Building Integrated Photovoltaics - Modelling, Simulation and Assessment

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Content

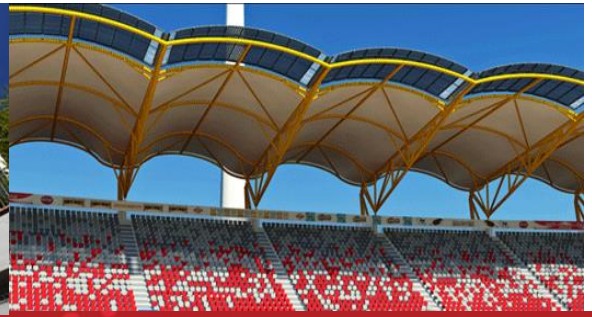
- Introduction
- Detailed analysis in an Australian project – BIPV (façade, Poly-crystalline) +BAPV
- Building precincts
- Current research

Building Integrated Photovoltaics (BIPV)

Buildings account for approximately 40% of global electricity use and 19% of energy related greenhouse gas emissions.

According to the Climate Commission (2013) Australia will be capable of providing 29% of electricity needs with the use of solar by 2050.





Building Integrated Photovoltaics (BIPV)

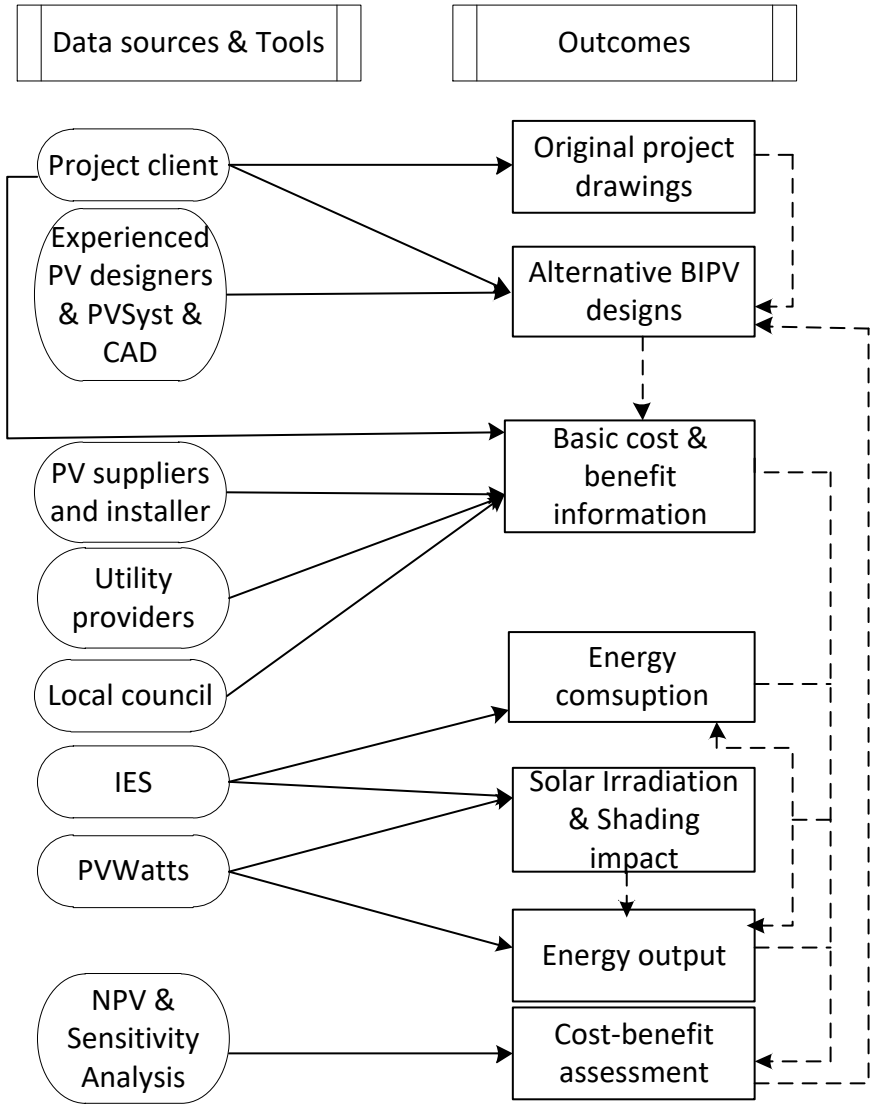
- Key barrier in the PV industry is the relatively high capital costs.
- There is very limited data on the environmental and economic benefits available of commercial construction in Australia.
- We conduct a comprehensive analysis to address the industry's concerns by developing alternative design scenarios and conducting cost benefits assessment.

ACCURACY!

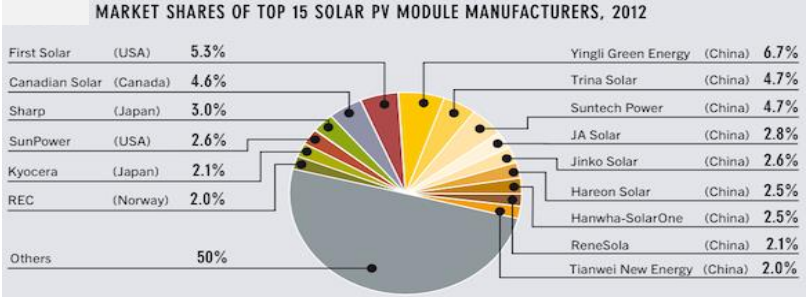
Value for Money!

Building – UniLodge Bundoora

Methods used in this study



BIPV design



- Poly-crystalline PV (JA Solar, Fixed)
  - Rated Maximum Power at STC (W) : 260
  - Open Circuit Voltage (Voc/V): 37.98
  - Maximum Power Voltage (Vmp/V): 30.63
  - Short Circuit Current (Isc/A): 9.04
  - Maximum Power Current (Imp/A): 8.49
  - Module Efficiency 15.9%
  - Tem. Coefficient of Isc: +0.058%/$^{\circ}$C
  - Tem. Coefficient of Voc: -0.330%/$^{\circ}$C
  - Tem. Coefficient of Pmax: -0.430%/$^{\circ}$C
  - STC: Irradiance 1000W/m^2, Module tem: 25°C, Air Mass: 1.5
  - Lifespan: 25 years
  - System attenuation rate – 0.5% per annum

PV Module Market Share Ranking (as of May 2015)

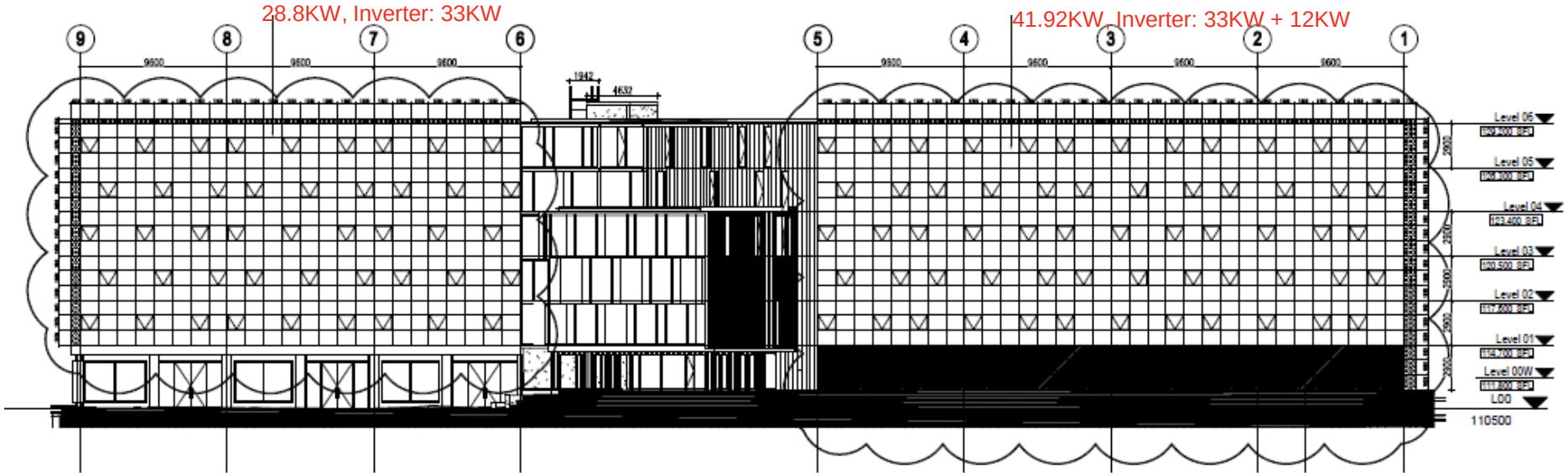
	2010	2011	2012	2013	2014	Q42014
1st	Suntech	Suntech	Yingli	Yingli	Trina Solar	Trina Solar
2nd	First Solar	First Solar	Suntech	Trina Solar	Yingli	Canadian Solar
3rd	Sharp	Yingli	Trina Solar	Canadian Solar	Canadian Solar	JA Solar
4th	Yingl	Trina Solar	Canadian Solar	Sharp	Jinko Solar	Yingli
5th	Trina Solar	Canadian Solar	First Solar	Jinko Solar	JA Solar	Jinko Solar
6th	Canadian Solar	Sharp	Sharp	Renesola	Sharp	First Solar

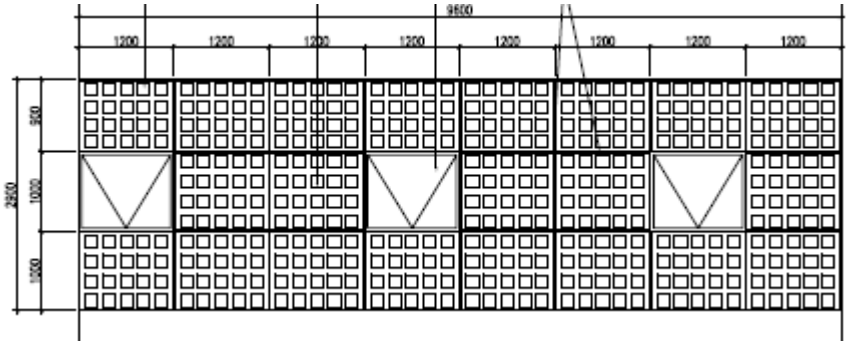
Market Realist

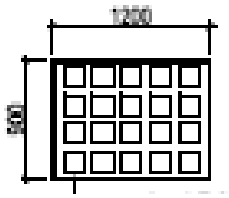
Source: Investor Presentation, Company Press Releases & Analyst Reports

BIPV design

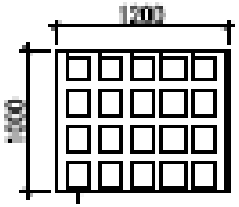
North face façade



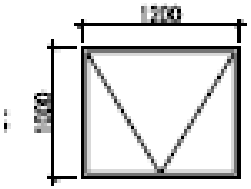




Module type 1



Module type 2



Window

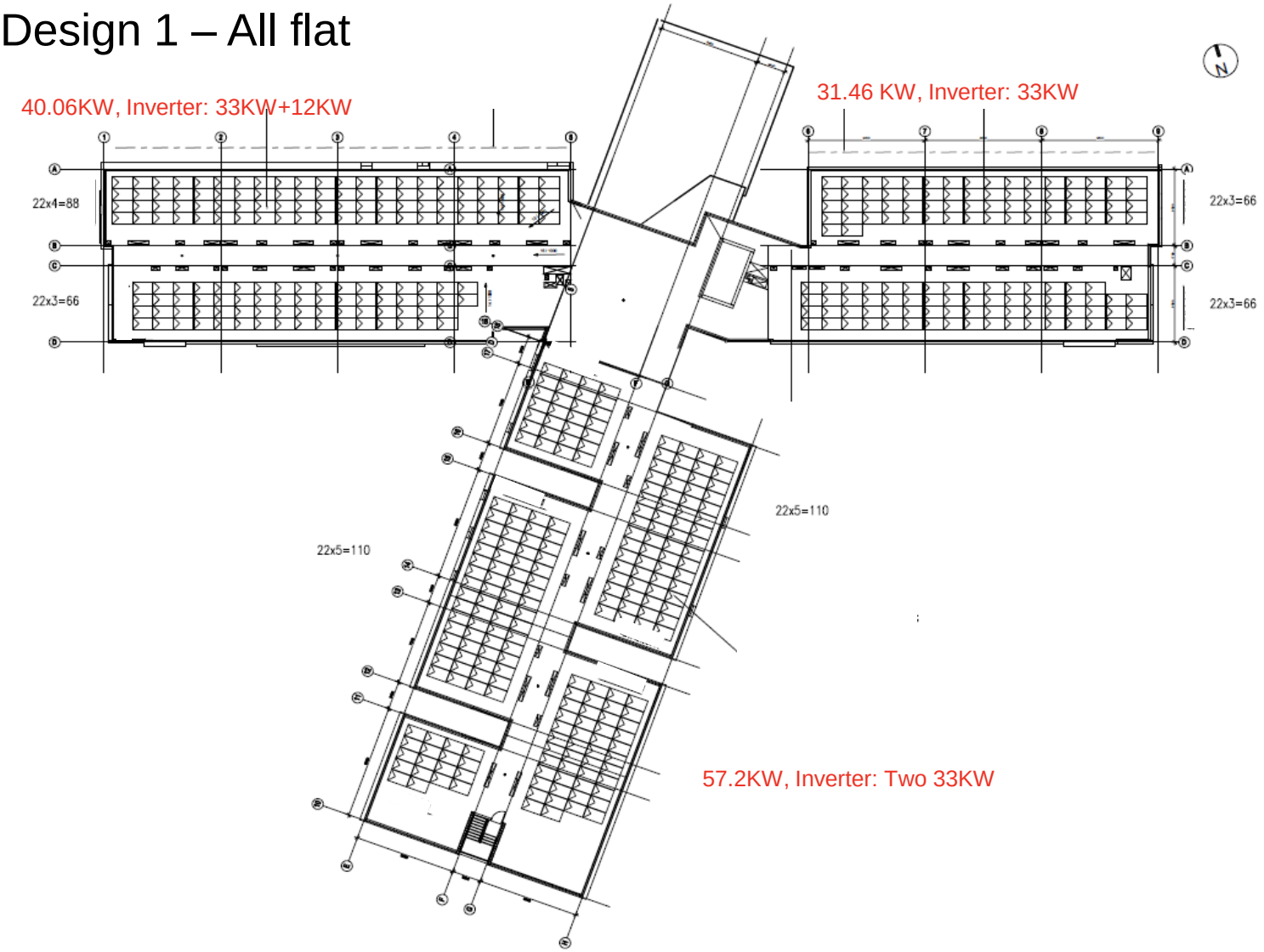
BIPV design

- North face façade
  - PV cells
    - 156*156
    - 80W
  - Module type 1
    - NO.: 312
    - 20 cells each
  - Module type 2
    - NO.: 572
    - 20 cells each
  - Centralised Inverters
    - One 33KW
    - One 33 KW +12KW

PV Cell size: 429.287m²
Capacity: 70.72KW
PV module size: 884.541m²
Window size: 140.4m²
Façade size: 1024.941m²

BIPV design

Roof – Design 1 – All flat



BIPV design

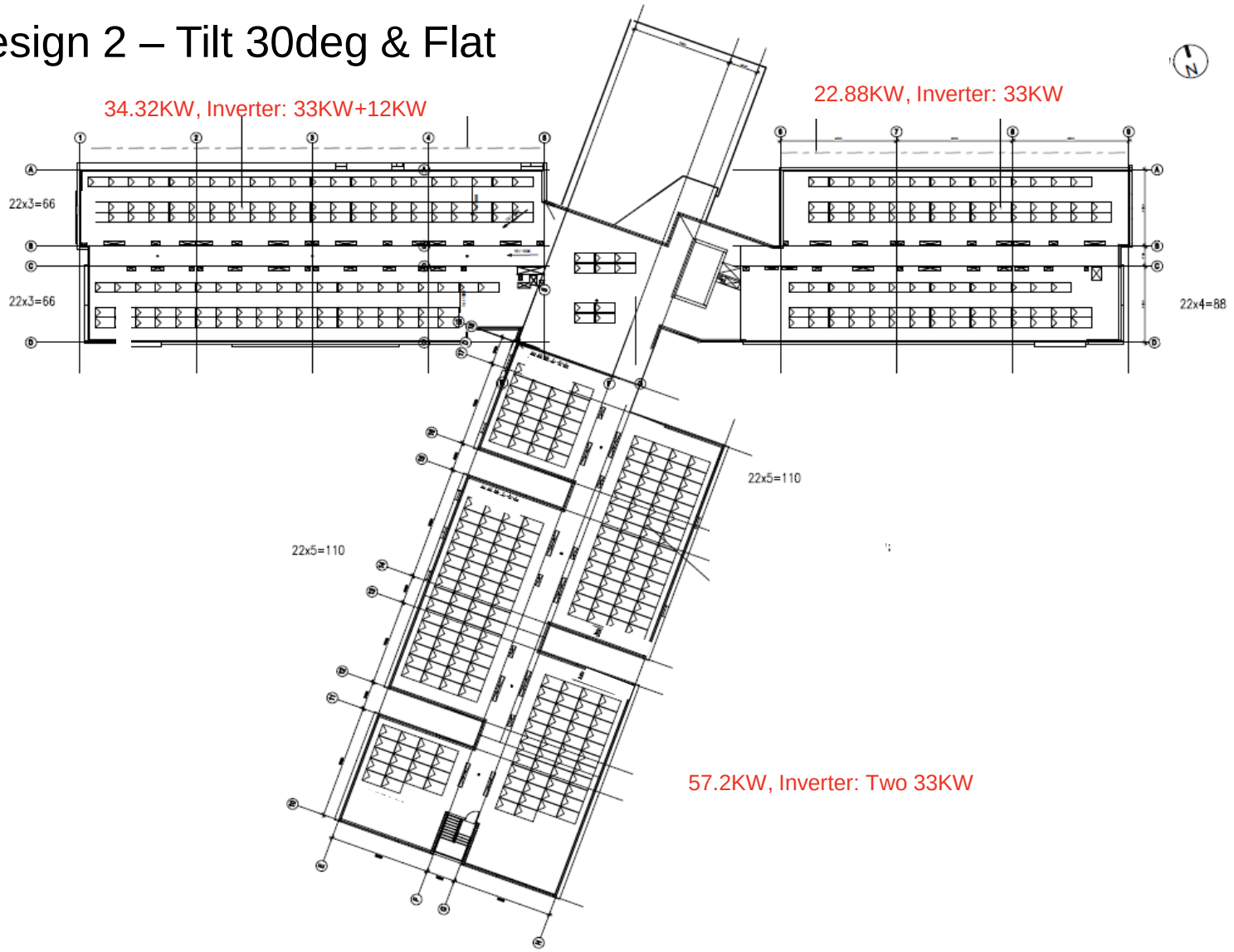
- Roof – Design 1 – All flat
  - Module
    - 1650*992*35
    - 260W
    - No: 506
  - Centralised Inverters
    - Three 33KW
    - One 33KW+12KW

PV size: 828.221m²

Capacity: 131.56KW

BIPV design

Roof – Design 2 – Tilt 30deg & Flat



BIPV design

- Roof – Design 2 – Tilt 30deg & Flat
  - Module
    - 1650*992*35
    - 260W
    - No: 440
    - Flat size: 360.096m2, 57.2KW
    - 30deg: 360.096m2, 57.2KW
  - Centralised Inverters
    - Three 33KW
    - One 33KW+12KW

PV size: 720.192m²

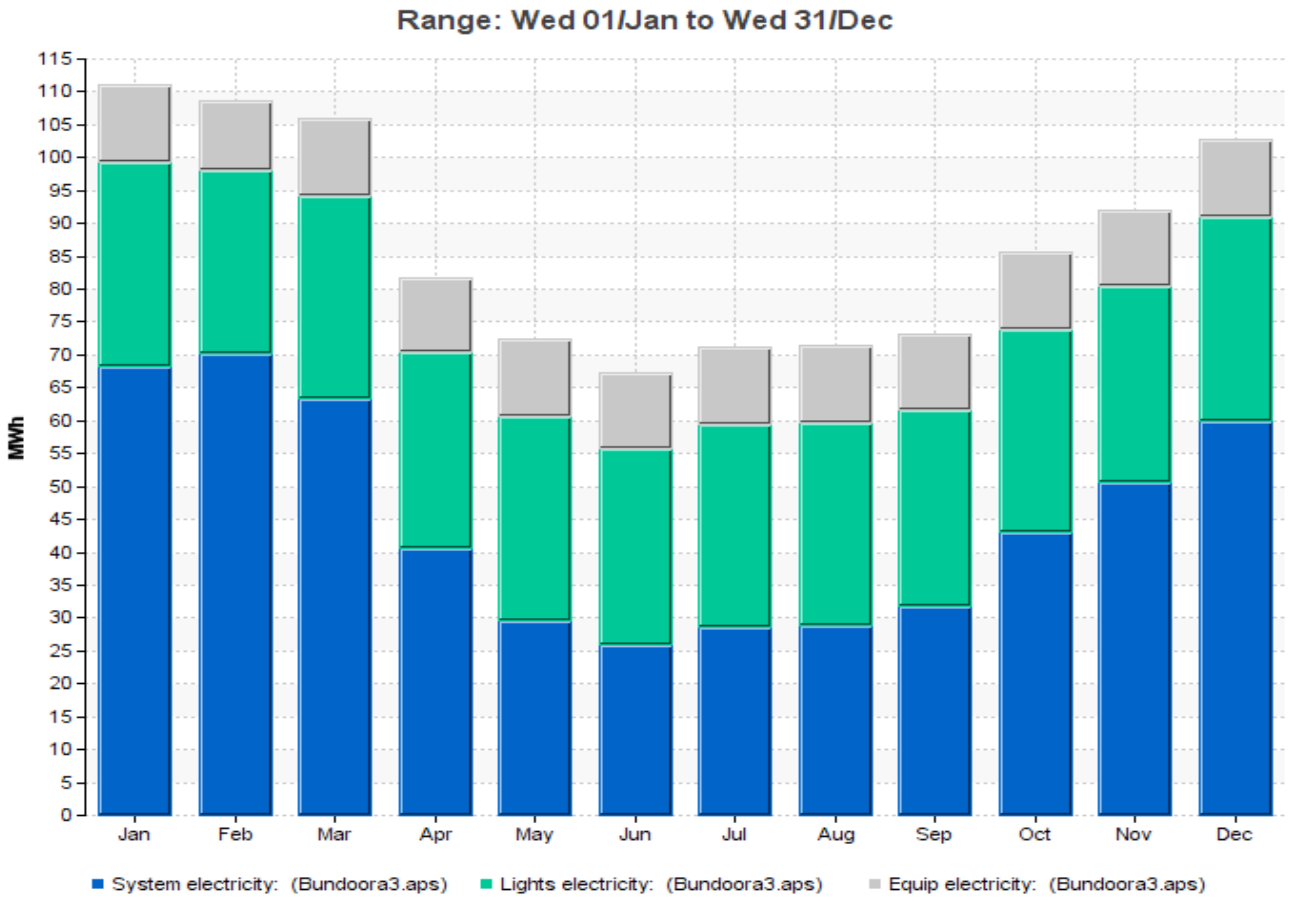
Capacity: 114.40KW

Estimating building electricity requirements

- Building information
  - Building fabric
    - Mostly derived from drawings
  - HVAC systems
    - Split systems used for Heating and Cooling
    - Lighting: fluorescent
  - Hot-water
    - Electric heat pump
- Use assumptions
  - IESVE standard zone assumptions
    - Dormitory (9 pm to 9 am HVAC)
    - Dining Room (10 am to 12 am HVAC)

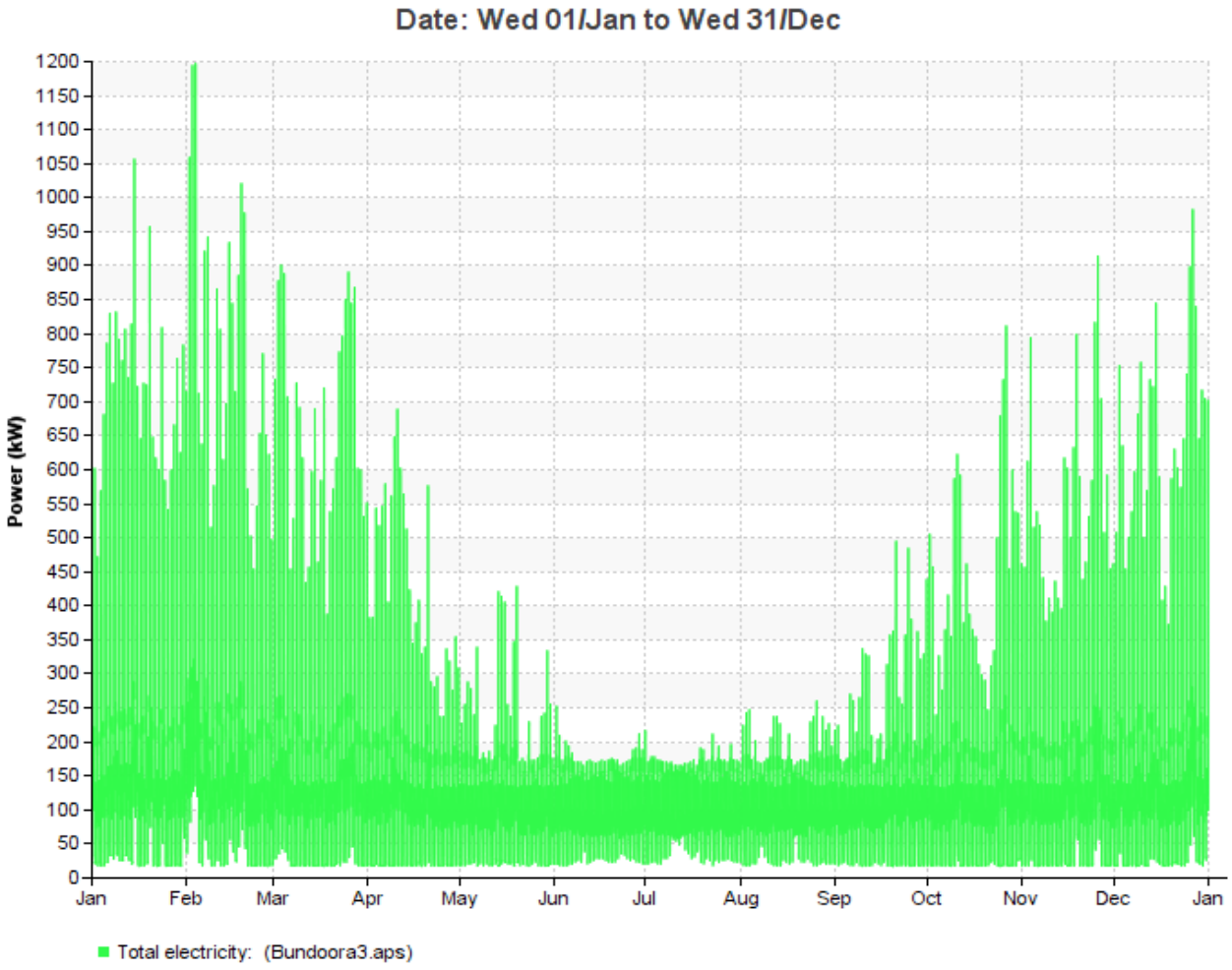
Energy consumption

	Energy intensity	
IES Load	83	kWh/m2
Residential apt building	70	kWh/m2
Hotel	455	kWh/m2



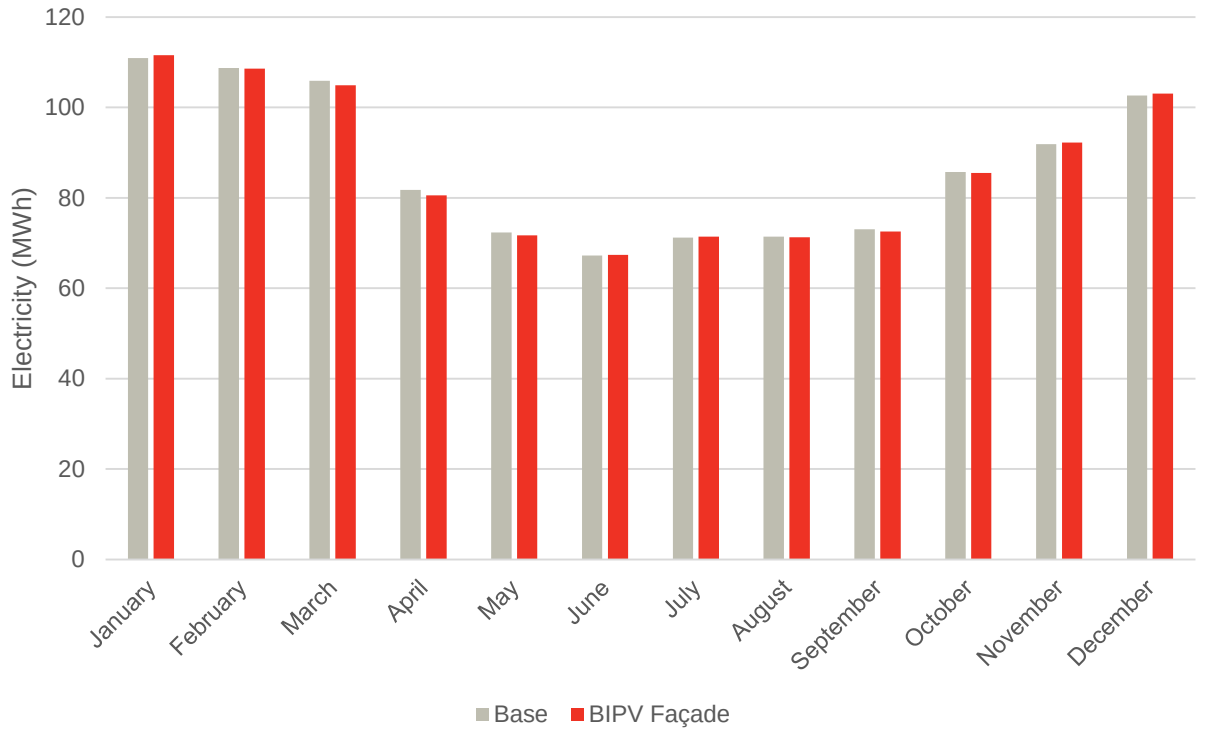
Total electricity consumption

Energy consumption



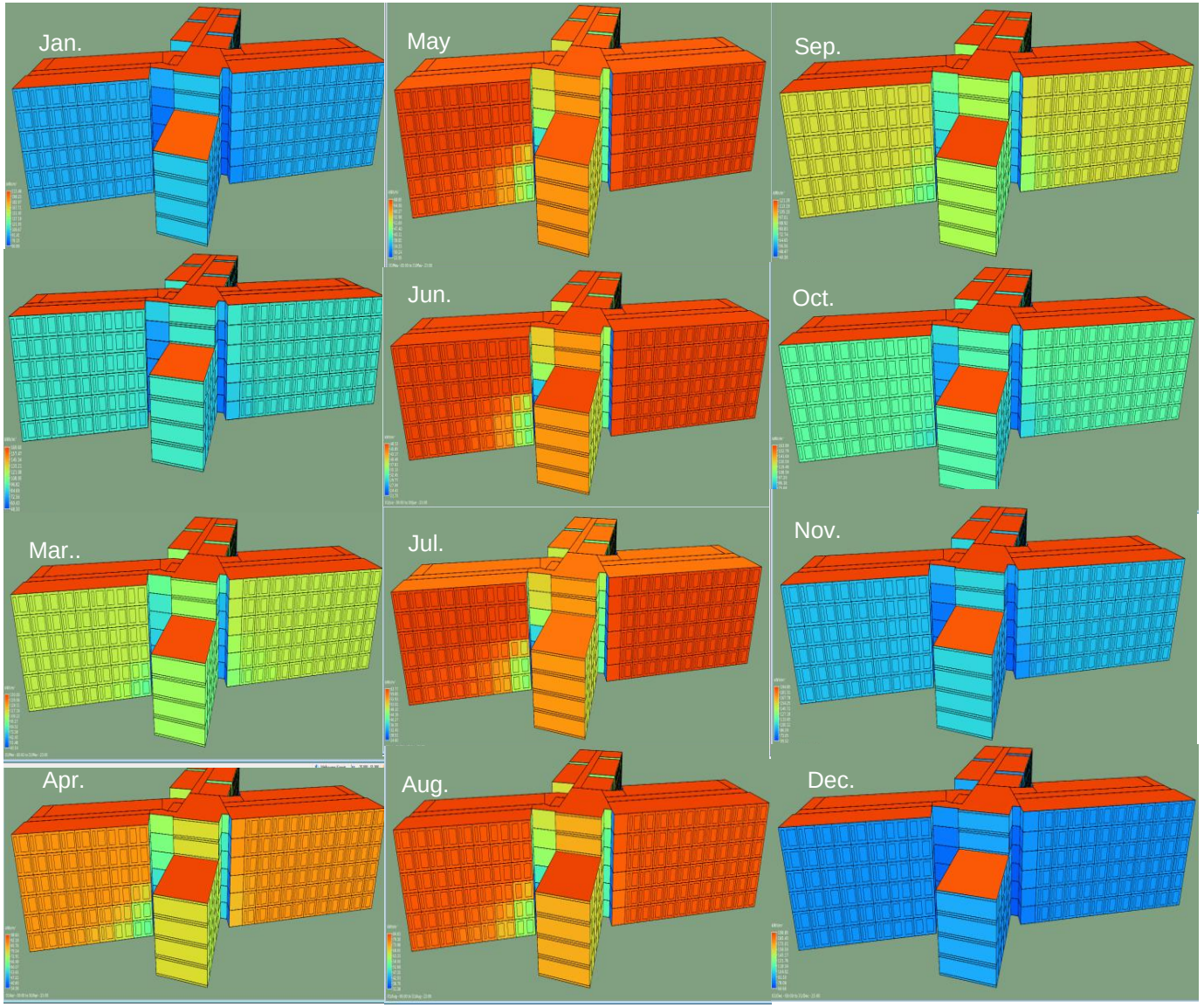
Hourly electricity demand

Energy consumption



Base Building Load Compared to BIPV Design Load

Solar Irradiation and Shading impact



Solar irradiation

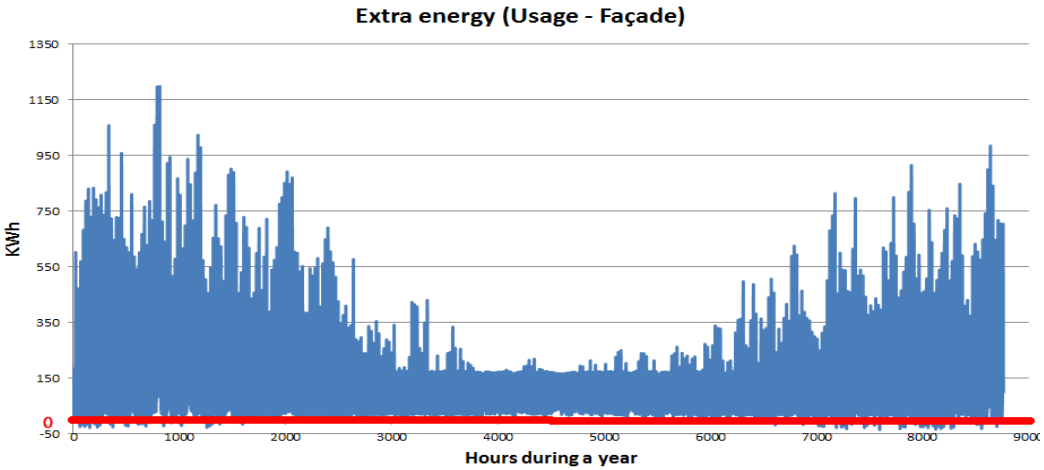
Months	PVWatts (KWh/M^2)			IESVE (KWh/M^2)		
	Façade	Roof		Façade	Roof	
		Flat	Tilt		Flat	Tilt
Jan	82.83	214.78	206.79	106.67	213.48	205.58
Feb	90.42	172.61	180.54	96.82	169.60	173.61
Mar	118.25	153.05	179.35	106.22	150.00	172.31
Apr	114.89	103.41	138.16	85.76	98.60	118.4
May	85.83	63.16	90.83	68.85	64.54	83.54
Jun	90.14	55.03	87.13	48.53	48.53	58.68
Jul	89.24	62.15	91.51	63.77	55.93	75.28
Aug	103.06	85.82	116.98	79.30	84.63	104.59
Sep	96.05	110.96	133.19	97.01	121.28	138.72
Oct	99.48	165.79	178.47	119.49	163.89	172.25
Nov	77.10	177.64	174.97	100.12	194.85	190.42
Dec	73.76	196.48	186.46	91.50	198.85	189.52

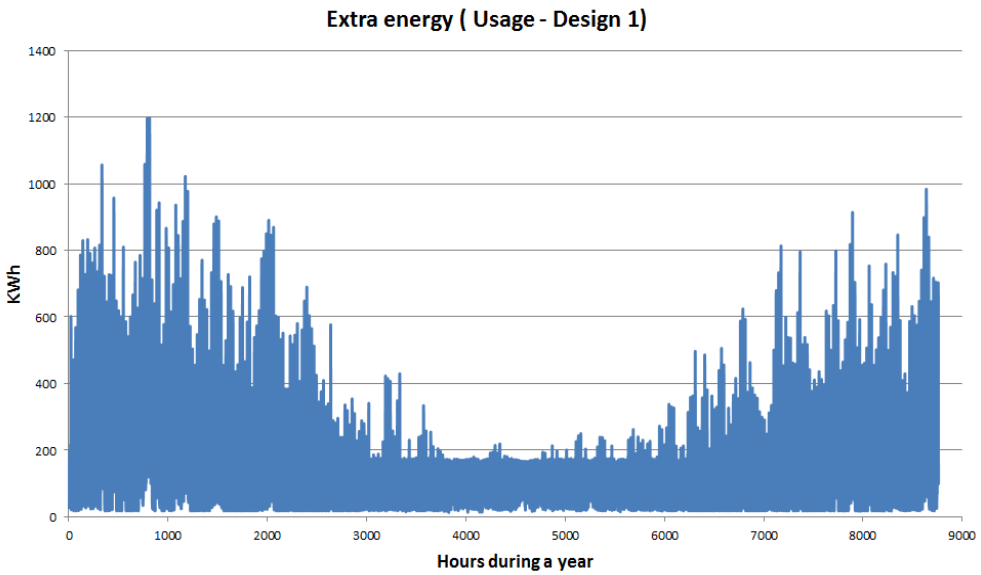
Solar and Wind Energy Resource Assessment Programme (SWERA)
The ASHRAE International Weather for Energy Calculations Version 1.1 (IWEC)

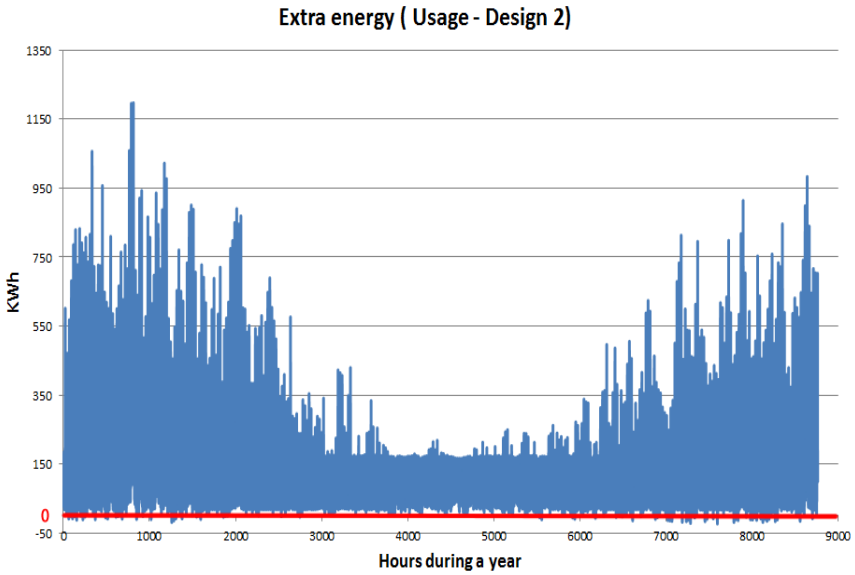
Energy outputs

Year	PVWatts (KWh)			IES (KWh)		
	Façade	Design 1	Design 2	Façade	Design 1	Design 2
1	68867.6	184993.4	171350.2	65365.01	185384.1	167321.2
2	68523.26	184068.4	170493.5	65038.18	184457.2	166484.6
3	68180.65	183148.1	169641	64712.99	183534.9	165652.2
4	67839.74	182232.3	168792.8	64389.43	182617.3	164823.9
5	67500.55	181321.2	167948.8	64067.48	181704.2	163999.8
6	67163.04	180414.5	167109.1	63747.14	180795.6	163179.8
7	66827.23	179512.5	166273.5	63428.41	179891.7	162363.9
8	66493.09	178614.9	165442.2	63111.27	178992.2	161552.1
9	66160.63	177721.8	164615	62795.71	178097.2	160744.3
10	65829.82	176833.2	163791.9	62481.73	177206.8	159940.6
11	65500.67	175949.1	162972.9	62169.32	176320.7	159140.9
12	65173.17	175069.3	162158.1	61858.48	175439.1	158345.2
13	64847.3	174194	161347.3	61549.18	174561.9	157553.4
14	64523.07	173323	160540.5	61241.44	173689.1	156765.7
15	64200.45	172456.4	159737.8	60935.23	172820.7	155981.8
16	63879.45	171594.1	158939.1	60630.55	171956.6	155201.9
17	63560.05	170736.1	158144.5	60327.4	171096.8	154425.9
18	63242.25	169882.4	157353.7	60025.77	170241.3	153653.8
19	62926.04	169033	156567	59725.64	169390.1	152885.5
20	62611.41	168187.9	155784.1	59427.01	168543.1	152121.1
21	62298.35	167346.9	155005.2	59129.87	167700.4	151360.5
22	61986.86	166510.2	154230.2	58834.22	166861.9	150603.7
23	61676.93	165677.6	153459	58540.05	166027.6	149850.7
24	61368.54	164849.3	152691.7	58247.35	165197.5	149101.4
25	61061.7	164025	151928.3	57956.12	164371.5	148355.9

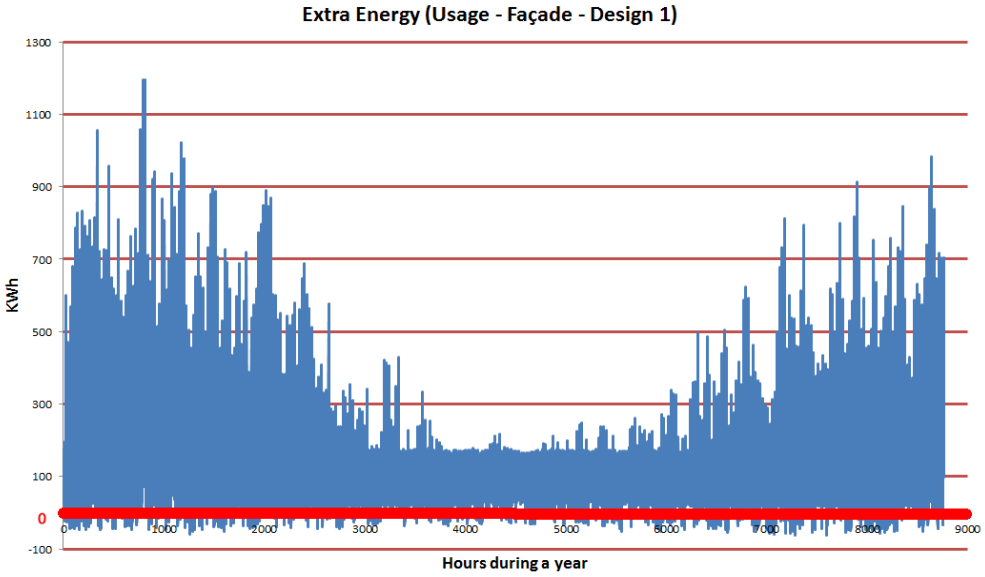
Comparison of hourly energy load and energy outputs

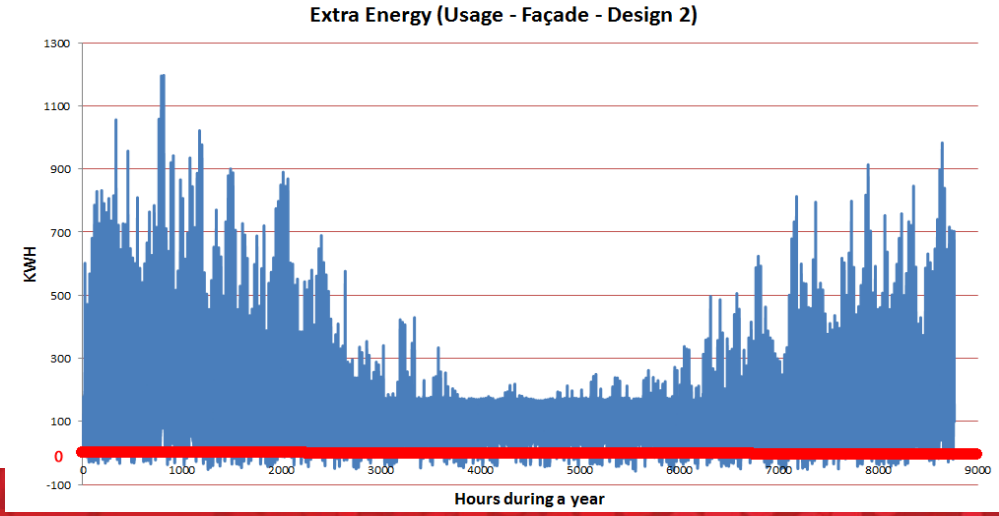






Comparison of hourly energy load and energy outputs





Cost-benefit analysis

- Net Present Value (NPV)
  - Present value of a series of future cash flows
  - $NPV = -C_0 - \sum_{n=6}^{T} \frac{M_1}{(1+r)^n} + \sum_{n=1}^{T} \frac{C_1}{(1+r)^n}$
- C_0 = net construction costs
- M_{6-25} =maintenance costs
- C_{1-25} =electricity savings, carbon trade gains

Cost information

Designs	Items	AUD
Façade	PV modules	120,224
	Centralised inverters	15,600
	Micro Inverters	78,000
	Others (Sealing, insulation, cable, isolators, circuits etc.)	14,144
	Transportation	4,000
	Installation	132,681
Roof design 1	PV modules	131,560
	Centralised inverters	26,312
	Micro Inverters	131,560
	Others (Sealing, insulation, cable, isolators, circuits etc.)	26,312
	Transportation	4,000
	Installation	57,975
Roof design 2	PV modules	114,400
	Centralised inverters	26,312
	Micro Inverters	114,400
	Others (Sealing, insulation, cable, isolators, circuits etc.)	22,880
	Transportation	4,000
	Installation	50,413

Cost-benefit analysis

- Benefits
  - Electricity rate: 0.25AUD per KWh
  - Electricity rate growth rate: 4% per annum
  - Feed-in-Tariff: 0.08AUD per KWh
  - Tax breaks & Small-scale Technology certificates: 5000 AUD
  - Transmission loss: 6.6%

Scenarios

Independent Variables	Scenarios
Discount rate	3%, 7%, 10%
Inverters	Centralised VS Micro
Carbon prices	$0/tonne, $24.15/tonne
Government incentive	$0, $5000
Energy output data	PVWatts VS IESVE
Designs	Façade only, Design 1 only, Design 2 only, Façade + Design 1, Façade + Design 2

240 scenarios

Cost-benefit (IES) – Façade

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$719.50	$861.20	$805.20
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$41/M²	$130/M²	$170/M²
		24.15	$136.50	$458.00	$124
			(Payback time: Year 24)	(Payback time: Year 25)	(Payback time: Year 25)
			$4/M2	$105/M²	$150/M²
	None	0	$142.20	$283.90	$228.00
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$46/M²	$135/M²	$175/M²
		24.15	443.7	$765.20	$431.20
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$10/M²	$111/M²	$156/M²
Micro Inverters	5000	0	$138.20	$841.60	$695.60
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$88/M²	$187/M²	$231/M²
		24.15	$439.70	$438.40	$14
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$52/M²	$162/M²	$211/M²
	NONE	0	$445.40	$264.30	$118.30
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$94/M²	$192/M2	$236/M²
		24.15	$746.90	$745.60	$321.50
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$58/M²	$168/M²	$217/M²

Cost-benefit (PVWatts) – Façade

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$159.20	$24.20	$504.80
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$24/M²	$118/M²	$161/M²
		24.15	$12,797.70	$784.30	$735
			(Payback time: Year 24)	(Payback time: Year 25)	(Payback time: Year 25)
			N/A	$93/M²	$141/M²
	None	0	$466.50	$331.40	$812.10
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$30/M²	$124/M²	$167/M²
		24.15	7797.7	$207.00	$157.70
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$0/M²	$98/M²	$146/M²
Micro Inverters	5000	0	$462.39	$4.61	$395.15
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$72/M²	$175/M²	$222/M²
		24.15	$717.28	$764.74	$625
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$34/M2	$150/M²	$202/M²
	None	0	$769.64	$311.86	$702.40
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$78/M²	$181/M²	$228/M²
		24.15	$139.99	$187.45	$48.03
			(Payback time: Year 25)	(Payback time: Year 25)	(Payback time: Year 25)
			$39/M²	$155/M²	$207/M²

Cost-benefit – Façade

To replace double glazed low-e glass façade, the integrated polycrystalline PV design is feasible in this and similar case buildings under the proposed scenarios.

Cost-benefit (IES) – Design 1

	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$490,922.06	$256,166.62	$150,235.85
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$575,635.23	$313,380.84	$195,062
			(Payback time: Year 6)	(Payback time: Year 6)	(Payback time: Year 7)
	NONE	0	$485,922.06	$251,166.62	$145,235.85
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 9)
		24.15	$570,635.23	$308,380.84	$190,061.91
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 7)
Micro	5000	0	$419,820.98	$171,093.83	$59,043.37
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 16)
		24.15	$504,534.15	$228,308.05	$103,869
			(Payback time: Year 7)	(Payback time: Year 10)	(Payback time: Year 13)
	NONE	0	$414,820.98	$166,093.83	$54,043.37
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 16)
		24.15	$499,534.15	$223,308.05	$98,869.44
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 13)

Cost-benefit (PVWatts) – Design 1

	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$489,306.92	$255,075.77	$149,381.20
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$573,841.53	$312,169.39	$194,113
			(Payback time: Year 6)	(Payback time: Year 6)	(Payback time: Year 7)
	NONE	0	$484,306.92	$250,075.77	$144,381.20
			(Payback time: Year 6)	(Payback time: Year 8)	(Payback time: Year 9)
		24.15	$568,841.53	$307,169.39	$189,112.77
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 7)
Micro	5000	0	$418,205.84	$170,002.98	$58,188.72
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 16)
		24.15	$502,740.44	$227,096.60	$102,920
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 13)
	NONE	0	$413,205.84	$165,002.98	$53,188.72
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 16)
		24.15	$497,740.44	$222,096.60	$97,920.30
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 13)

Cost-benefit (IES) – Design 2

	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$443,547.17	$233,185.14	$138,261.68
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$520,006.29	$284,824.68	$178,720
			(Payback time: Year 6)	(Payback time: Year 6)	(Payback time: Year 7)
	NONE	0	$438,547.17	$228,185.14	$133,261.68
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$515,006.29	$279,824.68	$173,720.10
			(Payback time: Year 6)	(Payback time: Year 6)	(Payback time: Year 7)
Micro	5000	0	$389,606.09	$165,272.35	$64,229.20
			(Payback time: Year 9)	(Payback time: Year 11)	(Payback time: Year 15)
		24.15	$466,065.21	$216,911.88	$104,688
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 12)
	NONE	0	$384,606.09	$160,272.35	$59,229.20
			(Payback time: Year 9)	(Payback time: Year 11)	(Payback time: Year 15)
		24.15	$461,065.21	$211,911.88	$99,687.63
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 12)

Cost-benefit (PVWatts) – Design 2

	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$460,199.96	$244,432.23	$147,073.52
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$538,500.19	$297,315.23	$188,506
			(Payback time: Year 5)	(Payback time: Year 6)	(Payback time: Year 7)
	NONE	0	$455,199.96	$239,432.23	$142,073.52
			(Payback time: Year 6)	(Payback time: Year 7)	(Payback time: Year 8)
		24.15	$533,500.19	$292,315.23	$183,506.17
			(Payback time: Year 6)	(Payback time: Year 6)	(Payback time: Year 7)
Micro	5000	0	$372,111.96	$156,344.23	$58,985.52
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 15)
		24.15	$450,412.19	$209,227.23	$100,418
			(Payback time: Year 8)	(Payback time: Year 9)	(Payback time: Year 12)
	NONE	0	$367,111.96	$151,344.23	$53,985.52
			(Payback time: Year 9)	(Payback time: Year 12)	(Payback time: Year 15)
		24.15	$445,412.19	$204,227.23	$95,418.17
			(Payback time: Year 8)	(Payback time: Year 10)	(Payback time: Year 12)

Cost-benefit – BAPV

- Both designs have positive payback periods in all of the proposed scenarios.
- Under the current discount rate (3%) and using centralised inverters, the payback time is actually quite short, i.e. around 6-7 years.
- The longest payback year can go up to 16 within the most critical situation (i.e. discount rate as at 10%, and using micro inverters), which is also acceptable to clients.

Cost-benefit (IES) – Façade +Design 1

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$445,375.42	$132,037.47	$399.08
			(Payback time: Year 12)	(Payback time: Year 16)	(Payback time: Year 25)
			N/A	N/A	$11/m2
		24.15	$568,687.88	$215,321.17	$55,920
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 18)
			N/A	N/A	
	None	0	$450,375.42	$137,037.47	$91.83
			(Payback time: Year 11)	(Payback time: Year 15)	(Payback time: Year 22)
			N/A	N/A	$5/m2
		24.15	$573,688	$220,321.17	$60,920.05
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 17)
			N/A	N/A	
Micro	5000	0	$337,119.54	$1,526.26	$781.94
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
			N/A	N/A	$170/M2
		24.15	$460,432.00	$84,809.96	$577
			(Payback time: Year 13)	(Payback time: Year 19)	(Payback time: Year 25)
			N/A	N/A	$96/M2
	None	0	$332,119.54	$948.97	$204.64
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
			N/A	$5/M2	$175/M2
		24.15	$455,432.00	$79,809.96	$884.07
			(Payback time: Year 13)	(Payback time: Year 20)	(Payback time: Year 25)
			N/A	N/A	$102/M2

Cost-benefit (PVWatts) – Façade + Design 1

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$463,237.16	$145,724.13	$2,474.93
			(Payback time: Year 11)	(Payback time: Year 15)	(Payback time: Year 25)
			N/A	N/A	N/A
		24.15	$588,079.94	$230,041.39	$68,536
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 17)
			N/A	N/A	N/A
	None	0	$458,237.16	$140,724.13	$128.55
			(Payback time: Year 11)	(Payback time: Year 15)	(Payback time: Year 25)
			N/A	N/A	$3/M2
		24.15	$583,079.94	$225,041.39	$63,535.62
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 17)
			N/A	N/A	N/A
Micro	5000	0	$349,981.28	$10,212.92	$511.41
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
			N/A	N/A	$162/M2
		24.15	$474,824.06	$94,530.18	$232
			(Payback time: Year 13)	(Payback time: Year 19)	(Payback time: Year 25)
			N/A	N/A	$87/M2
	None	0	$344,981.28	$5,212.92	$818.66
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
			N/A	N/A	$168/M2
		24.15	$469,824.06	$89,530.18	$538.78
			(Payback time: Year 13)	(Payback time: Year 19)	(Payback time: Year 25)
			N/A	N/A	$93/M2

Cost-benefit (IES) – Façade +Design 2

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$403,000.53	$114,055.99	$501.23
			(Payback time: Year 12)	(Payback time: Year 16)	(Payback time: Year 25)
					$19/M²
		24.15	$517,430.06	$191,340.27	$44,245
			(Payback time: Year 10)	(Payback time: Year 13)	(Payback time: Year 19)
	None	0	$398,000.53	$109,055.99	$808.48
			(Payback time: Year 12)	(Payback time: Year 16)	(Payback time: Year 25)
					$25/M²
		24.15	$512,430.06	$186,340.27	$39,245.47
			(Payback time: Year 10)	(Payback time: Year 13)	(Payback time: Year 19)
Micro	5000	0	$306,904.65	$127.49	$660.52
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
				$5/M2	$164/M2
		24.15	$421,334.18	$72,989.06	$178
			(Payback time: Year 13)	(Payback time: Year 20)	(Payback time: Year 25)
					$95/M2
	None	0	$301,904.65	$434.73	$83.22
			(Payback time: Year 15)	(Payback time: Year 25)	(Payback time: Year 25)
				$11/M2	$169/M2
		24.15	$416,334.18	$67,989.06	$484.95
			(Payback time: Year 13)	(Payback time: Year 20)	(Payback time: Year 25)
					$101/M2

Cost-benefit (PVWatts) – Façade + Design 2

Inverters	Government Incentives (AUD)	Carbon Price (AUD/tonne)	Discount Rate		
			3%	7.00%	10%
Centralised Inverters	5000	0	$434,130.20	$135,080.58	$167.25
			(Payback time: Year 11)	(Payback time: Year 15)	(Payback time: Year 25)
		24.15	$552,263.61	$214,866.41	$62,678
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 17)
	None	0	$429,130.20	$130,080.58	$474.50
			(Payback time: Year 11)	(Payback time: Year 15)	(Payback time: Year 25)
					$6/M^2
		24.15	$547,263.61	$209,866.41	$57,677.68
			(Payback time: Year 9)	(Payback time: Year 13)	(Payback time: Year 18)
Micro	5000	0	$338,034.32	$16,729.37	$326.54
			(Payback time: Year 14)	(Payback time: Year 24)	(Payback time: Year 25)
					$145/M2
		24.15	$456,167.73	$96,515.21	$35
			(Payback time: Year 13)	(Payback time: Year 19)	(Payback time: Year 25)
					$74/M2
	None	0	$333,034.32	$11,729.37	$633.79
			(Payback time: Year 15)	(Payback time: Year 24)	(Payback time: Year 25)
					$151/M2
		24.15	$451,167.73	$91,515.21	$341.80
			(Payback time: Year 13)	(Payback time: Year 19)	(Payback time: Year 25)
					$80/M2

Cost-benefit – Façade + BAPV

- In most scenarios, the payback times are positive disregarding how much the material offsets would be.
- Only when the discount rate is 10%, the minimum façade costs per square meter should be considered. However, the costs are still less than the general total cost of double glazed low-e glass, which means the combined façade and roof designs are feasible in the case project.

The payback years by offsetting double glazed low-e glass ($300/m^2)

Designs	Inverters	PVWatts			IES		
		Discount Rate			Discount Rate		
		3%	7.00%	10%	3%	7.00%	10%
Façade + Design 1	Centralised Inverters	Year 5	Year 6	Year 6	Year 5	Year 6	Year 6
	Micro Inverters	Year 8	Year 11	Year 13	Year 9	Year 11	Year 14
Façade + Design 2	Centralised Inverters	Year 5	Year 5	Year 6	Year 5	Year 6	Year 6
	Micro Inverters	Year 8	Year 10	Year 12	Year 8	Year 10	Year 13

Cost-benefit – Façade + BAPV

- If using centralised inverters, the payback time is around 5-6 years even with high discount rate; while when going to micro inverters, the payback year can reach to about half of the PV lifecycle.

Interesting findings

- When comparing the NPV results of the two roof designs, we find that although under some scenarios the payback time is one year shorter in Design 2, generally the NPV values in Design 1 are higher than Design 2.
- It indicates that in the case building, the flat design is better than the tilted design from client's economic perspective. This is because the flat design can use more solar panels on the same size of roof spaces comparing to tilted design.
- This finding is different from the rule of thumb in PV designs that the tilted degree is consistent with the local altitude.

Interesting findings

- Under the most critical situation (i.e. ‘no carbon price and government incentive’ scenario), the roof designs show the payback time as 6-9 years by using centralised inverters, and 9-16 years for micro inverters.
- When combining the roof designs with the integrated façade design (considering material offset), we notice that the payback periods are reduced for at least one year time.
- The conclusion from this finding is that the integrated façade PV design is actually more economically beneficial comparing to the roof mounted designs only when the original façade material is double glazing low-e glass.

Interesting findings

- The use of micro inverters to replace the centralised inverters will reduce the maintenance costs; however due to the higher capital costs, the payback time will be delayed for another 3-7 years depending on the discount rates.
- The revoked carbon price $24.15/ton and the current government incentives in Melbourne would not significantly impact on the payback time, at least in the case building.
- This has been a huge change and a successful example on promoting green products in buildings in the last two decades due to the reduction of PV costs.

Building cluster - PV

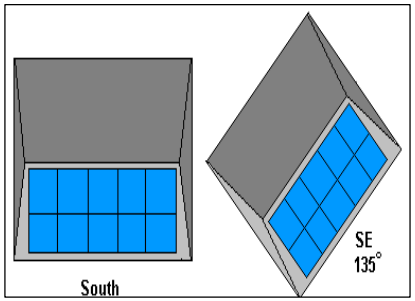
This study focuses on PV designs for a building cluster in Melbourne. The aim is to optimise the green energy generation to match with the energy consumptions in a precinct.

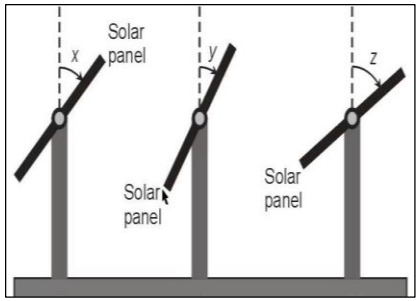
This study generates the best Value-for-Money solutions and strategies for changing the existing buildings to powerhouses.

AIM OF THE STUDY

COST BENEFIT ANALYSIS BY INSTALLING A SOLAR PV SYSTEM

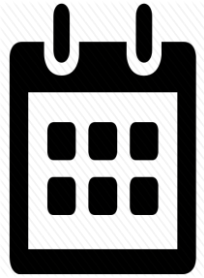
1. Different designs of the solar PV system
2. Difference in the output based on: 15-minutes interval and monthly interval
3. Individual meter system is better or the cluster system

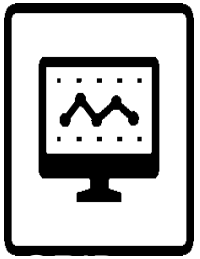




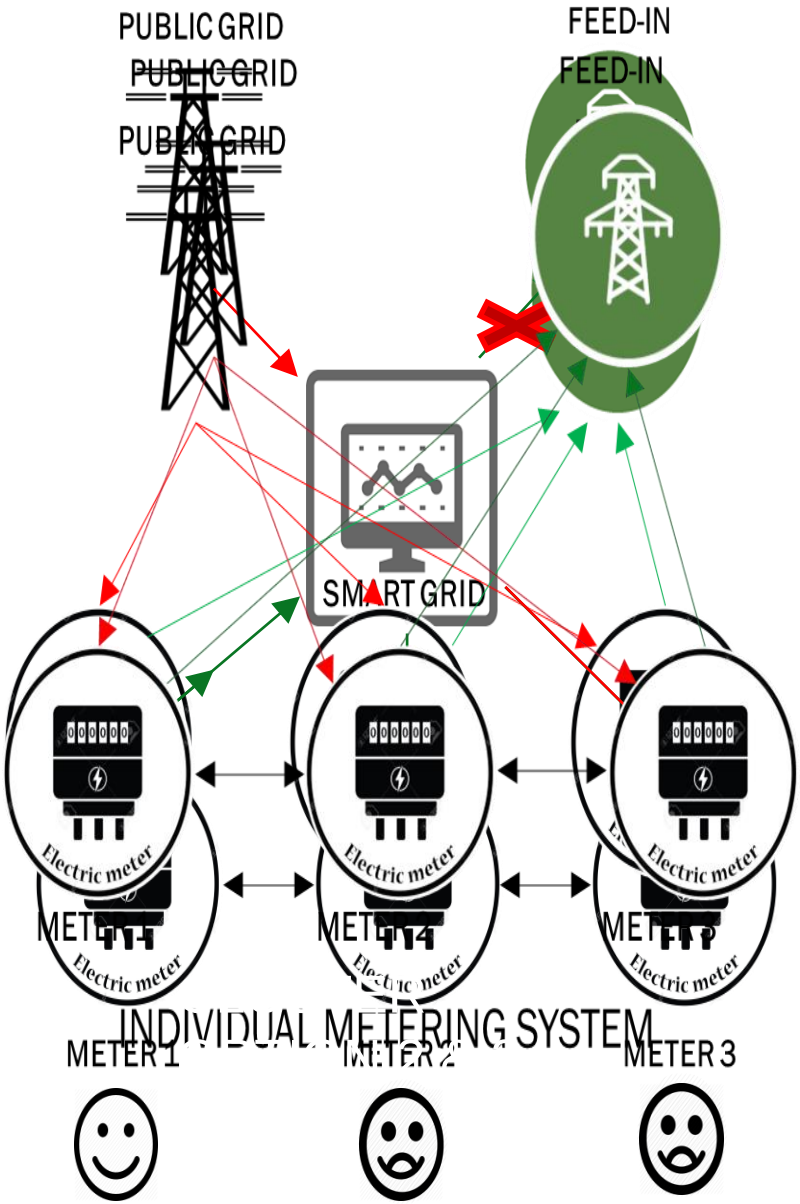
CONTRIBUTION TO THE INDUSTRY

1. Currently data analysis on hourly or monthly basis
2. But, 15-minutes interval data analysis → accurate projection
3. Difference of cost benefit analysis?
4. Benefit from using a cluster design system





INDIVIDUAL AND CLUSTER METERING SYSTEM



IF METER 1 HAS NO EXTRA ENERGY

IF METER 1 HAS EXTRA ENERGY

Note:
CLUSTER OPTION 2: No Smart Grid
No-min interval data

CLUSTER OPTION 1: Using a Smart Grid
15-min interval data

CLUSTER OPTION 3: No Smart Grid
Monthly interval data

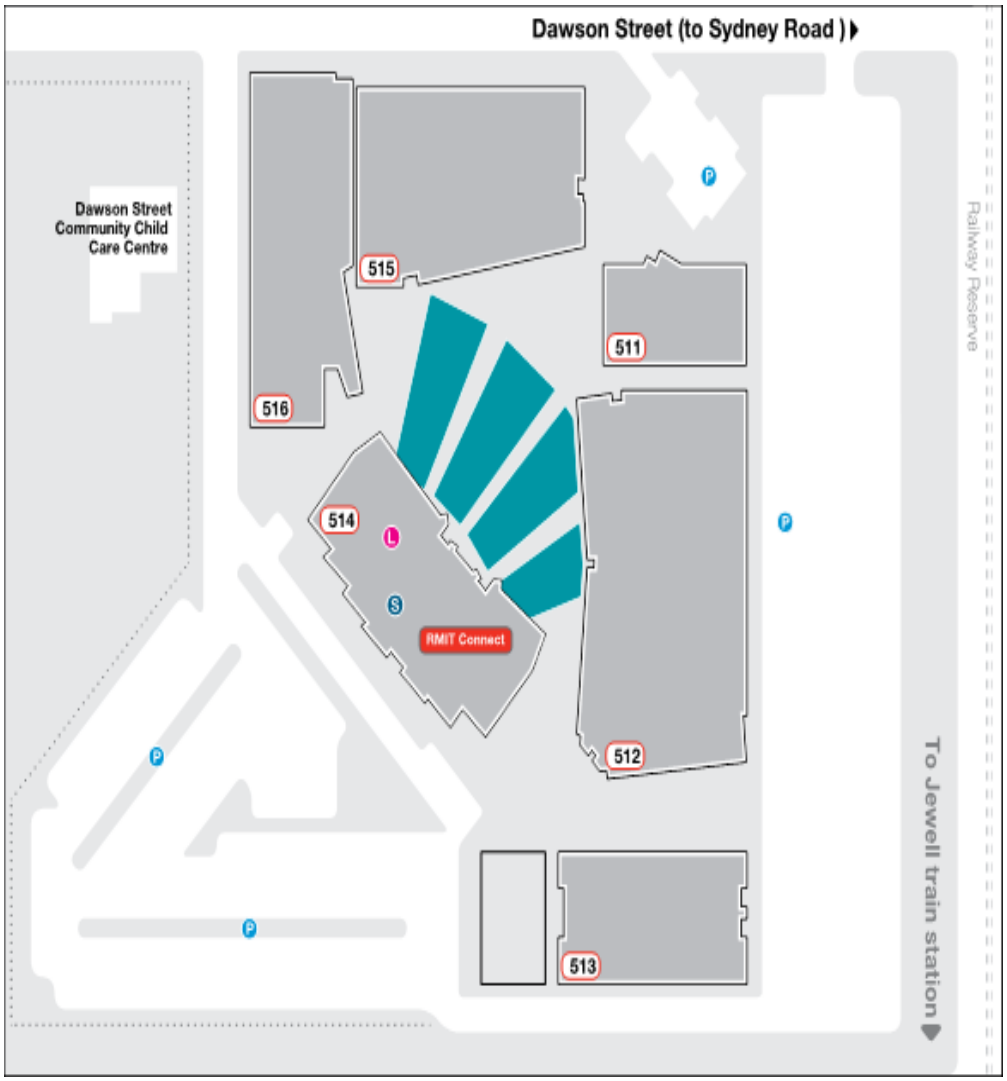
Note:
CLUSTER OPTION 2: No Smart Grid
No-min interval data

CLUSTER OPTION 1: Using a Smart Grid
15-min interval data

CLUSTER OPTION 3: No Smart Grid
Monthly interval data

CLUSTER

BACKGROUND



TILT	ORIENTATION
Flat	0-degree azimuth
10 degree	0, 10 degree east, 10 degree west
20 degree	0, 10 degree east, 10 degree west
30 degree	0, 10 degree east, 10 degree west

Each Meter (1 case)

↓

10 Designs

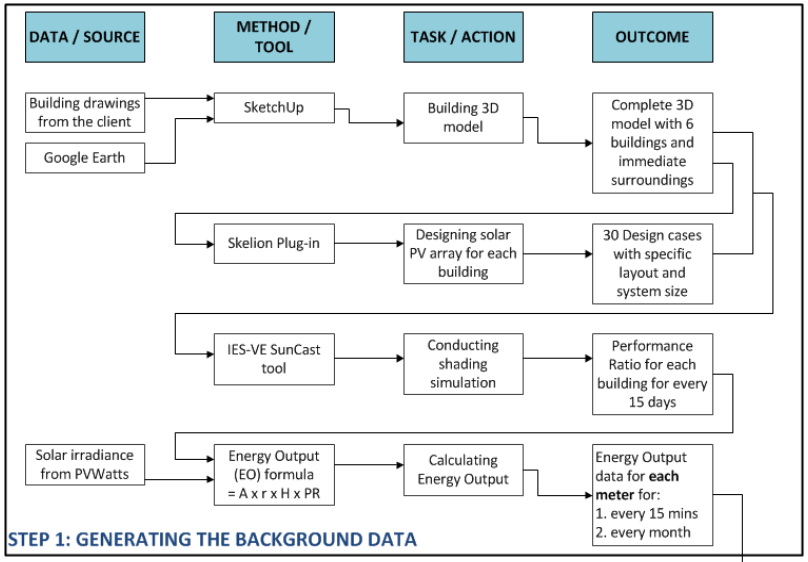
↓

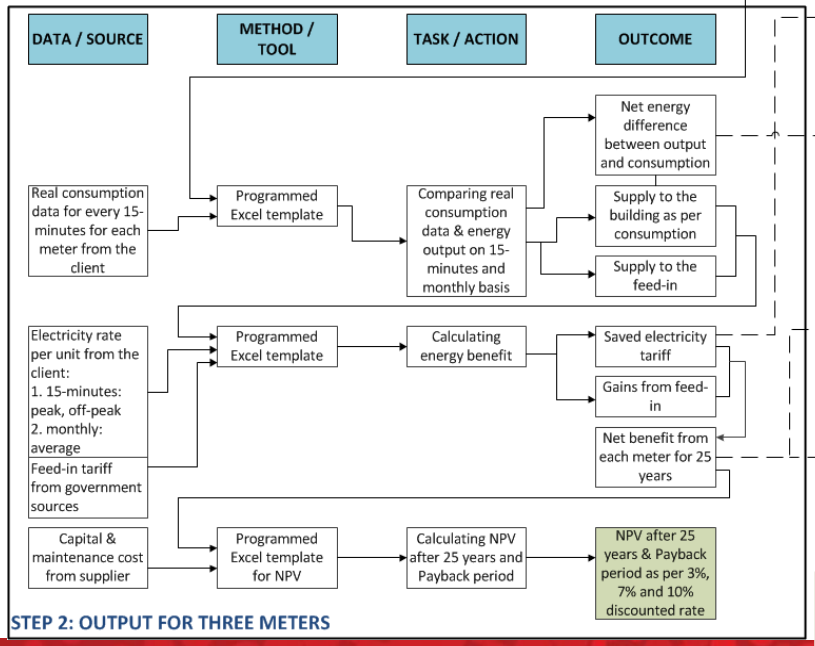
3 Meter→ 3 x 10

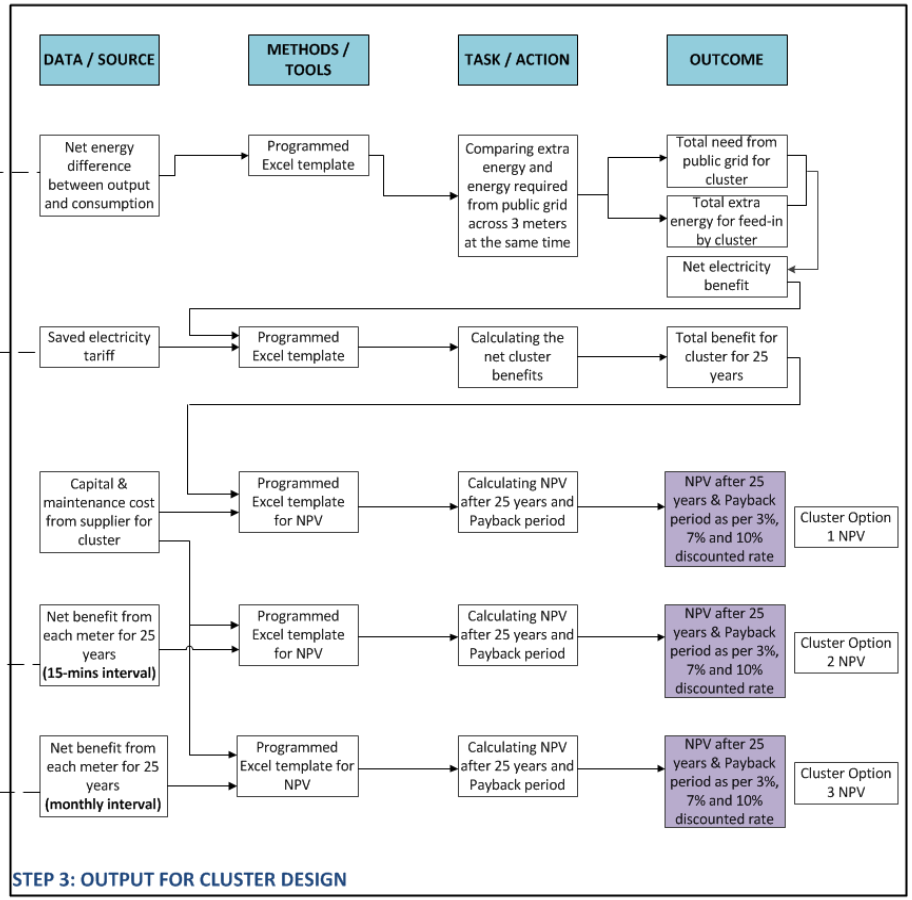
↓

30 DESIGN CASES!!!

INVESTIGATION PROCESS

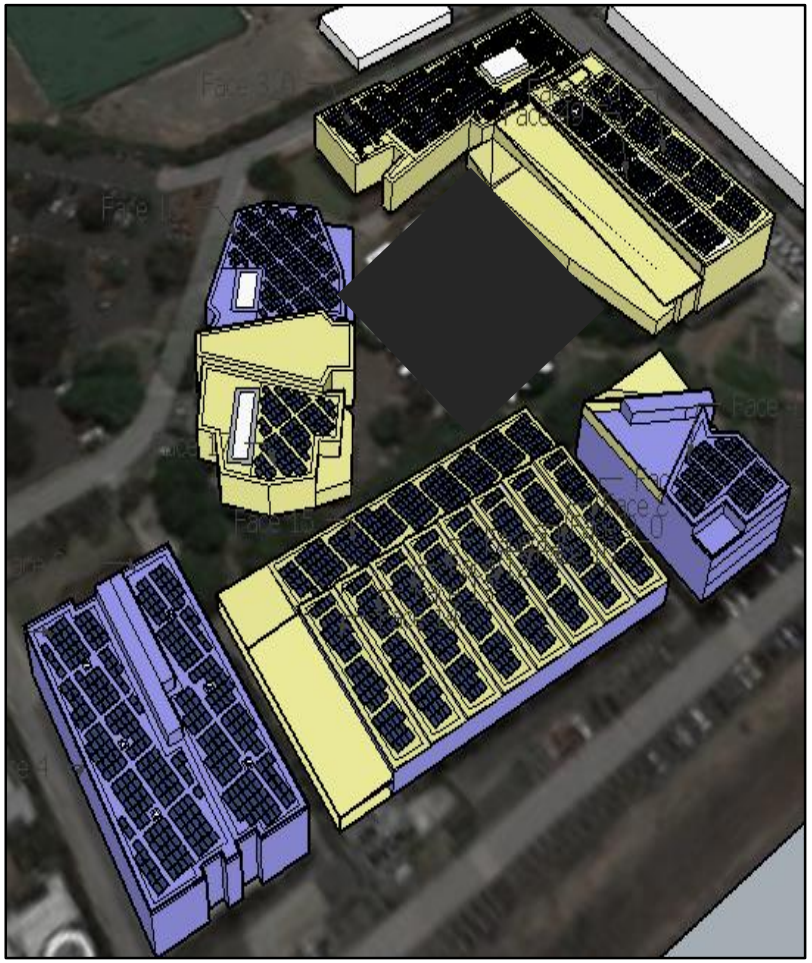




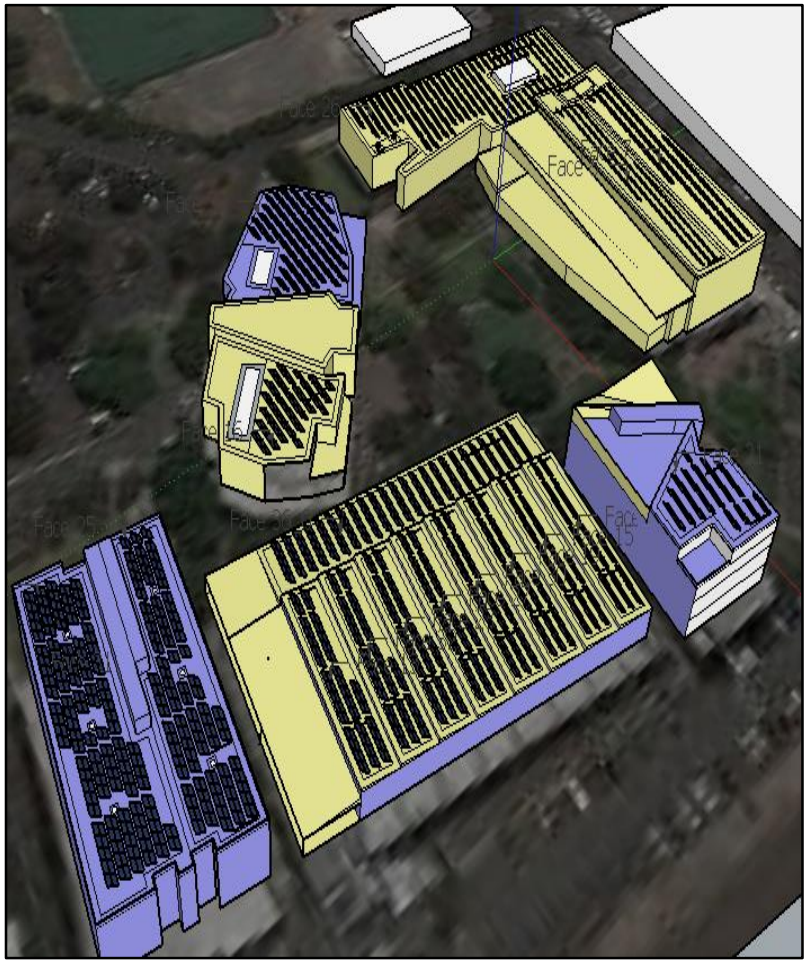


MODEL IMAGES

Solar PV System Layout



Solar PV array layout - Flat



Solar PV array layout – 30 degree + 10 East

OUTCOMES

SUMMARY TABLE – System Size

	B. 511 (No. of Panels)	**B. 512** (No. of Panels)	**B. 513** (No. of Panels)	**B. 514** (No. of Panels)	**B. 515** (No. of Panels)	**B. 516** (No. of Panels)	**SYSTEM SIZE** (KW)
Flat	85	781	367	291	512	439	618.75
10 D + 10 West	77	664	326	294	316	452	532.25
10 D + 0 Azi	70	648	342	294	320	462	534.00
10 D + 10 East	76	895	378	300	338	462	612.25
20 D + 10 West	80	656	353	310	314	460	543.25
20 D + 0 Azi	80	686	366	304	328	482	561.50
20 D + 10 East	88	900	384	310	349	480	627.75
30 D + 10 West	76	658	338	284	294	428	519.50
30 D + 0 Azi	81	698	346	294	316	448	545.75
30 D + 10 East	80	864	411	332	362	506	638.75

VALUES AND ASSUMPTIONS

- The consumption will be the same for 25 years
- Electricity rate per unit: $0.19/kWh – peak time

  $0.14/kWh – off-peak time

  $0.165/kWh – average for each month
- Electricity rate per unit will increase by 3.5% every year (AEMC)
- Feed-in tariff = $0.113/kWh (Essential Services Commission)
- The system performance will reduce by: 5% in Year 2

  0.5% from Year 3 to 25
- For capital costs: $1.40/watt – PV modules, frame, others

  $0.20/watt – inverter – also as maintenance cost every 10 years

  $70/sq.m. – installation cost
- Government rebates and discounts not included in the Capital Cost
- No additional cost considered for Smart Metering System in Cluster design

SUGGESTIONS TO THE CLIENT

- Best Design → 30 /20 D + 10 E

METER	BEST DESIGN	ENERGY OUTPUT (kWh)	NET BENEFIT (AUD)	NPV (AUD)	PAYBACK
Meter 1	30 D + 10 East	333448.92	54923.73	735669.85	9
Meter 2	20 D + 10 East	488025.36	82217.07	1123239.39	9
Meter 3	30 D + 10 East	148407.37	24539.03	308061.48	11

- Payback Period → 9 years
- Smart grid is not recommended

SUGGESTIONS TO THE PV INDUSTRY

- Design option affects the Energy Output and NPV

  No general best design but ‘East facing’ performs best

  Depends on the building design and that particular case

- 15-min better than monthly – accurate data, net benefits

DESIGN	NET BENEFIT YEAR 1 15-MINS INTERVAL METER 1	NET BENEFIT YEAR 1 MONTHLY INTERVAL METER 1	DIFFERENCE	% DIFFERENCE
Flat	53320.23	53322.52	-2.29	0.004
10 D + 10 W	46702.78	45862.67	840.11	1.799
10 D + 0 Azi	49391.59	48730.90	660.69	1.338
10 D + 10 E	48618.47	47954.57	663.90	1.366
20 D + 10 W	48714.54	47974.38	740.16	1.519
20 D + 0 Azi	50963.88	50475.86	488.02	0.958
20 D + 10 E	52047.03	51730.52	316.51	0.608
30 D + 10 W	46313.26	45336.23	977.03	2.110
30 D + 0 Azi	49049.01	48327.86	721.16	1.470
30 D + 10 E	54923.73	55019.07	-95.34	0.174

NET BENEFIT YEAR 1 15-MINS INTERVAL CLUSTER	NET BENEFIT YEAR 1 MONTHLY INTERVAL CLUSTER	DIFFERENCE	% DIFFERENCE
139738.72	137453.00	2285.72	1.636
129208.21	125818.20	3390.01	2.624
131627.78	128444.05	3183.73	2.419
147856.79	145245.74	2611.05	1.766
136394.67	133156.62	3238.05	2.374
141265.63	138366.33	2899.30	2.052
157058.76	154976.00	2082.76	1.326
132539.71	128939.15	3600.56	2.717
139731.49	136486.41	3245.08	2.322
161679.83	160030.47	1649.36	1.020

NPV AFTER 25 YEARS METER 1 15-MINS INTERVAL	NPV AFTER 25 YEARS METER 1 MONTHLY INTERVAL	DIFFERENCE AFTER 25 YEARS	DIFFERENCE PER YEAR	% DIFFERENCE
657543.26	684944.70	27401.44	1096.05	4.001
618163.94	616490.70	-1673.25	-66.92	0.271
670592.00	676475.06	5883.06	235.32	0.870
642972.54	647864.16	4891.62	195.66	0.755
659397.44	662645.78	3248.34	129.93	0.490
689782.20	701659.68	11877.48	475.09	1.693
702758.65	720199.88	17441.23	697.64	2.422
629933.59	625567.32	-4366.27	-174.65	0.698
670700.06	674907.40	4207.34	168.29	0.623
735669.85	767237.68	31567.83	1262.71	4.114

SUGGESTIONS TO THE PV INDUSTRY

- Cluster metering system better than individual metering system

	CLUSTER OPTION 1 (A)		CLUSTER OPTION 2 (B)		CLUSTER OPTION 3 (C)	
BEST DESIGN	NPV (AUD)	PAYBACK	NPV (AUD)	PAYBACK	NPV (AUD)	PAYBACK
30 D + 10 East	2200169.53	9	2178492.38	9	2217552.00	9
NPV (A) – NPV (B) = 2200169.53 – 2178492.38 = 21677.15						
NPV (C) – NPV (A) = 2217552.00 - 2200169.53 = 17382.47						

- Smart grid is not suitable for every project
- Payback is still not very acceptable for all clients
  need to find more strategies, government benefits, feed-in tariff

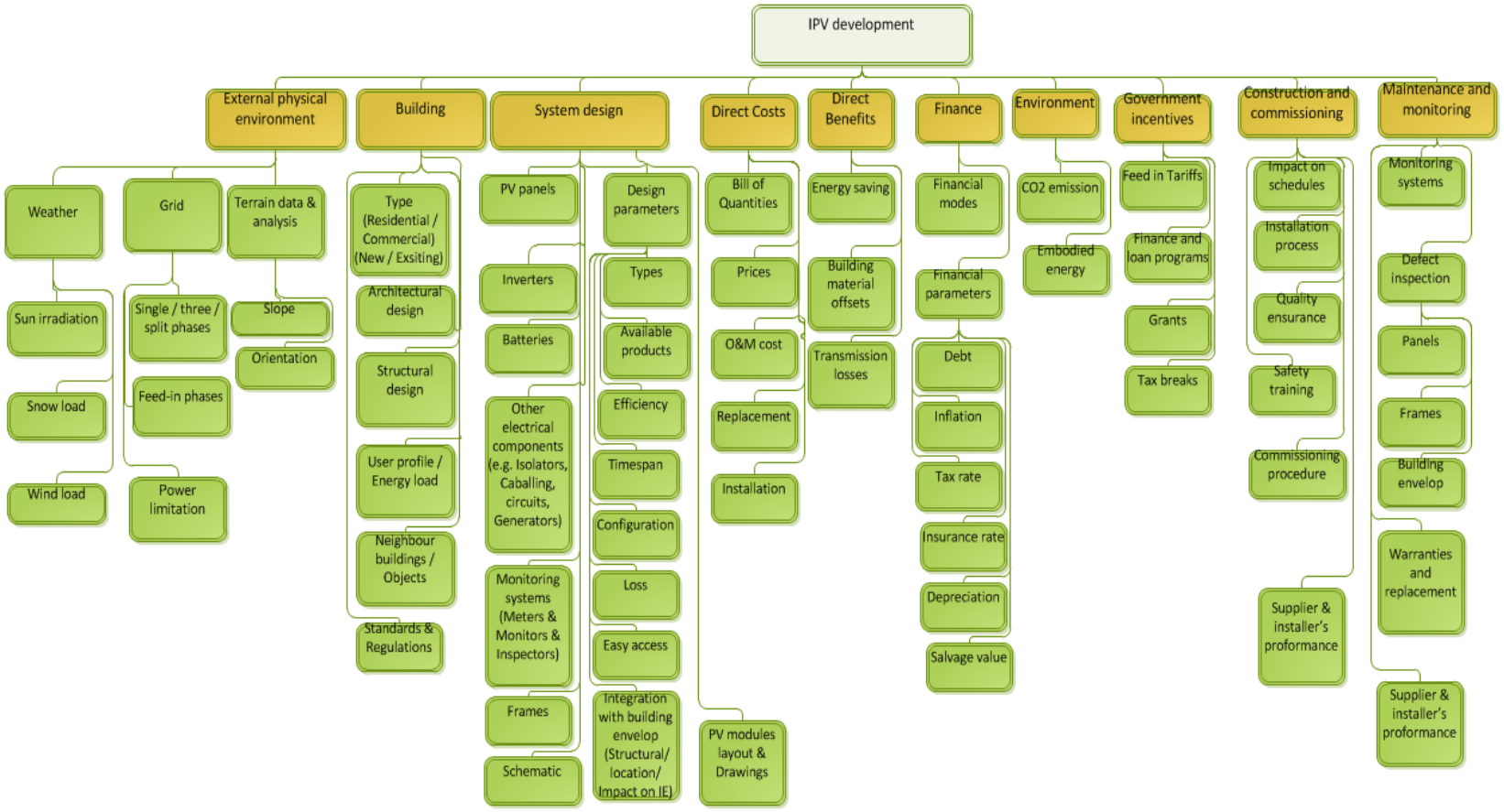
Big problem: Economical competitiveness of BIPV panels

Changes of design
and social
parameters can
impact the payback

Cost reduction and Deployment of Prefabricated Building Integrated Photovoltaics

- This research aims to evaluate the mechanisms driving the cost reductions and deployment of prefabricated Building Integrated Photovoltaics (BIPV). We will delve deeply into specific past technological innovations and policies, and prospectively asses BIPV's potential for future cost reduction.
- Being supported by RICS

BIPV development



Thank you!

Q&A