa.co.nz
- https://solarpathfinder.com

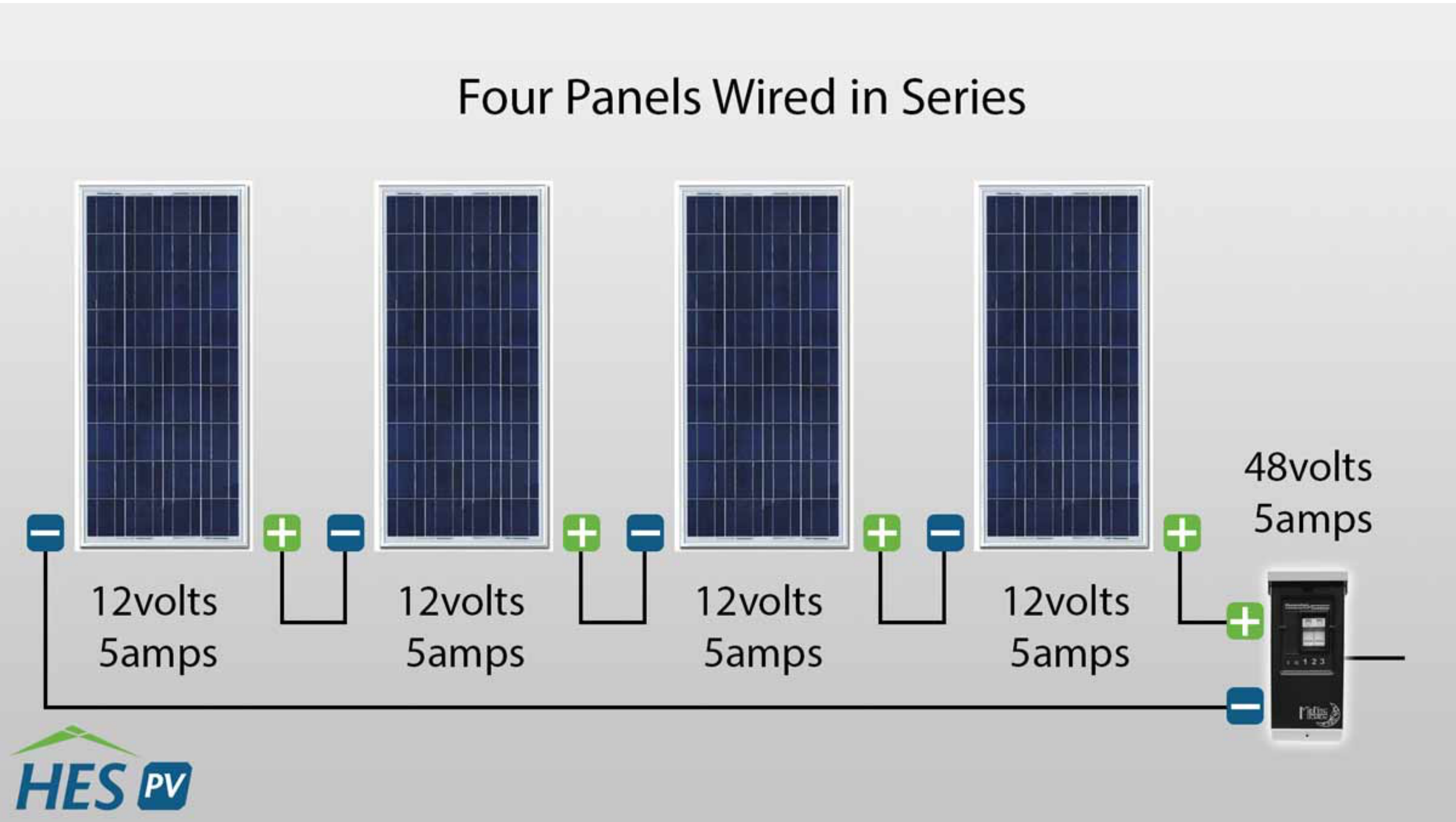




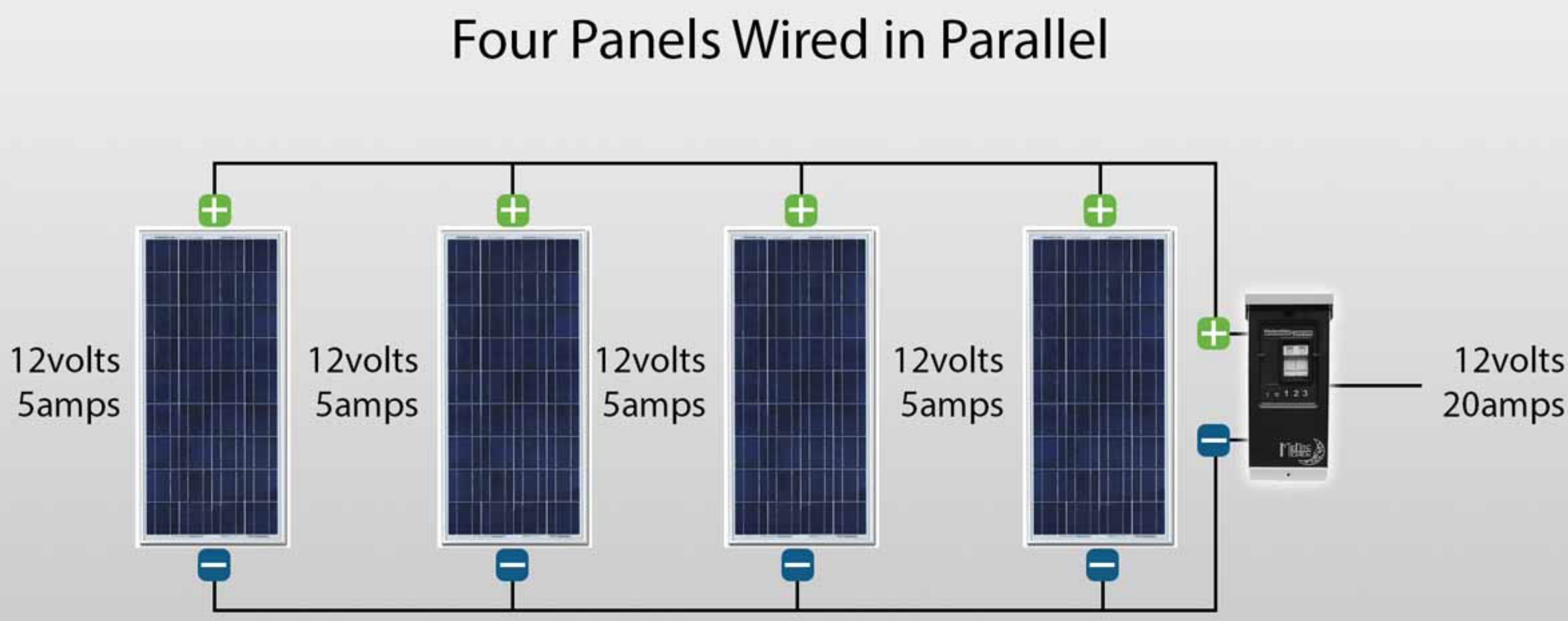
Evaluate the site / cabin

- A flat-plate collector should be tilted at an angle that is equal to the latitude to optimize the greatest average radiation
  - Although some people prefer to optimize the winter months by tilting the modules at a higher angle

Wiring the solar modules



Wiring the solar modules



HES PV

Develop the initial system concept

- Two or more small systems may be preferable to a larger system
- Typical system (excl batteries) efficiency is less that 80%
  - Losses in cables, connectors, interters, etc.
- Battery efficiency also in the order of 80%

Determine the PV array size

- $P_{array} = W / (t_{solar}.\eta_{sys})$
  - P_{array} in the peal power, in W
    - Based on the manufacturer's module label
  - W is daily energy requirement, in Wh
  - t_{solar} is the average hours of peak sunlight
  - η_{sys} is the overall efficiency of the system

Evaluate cabling and battery requirements

- For a given power, the current (and hence the required wire size) is smaller as the voltage is higher
- Smaller diameter wire costs less but is rated for less current and drops more voltage
  - Noted derating for higher temperatures
- Generally voltage drops should be in the range of 2 to 3%

Evaluate cabling and battery requirements

- Batteries are connected in series to increase voltage, and in parallel to increase capacity
- Batteries can have very high discharge currents
  - Disconnect switches and overcurrent devices must be selected with the appropriate ratings
  - Need protected enclosures
  - Need deep-cycle types

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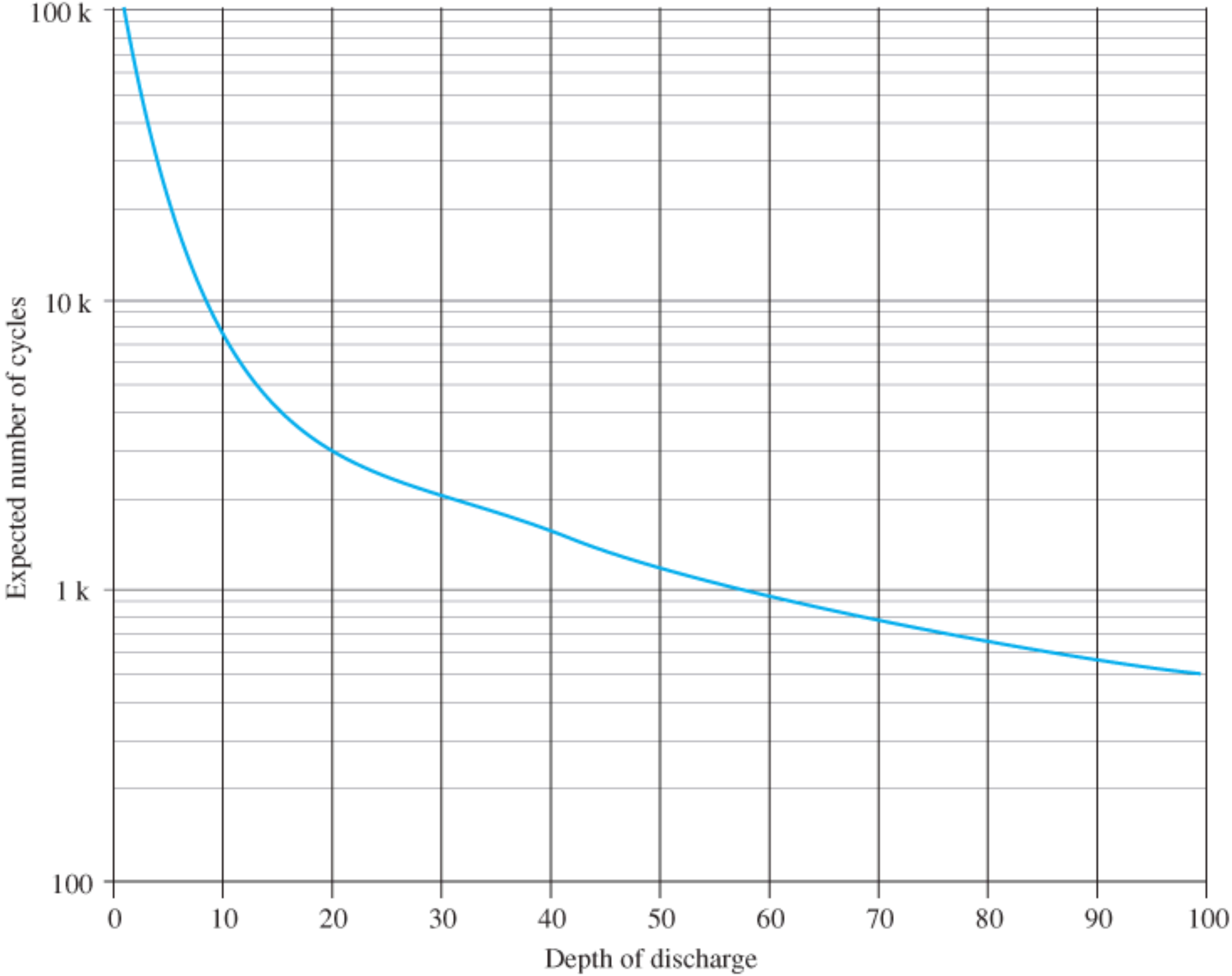
WHAKAPAPA
MAURI

Evaluate cabling and battery requirements

- $Ah = W_{day} \cdot t_{store} / (V \cdot B_{dod} \cdot \eta_{inv})$
  - Ah is the required ampere-hours from the batteries
  - W_{day} is the daily energy requirements, Wh/d
  - t_{store} is the backup time required, d
  - V is the DC system/inverter voltage
  - B_{dod} id the max. depth of discharge
  - η_{inv} if the efficiency of the inverter and cabling



100 k
10 k
1 k
100
Expected number of cycles
0
10
20
30
40
50
60
70
80
90
100
Depth of discharge

Select the components

- You will generally need the PV modules, combiner boxes, a charge controller, battery backup, and an inverter
- In addition, the system will require mechanical and electrical hardware components, which includes mounting hardware, racks, connectors, junction boxes, disconnect switches, fuse holders, contactors, surge arrestors, wiring and conduit, and other parts

Select the components

- Enhance the efficiency if possible

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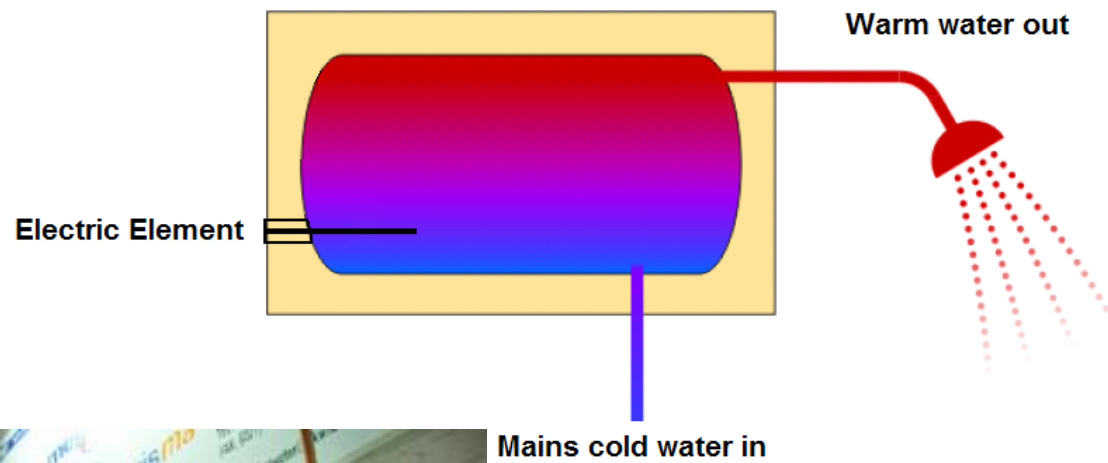
Capital thinking.
Globally minded.

Review the design

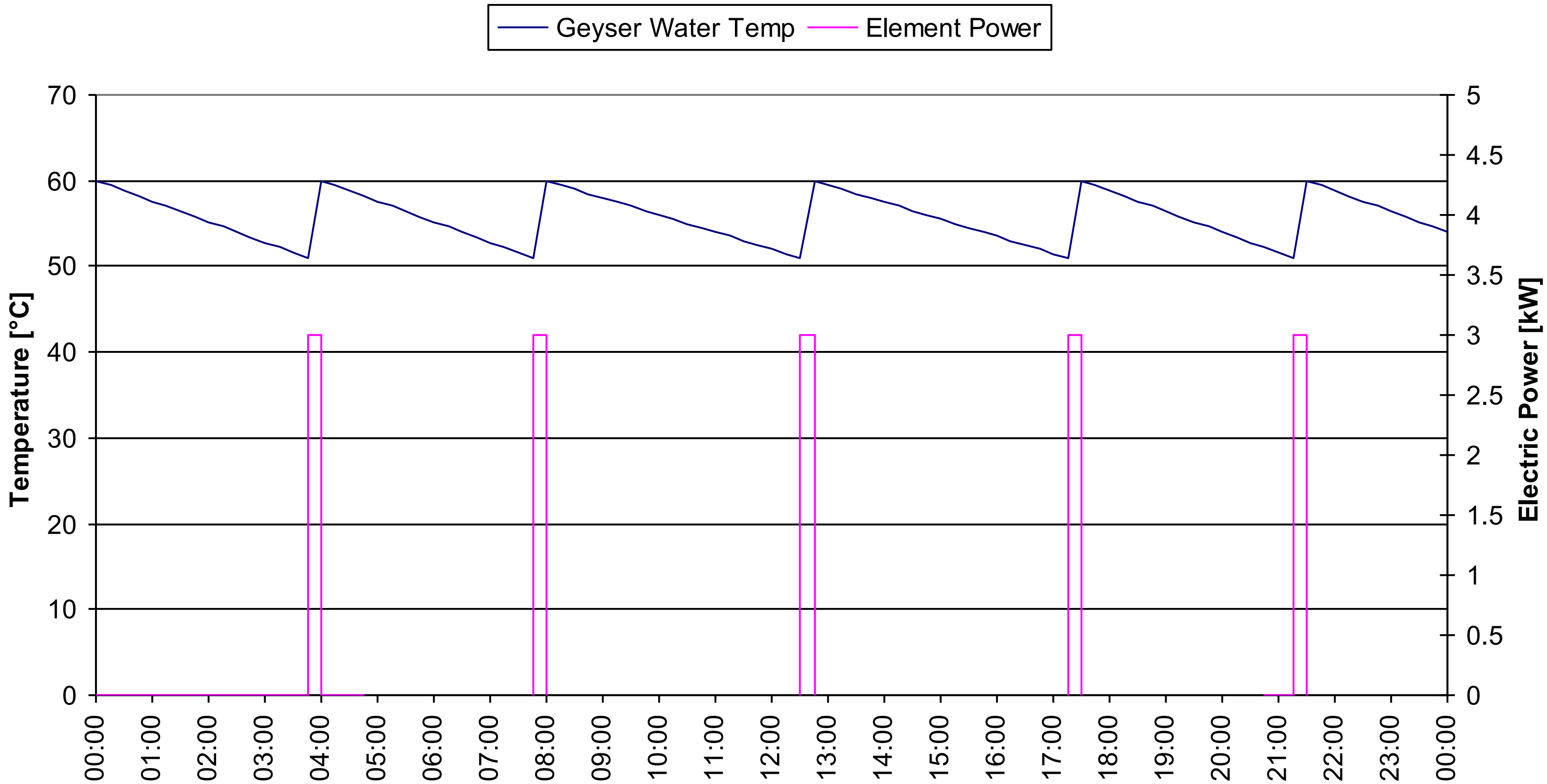
- Model uncertainties
- Do a contingency analysis
- Optimize for cost
- Reflect on maintenance issues

Options for heating

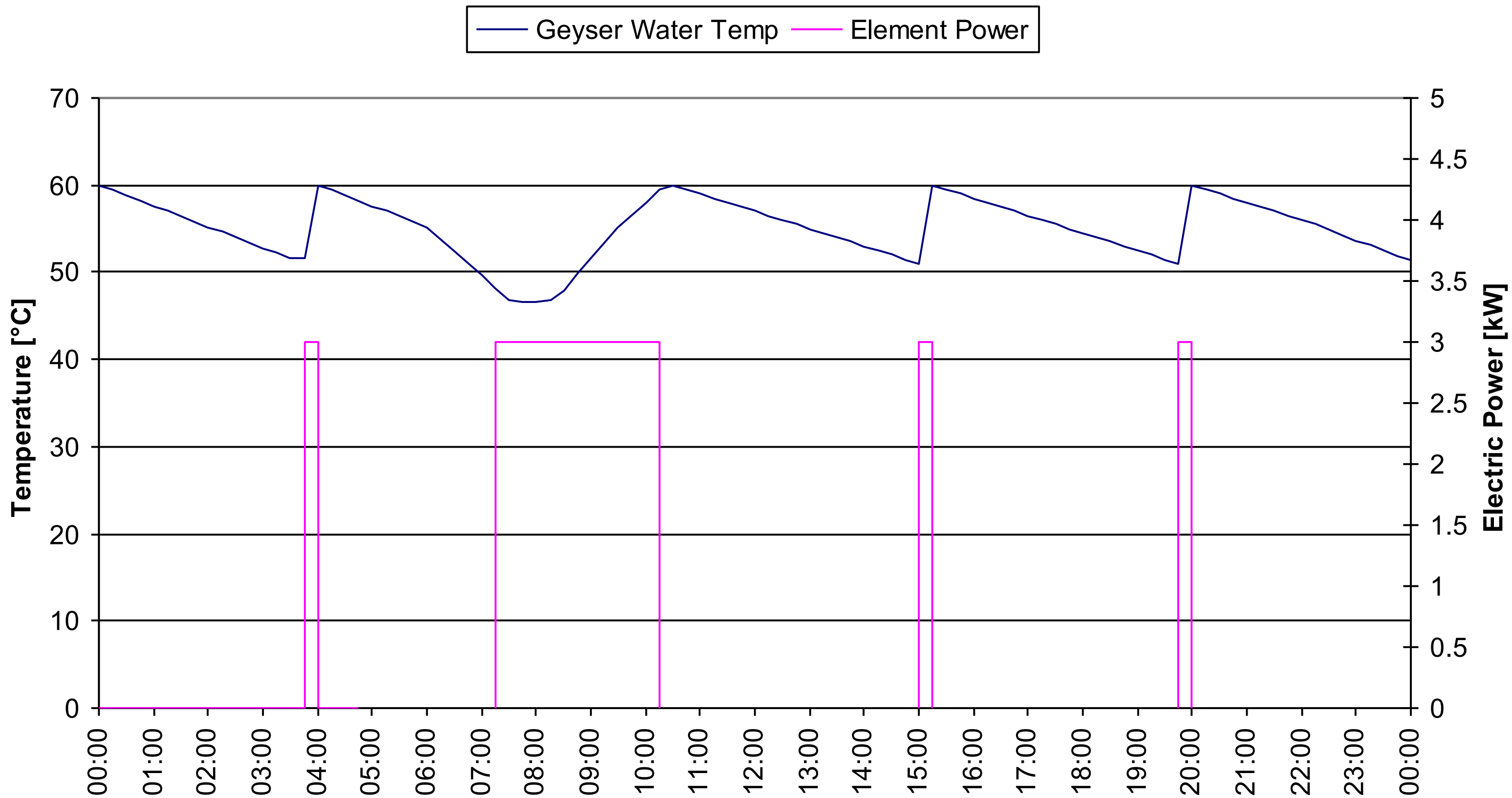
- Hot water tanks
- Boilers
- Heat pumps
- Various heaters



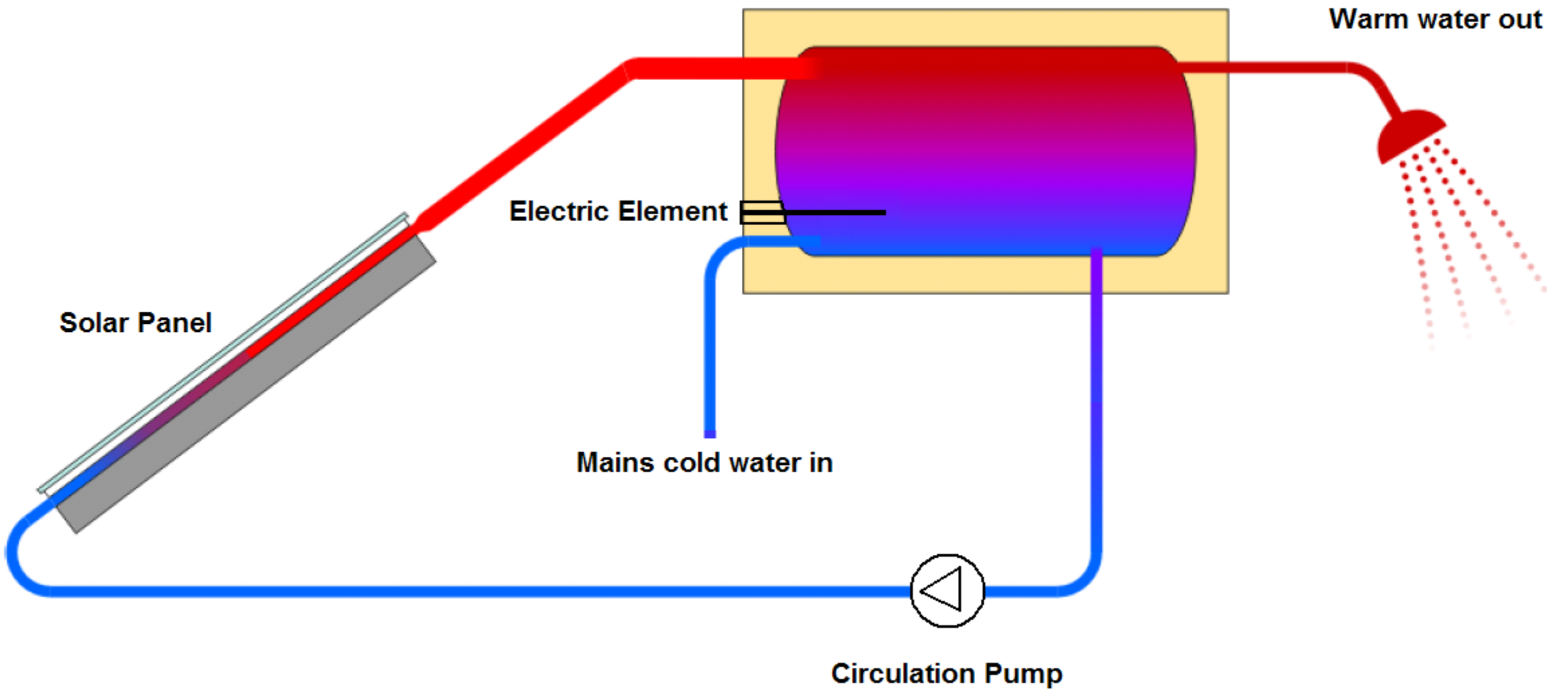
Operation of a conventional water heating tank



Operation of a conventional water heating tank



Adding solar thermal



The basic principles, and types

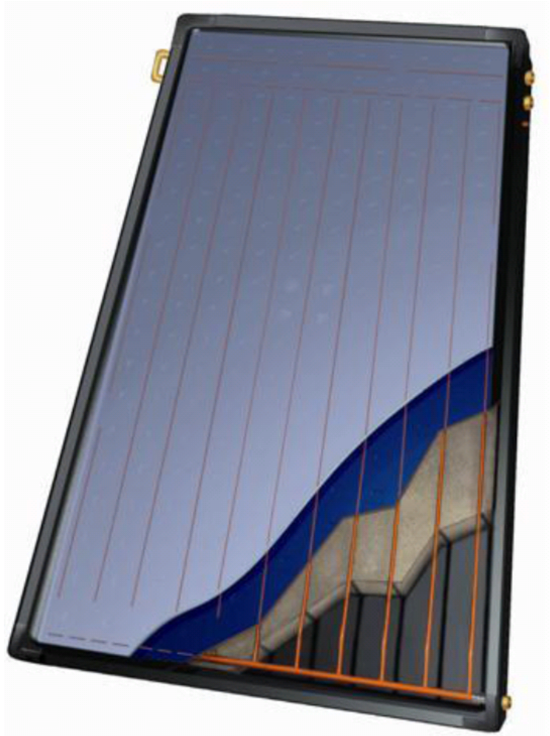
- https://www.youtube.com/watch?v=e28aOibxjuk
- Passive systems
- Active systems
- Optimal positioning of the collector
- Options for different temperature contexts

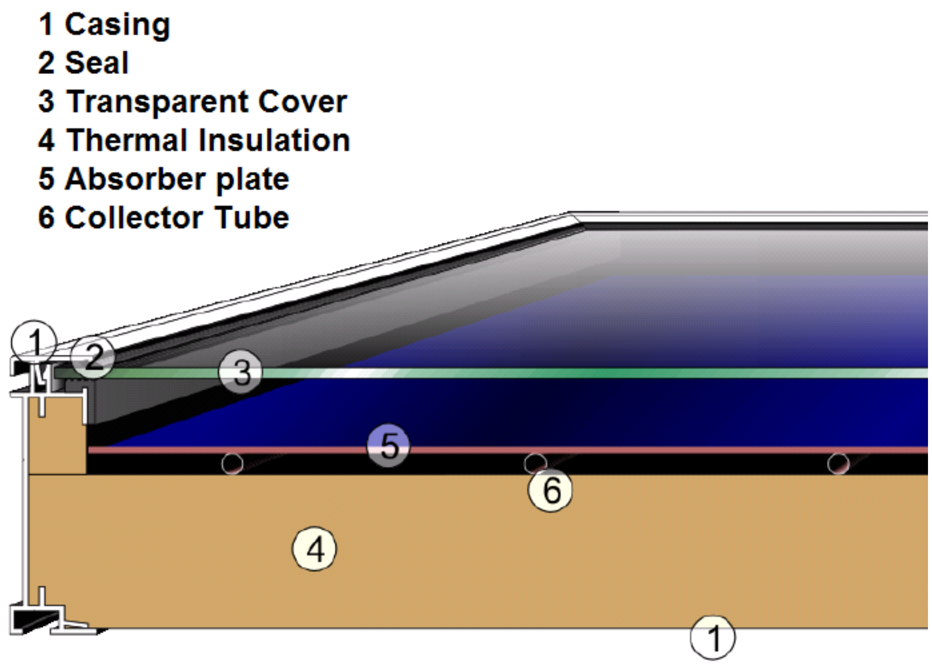
Solar collector panels

- Flat plate collectors
- Evacuated tube collectors

Flat plate collectors

- Fairly easy to construct and require simple tools

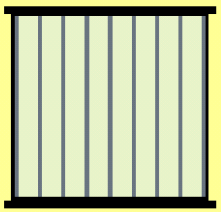




Flat plate collector types

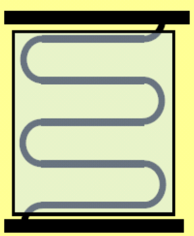
- Heat collection

Header Riser Type:



- Low pressure loss
- Suitable for series connection
- Low flow systems

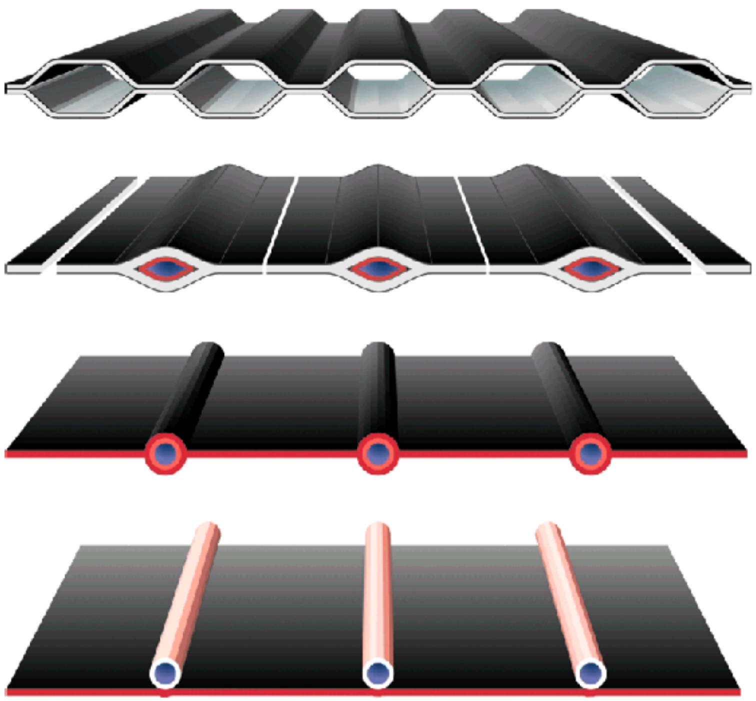
Meander Type:



- high pressure loss
- Suitable for parallel connection
- High flow systems

Flat plate collector types

- Absorber configurations



Aluminium absorber rollbonded

Aluminium Absorber with copper inlay

Copper pipe between two copper sheets

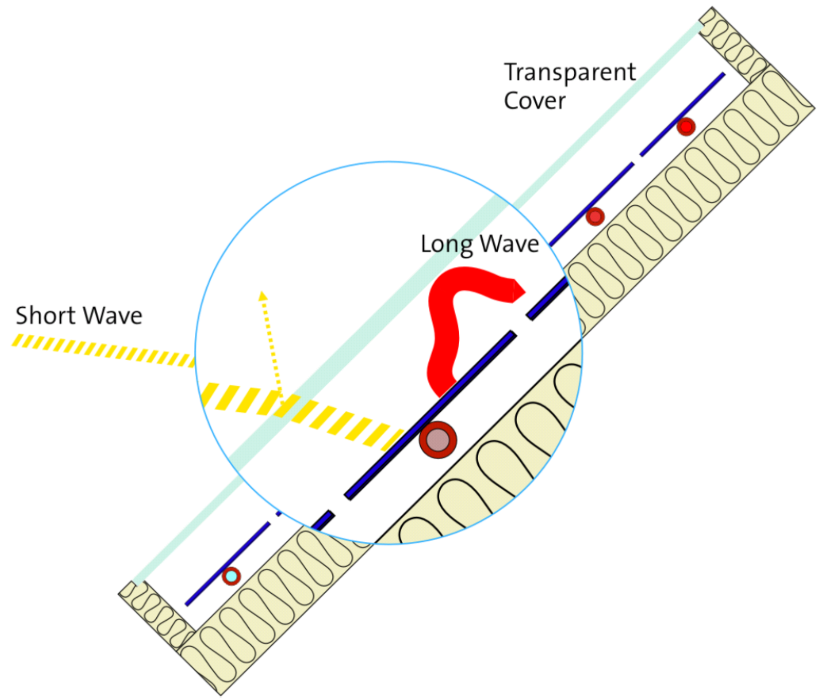
Copper pipe soldered or welded to a copper sheet

Flat plate collector types

- Absorber configurations

Absorber Coatings

- High absorbtion + low emission
- Optimised heat transfer from plate to liquid
- Non – corroding, long-term stable
- Easy coating process
- Optimised material usage and cost

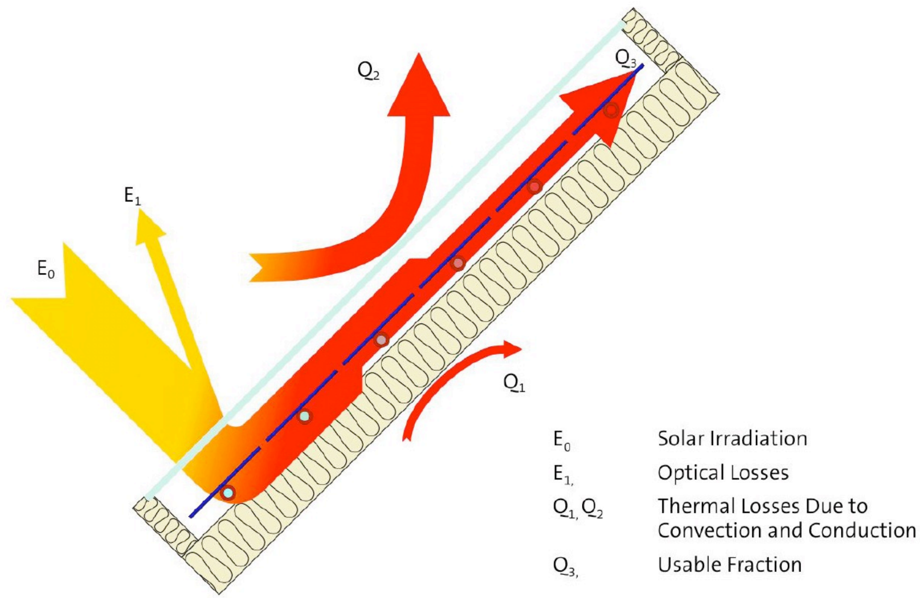


Flat plate collector types

- Glazing

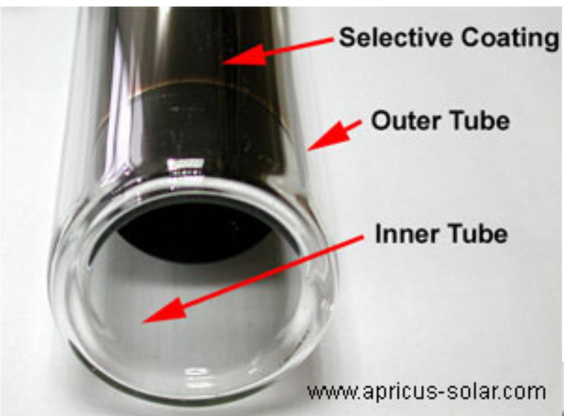
Transparency:

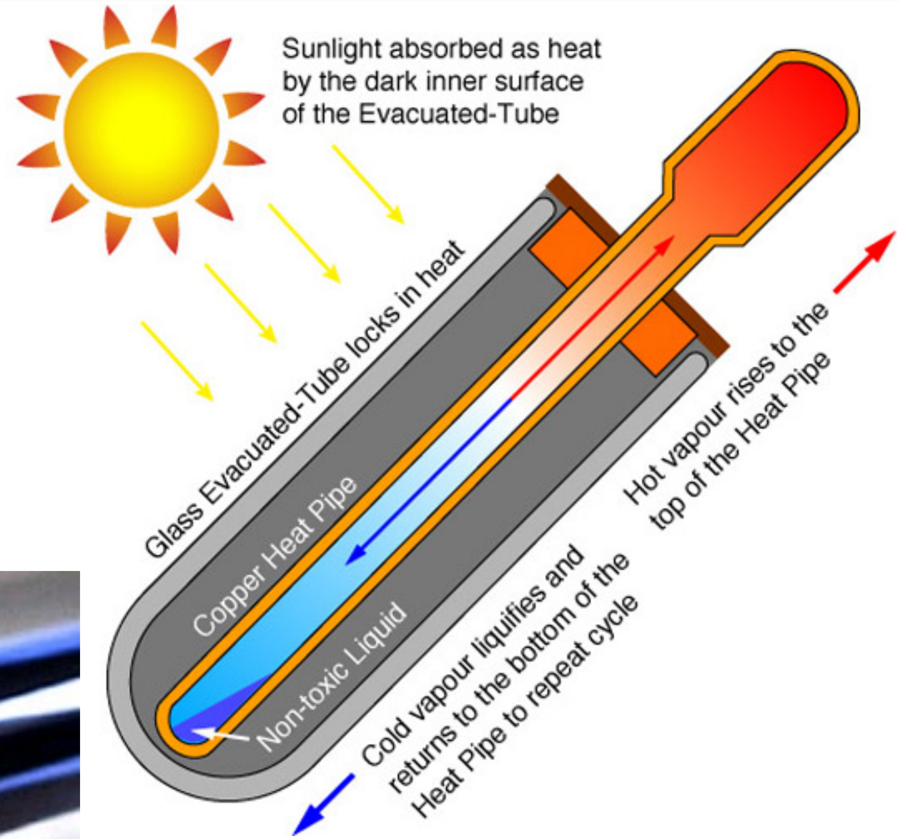
- Ordinary glass 85% - 88%
- Solar glass (low iron) 91%
- Solar glass with antireflex coating up to 95%



Evacuated tube collectors

- More complicated and costly; more efficient





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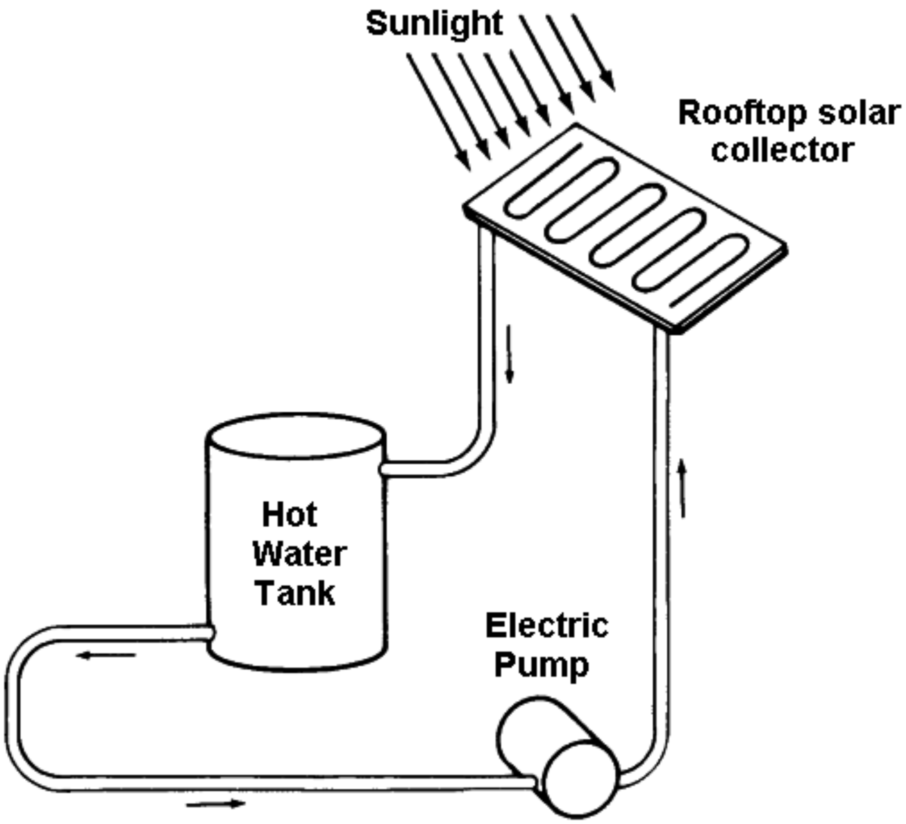
Evacuated tube collectors

- Excellent for process heat

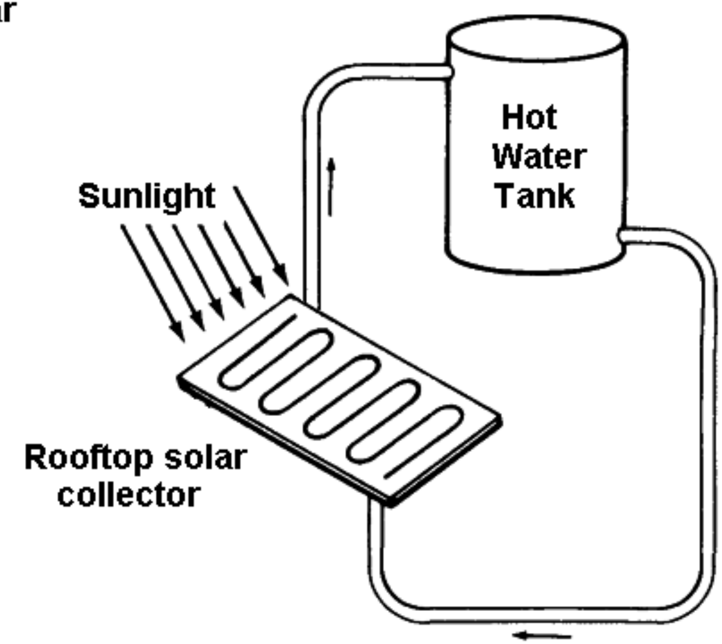
Low-cost innovations

Active versus Passive systems

- Active systems require a pump and controller



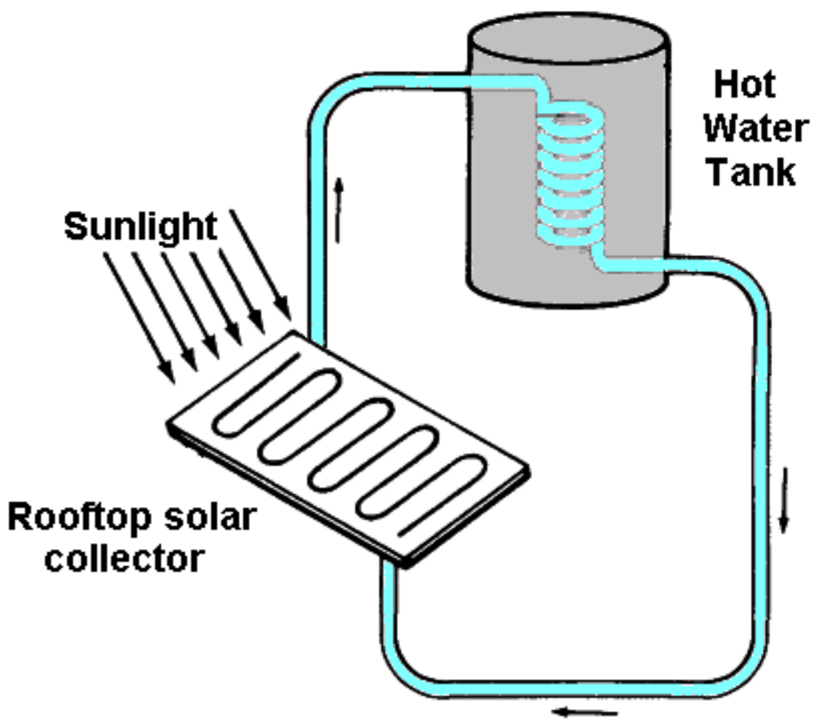
Active System



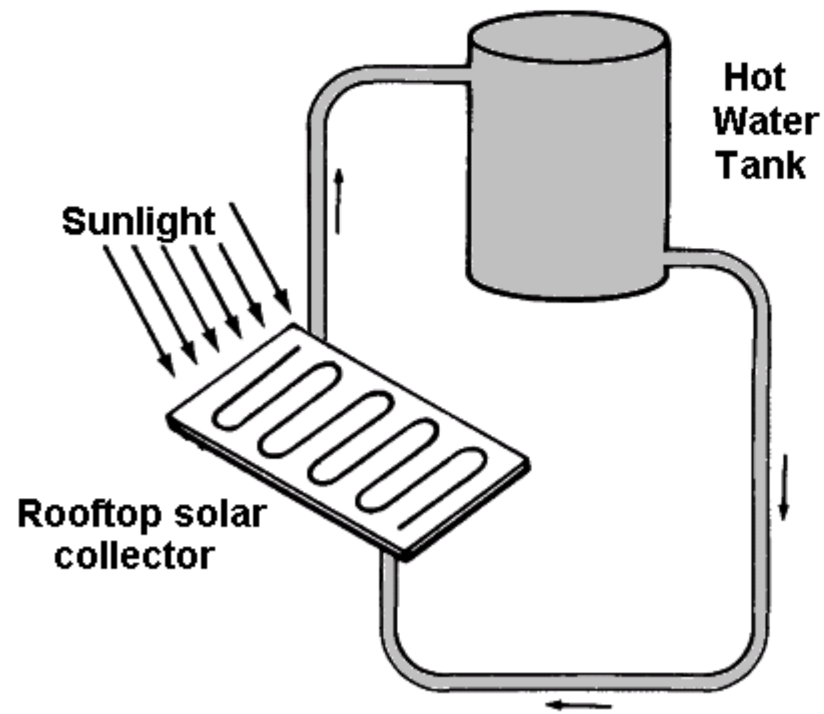
Passive System

Direct versus Indirect systems

- A water/glycol mixture is typically used in the panel with indirect systems



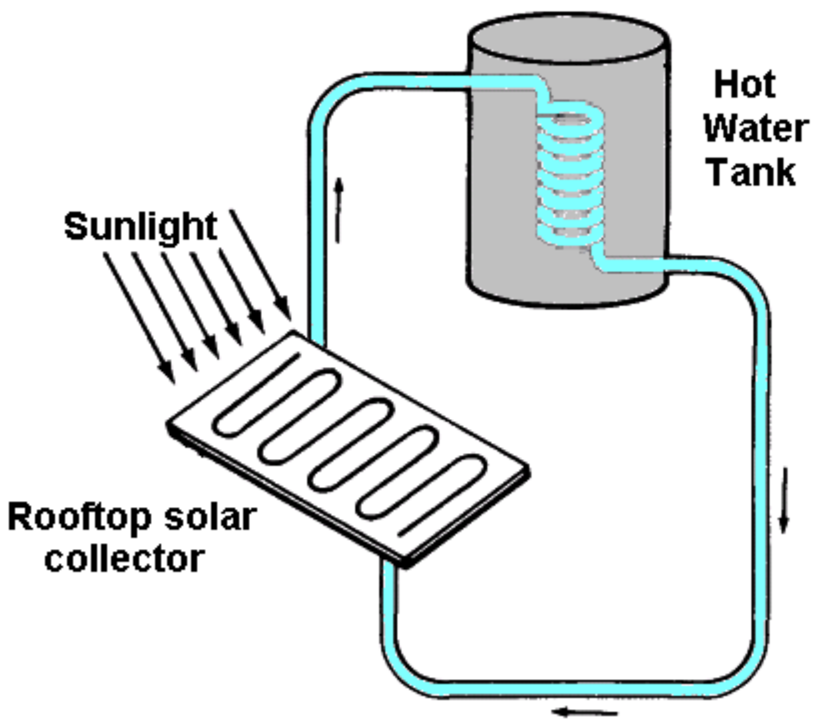
Indirect



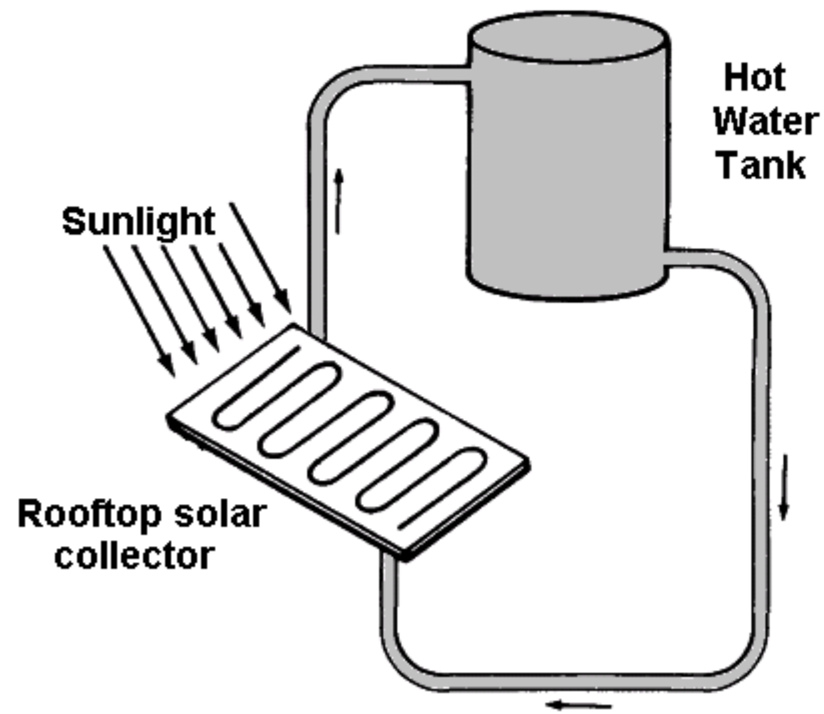
Direct

Direct versus Indirect systems

- A water/glycol mixture is typically used in the panel with indirect systems



Indirect



Direct

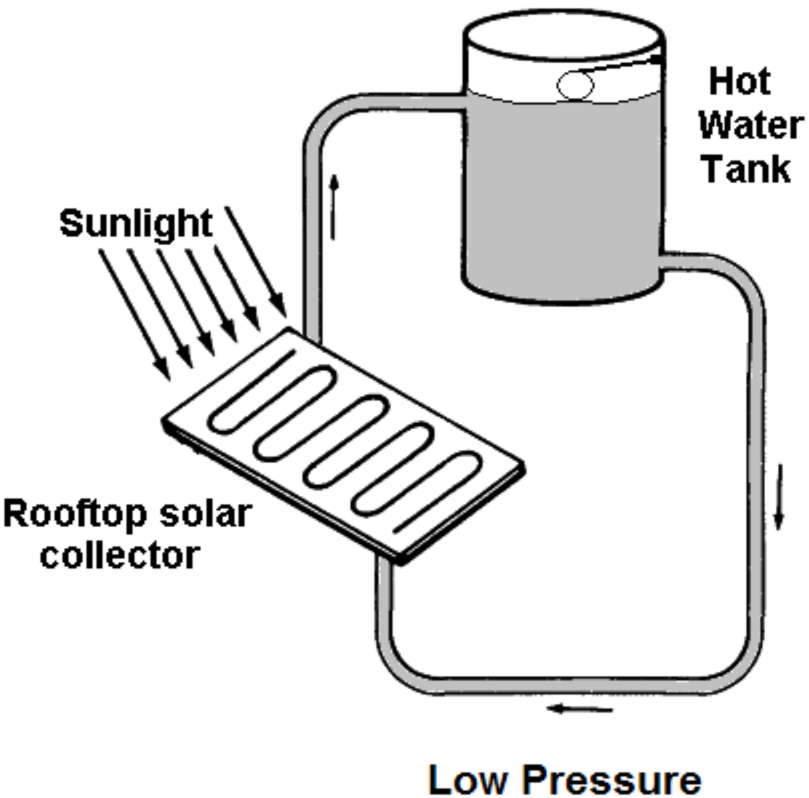
Direct versus Indirect systems

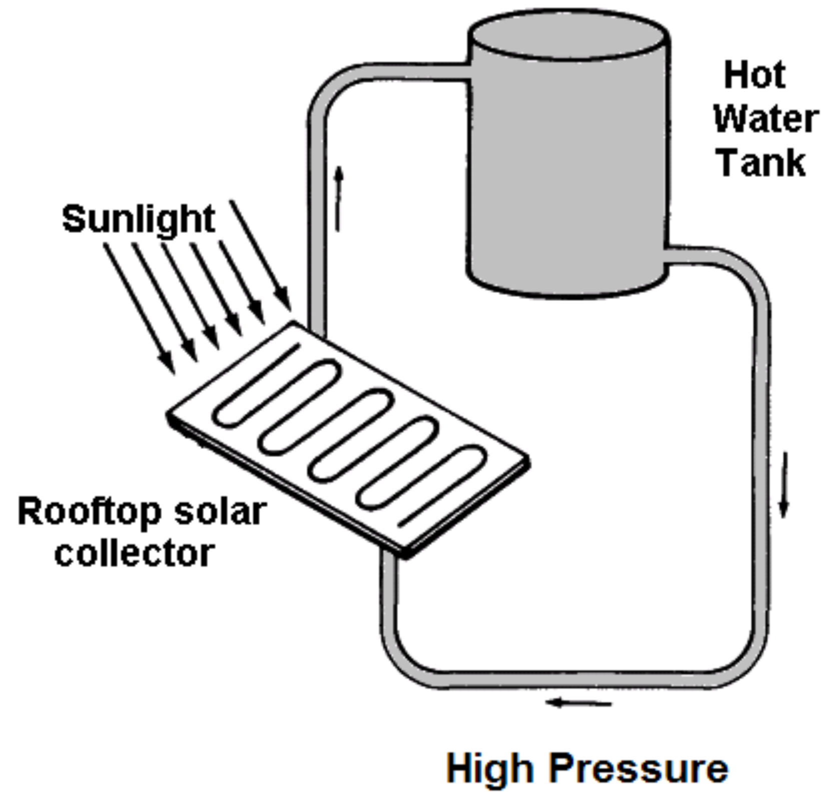
- A water/glycol mixture is typically used in the panel with indirect systems

Capital thinking.
Globally minded.

Low versus High pressure systems

- Atmospheric versus mains pressure



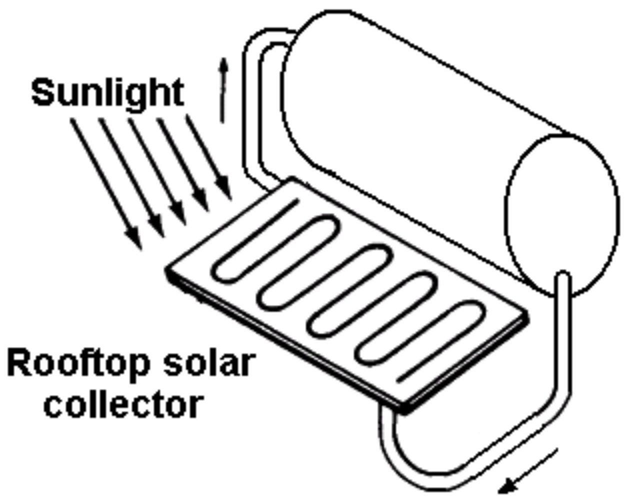


Low pressure systems

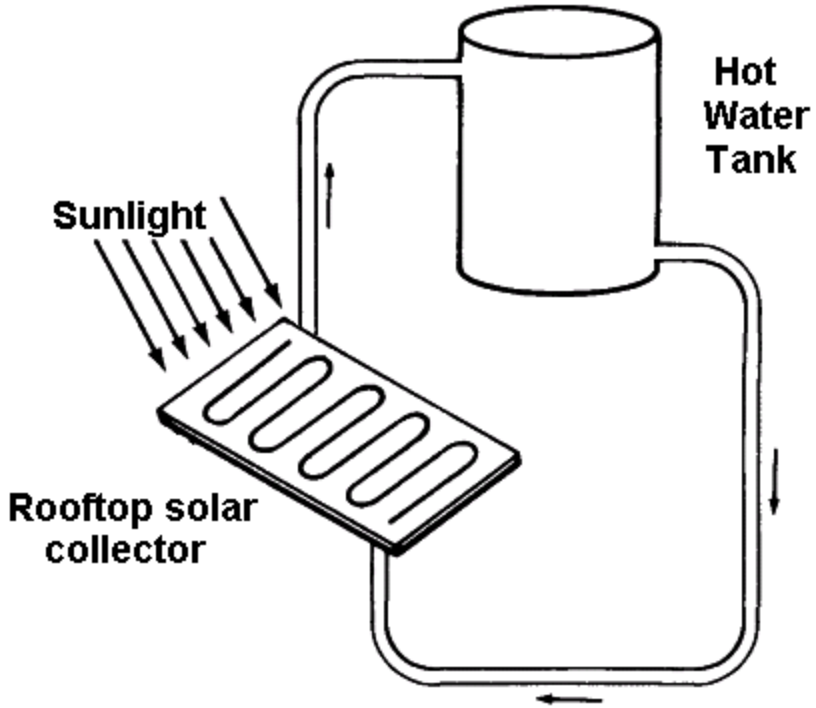
- In many of these systems there are no heat pipes inside the evacuated tubes

Close versus Split coupled systems

- Position of the tank and the collector



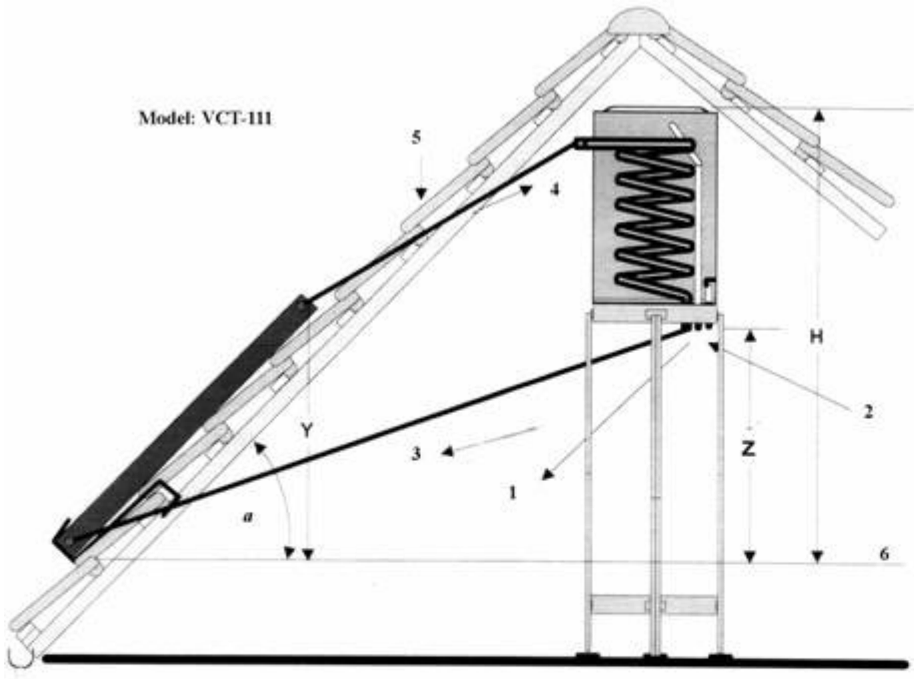
Close Coupled

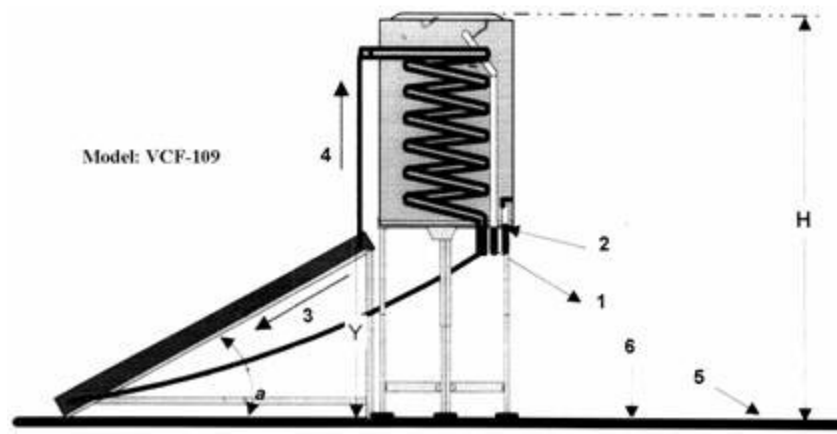


Split Coupled

Close versus Split coupled systems

- Position of the tank and the collector





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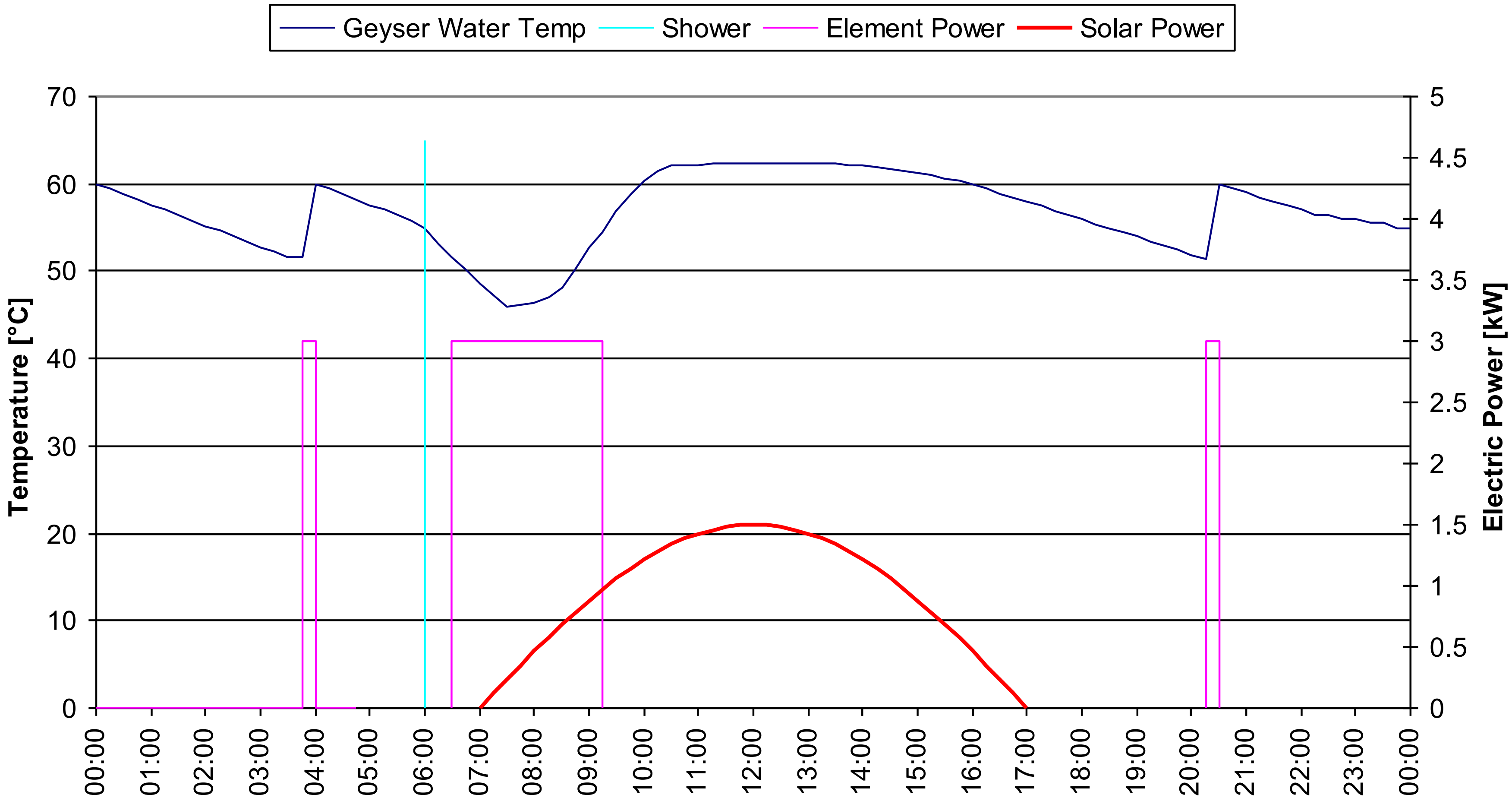
Installation

- https://www.youtube.com/watch?v=e28aOibxjuk

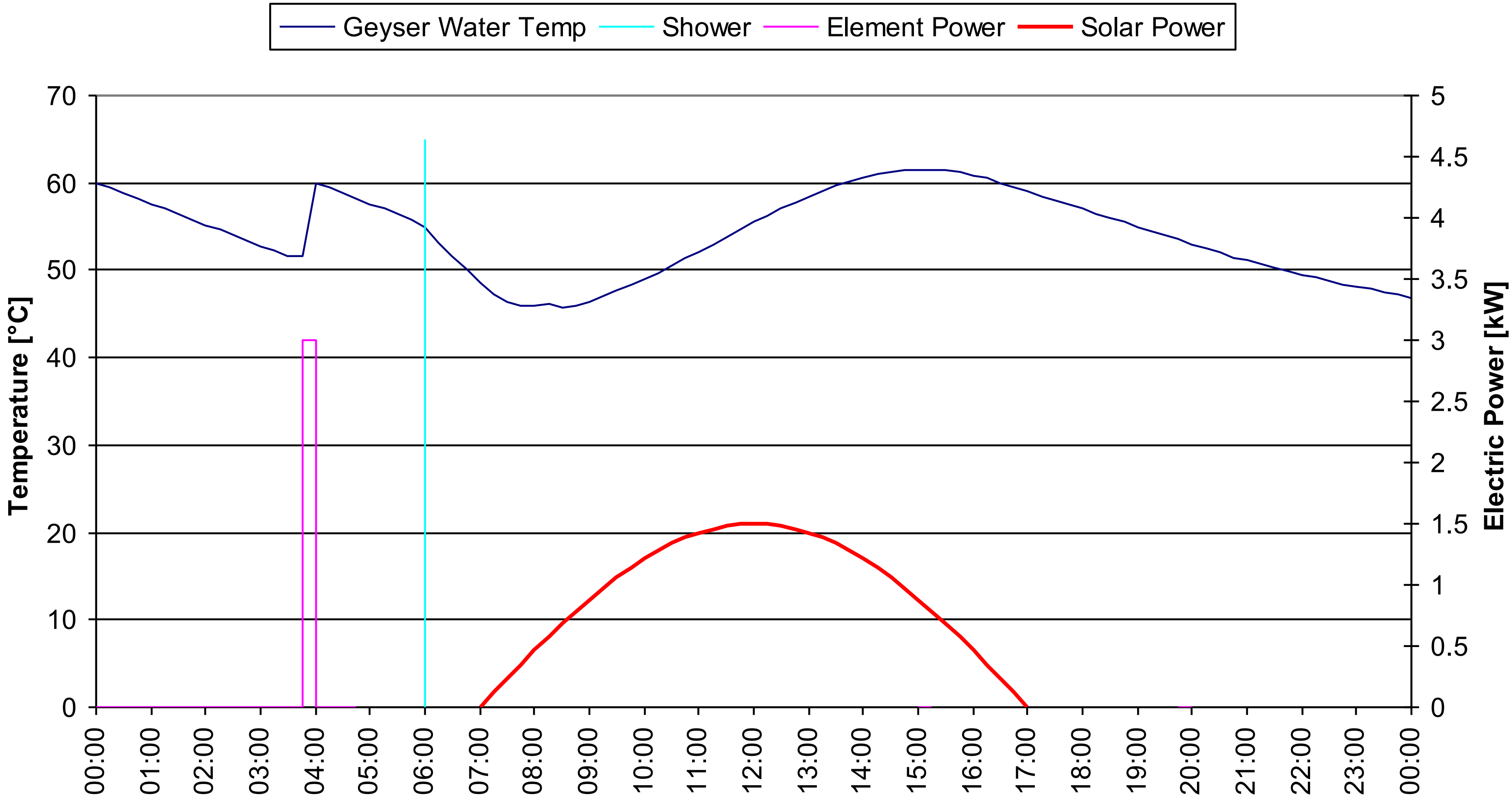
SWH operations

- Usage patterns are important



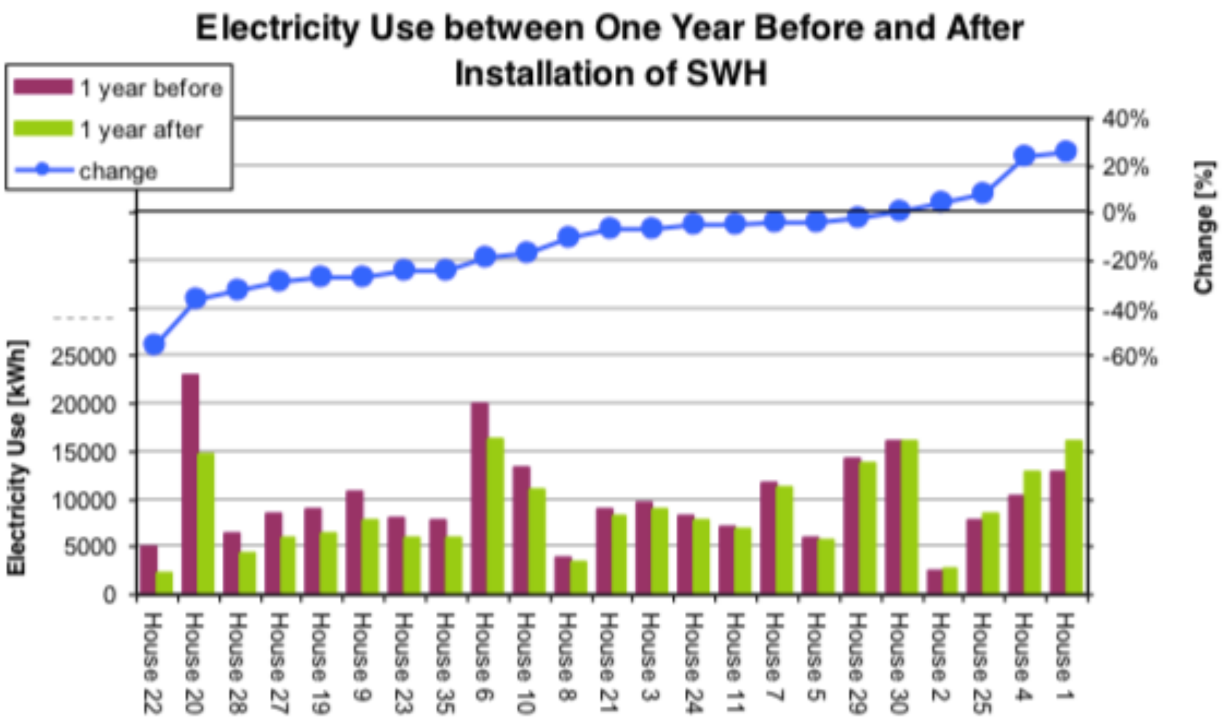
SWH operations

- A timer and temperature settings?



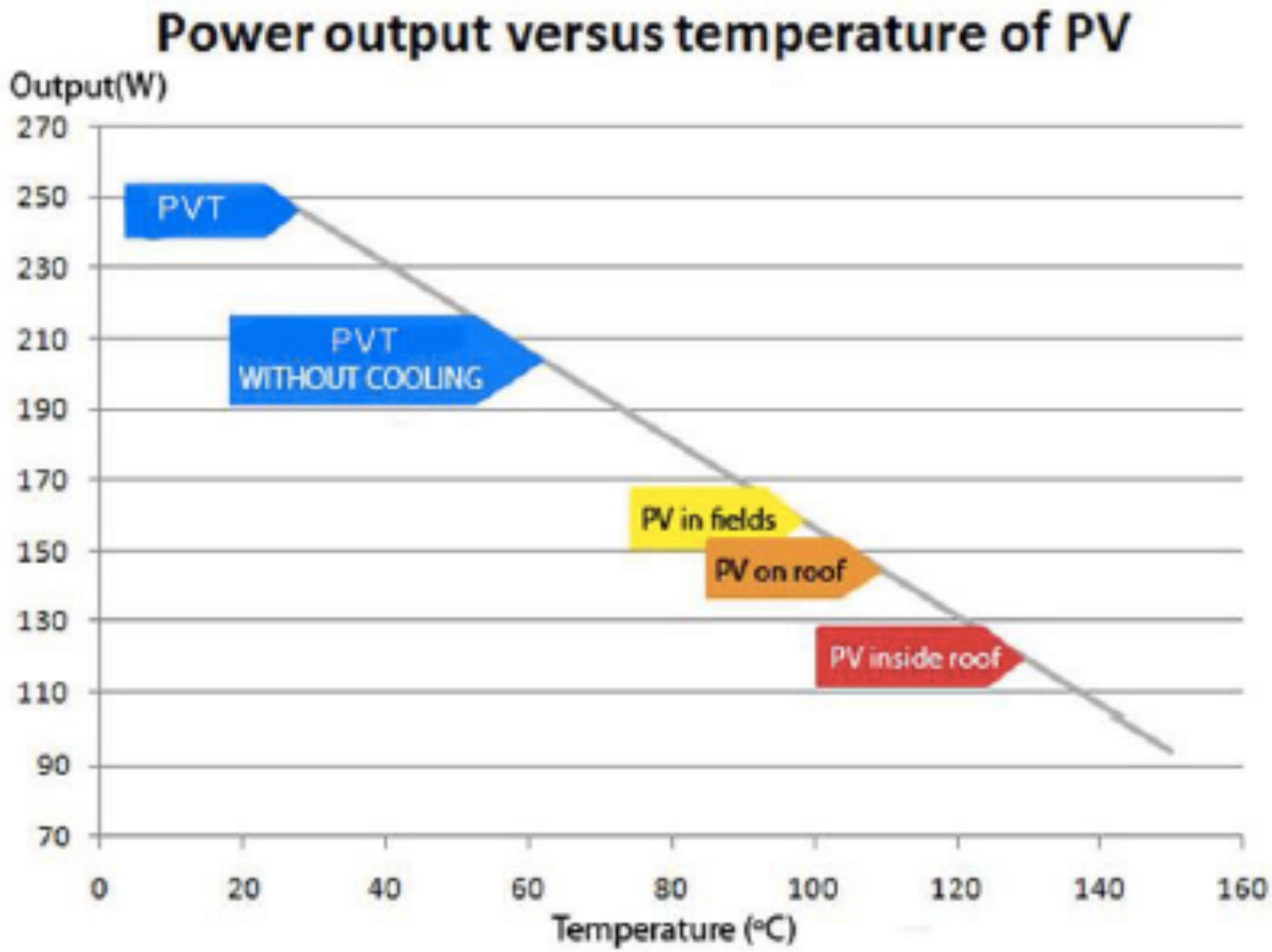
Potential savings

- See the BRANZ report

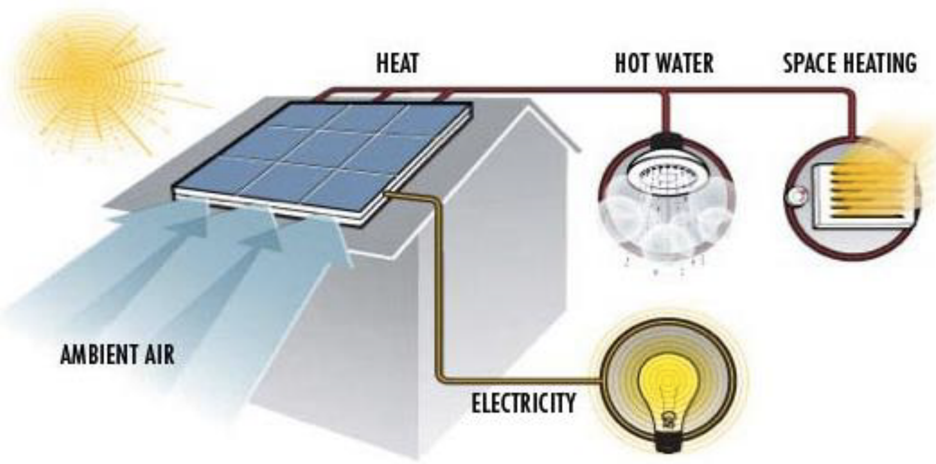


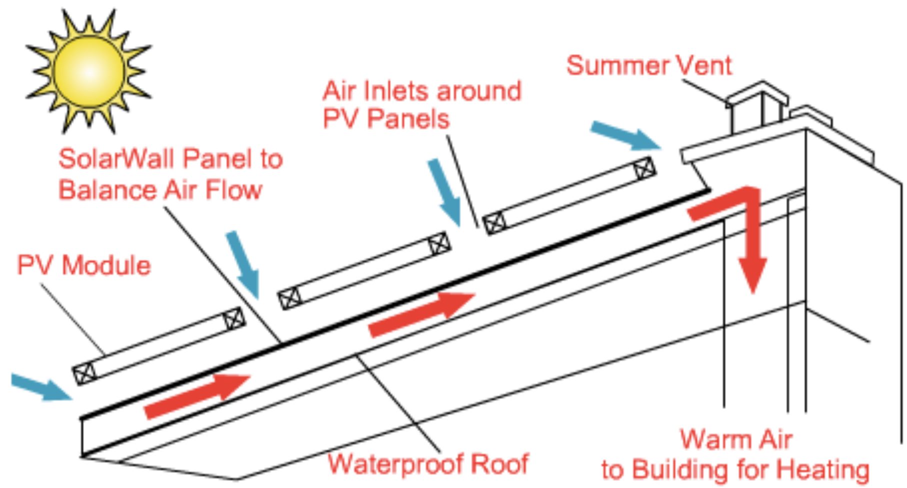
Combine with PV

- Thermal management of PV systems is necessary



Combine with PV





Discussion

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

http://www.victoria.ac.nz/sustainable-energy-systems

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Capital thinking.
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