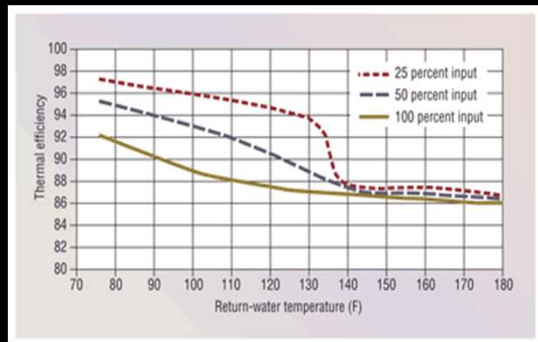
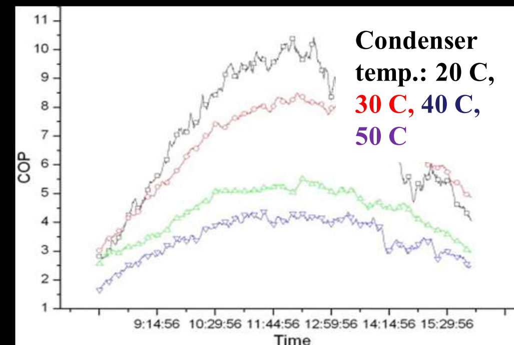
Numerical method: systems

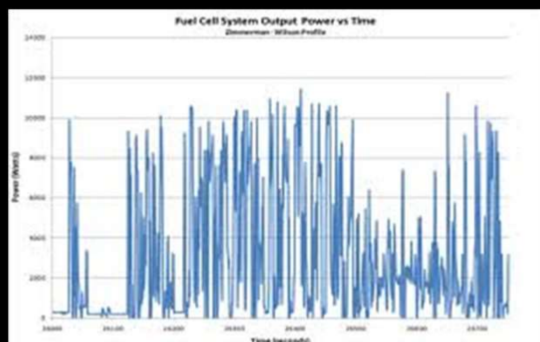
Equipment performance: dynamic and non-linear

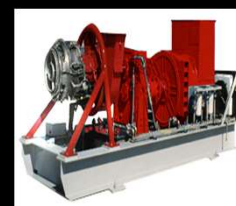


heat pump

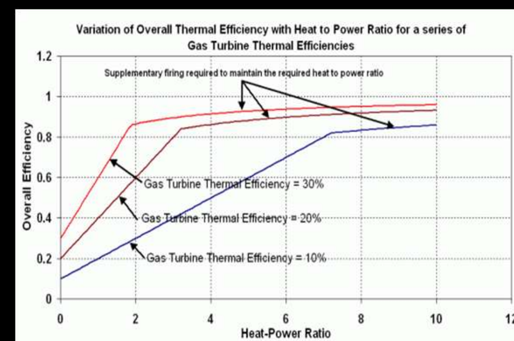


fuel cell

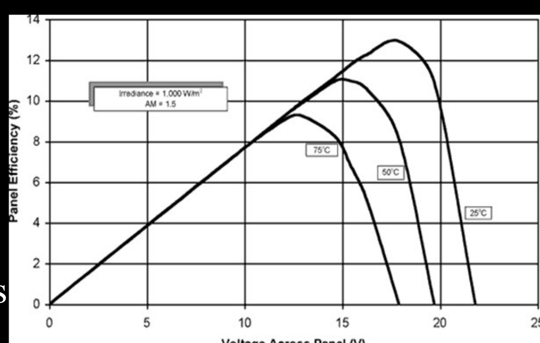




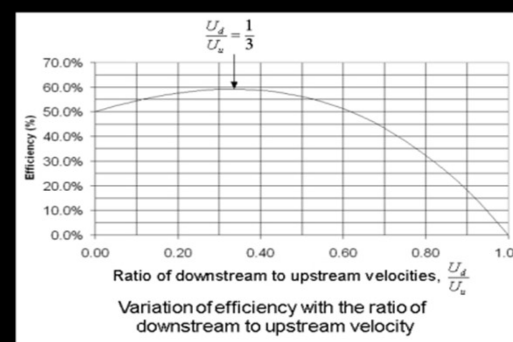
gas turbine



photovoltaics

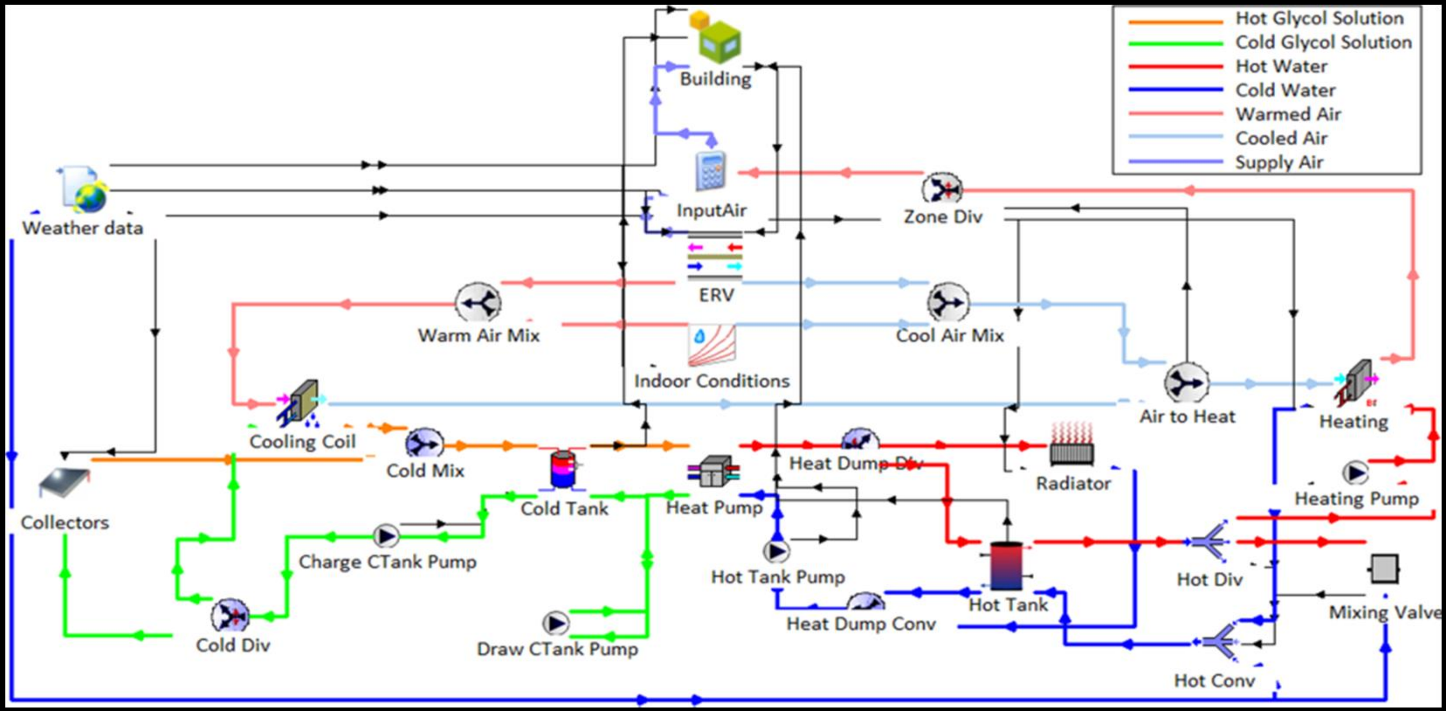


wind turbine



Issues: dynamic response, conditions monitoring, hybrid systems design and control.

Plant and systems simulation



Two approaches:

- Sequential, where components are replaced by an equivalent input/output relationship so that the output from one component becomes the input to the next. Iteration is then employed to achieve solution convergence throughout the network.
- Simultaneous, where plant components are represented by finite volumes and corresponding conservation equations added to the whole system matrix equation.

Sequential vs. simultaneous: pros and cons

❑ Sequential approach using black-box, input-output models:

- ✓ supports system design (sizing components);
- ✓ allows checking that components will work together;
- ✓ supports testing of system control strategies;

- ✗ problems with inter-component dependencies;
- ✗ fixed parameters not valid in off-design conditions.

❑ Simultaneous approach using full numerical discretisation

- ✓ components have a description of the fundamental processes in each component;
- ✓ can be used to optimise the internal design of each component;
- ✓ does not rely on 'design-condition' parameters;
- ✓ can be used to study control variables within components and globally;

- ✗ requires detailed information (e.g. geometry, material properties) that is not always available from manufacturers.

Example system: ground and air source heat pump

A, B, C: Evaporation and sensible heating of refrigerant in the evaporator (heat transfer from the colder source):

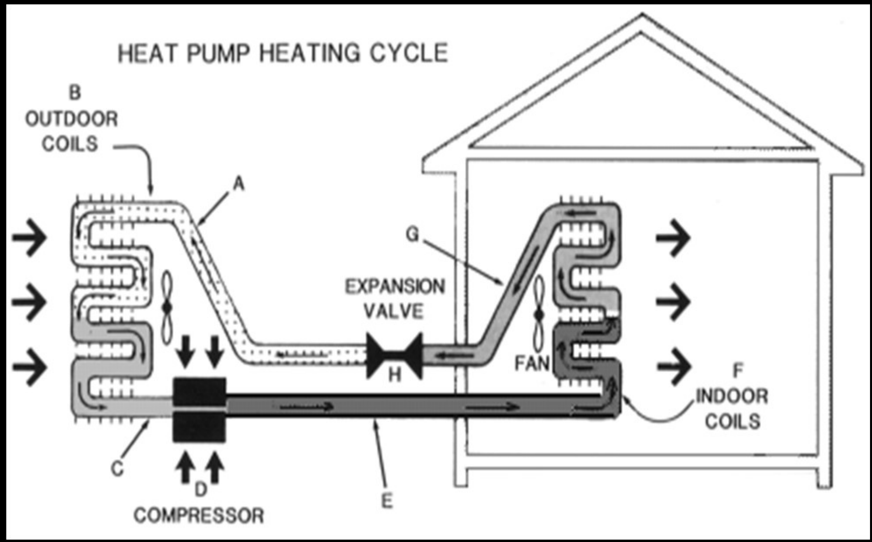
- convection from source fluid to heat exchanger surface;
- conduction through heat exchanger wall;
- convection to boiling refrigerant.

D: Electrical energy converted into potential energy (pressure) and heat (temperature increase) in compressor.

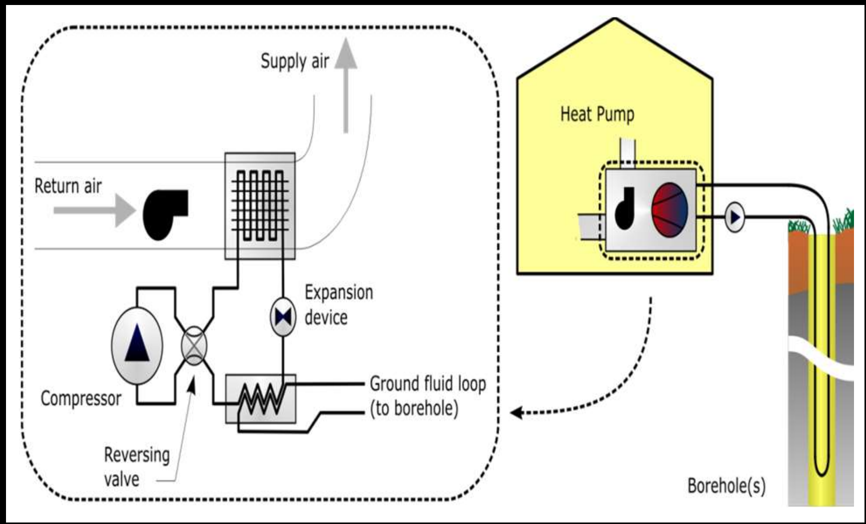
E, F, G: Condensation and sensible cooling of refrigerant in the condenser (heat transfer to hotter sink):

- convection from condensing refrigerant;
- conduction through heat exchanger wall;
- convection from heat exchanger surface to supply air.

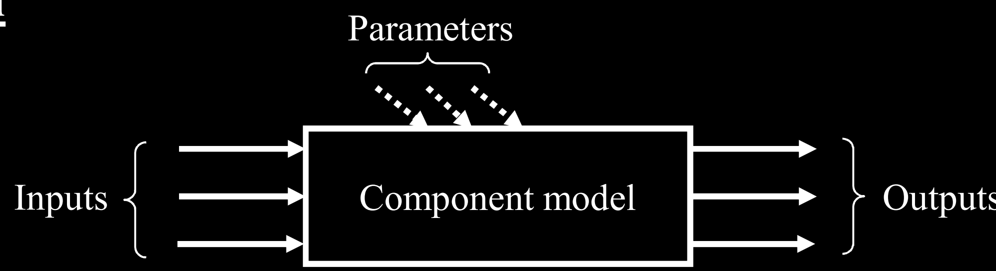
H: Pressure drop and cooling across expansion valve.



$$COP_{Heating} = \frac{useful}{paid\ for} = \frac{3}{1}(typically)$$



Heat pump: sequential approach



or a simple model, e.g. a wind turbine: $P = {}^{1}/_{2}\,\rho A C v^{3}$

Inputs

Entering water temperature & flow

Entering air temperature, humidity & flow

On/off signal

Parameters

Manufacturer data (performance map)

Fluid properties (constant)

700 CFM Nominal (Rated) Airflow Cooling, 700 CFM Nominal (Rated) Airflow Heating — Performance capacities shown in thousands of Btuh

EWT °F	GPM	WPD PSI	WPD FT	COOLING - EAT 80/67 °F Airflow CFM	TC	SC	Sens/Tot Ratio	kW	HR	EER	HEATING - EAT 70 °F Airflow CFM	HC	kW	HE	LAT	COP
20	2.8	0.8	1.8	Operation not recommended							Operation not recommended					
	4.1	2.4	5.5													
	5.5	3.9	9.0								530	11.7	1.24	7.7	90.4	2.77
											700	12.0	1.14	8.2	85.9	3.09
30	2.8	0.7	1.6	530	20.0	12.4	0.62	0.66	22.2	30.3	530	12.9	1.26	8.8	92.5	3.01
				700	20.8	14.4	0.69	0.70	23.2	29.8	700	13.3	1.16	9.4	87.6	3.36
	4.1	2.1	4.9	530	20.3	12.4	0.61	0.64	22.4	31.7	530	13.4	1.26	9.2	93.3	3.10
				700	21.1	14.4	0.68	0.68	23.4	31.1	700	13.8	1.17	9.8	88.2	3.45
	5.5	3.5	8.1	530	20.5	12.4	0.60	0.63	22.6	32.3	530	13.6	1.27	9.5	93.8	3.14
				700	21.3	14.4	0.66	0.67	23.6	31.8	700	14.0	1.17	10.1	88.5	3.51
40	2.8	0.6	1.4	530	20.7	13.2	0.64	0.73	23.2	28.5	530	14.8	1.28	10.6	95.9	3.39
				700	21.6	15.4	0.71	0.77	24.2	28.0	700	15.3	1.19	11.3	90.2	3.76
	4.1	2.0	4.6	530	21.1	13.2	0.63	0.69	23.4	30.7	530	15.4	1.29	11.2	97.0	3.50
				700	21.9	15.4	0.70	0.73	24.4	30.1	700	15.9	1.19	11.9	91.0	3.91
	5.5	3.2	7.4	530	21.2	13.3	0.62	0.67	23.5	31.6	530	15.8	1.30	11.5	97.5	3.56
				700	22.1	15.4	0.70	0.71	24.5	31.1	700	16.2	1.20	12.2	91.5	3.98
50	2.8	0.5	1.2	530	20.7	13.6	0.65	0.82	23.4	25.3	530	16.9	1.31	12.6	99.6	3.79
				700	21.5	15.8	0.73	0.86	24.4	24.9	700	17.5	1.21	13.3	93.1	4.22
	4.1	1.7	3.9	530	21.1	13.6	0.64	0.76	23.6	27.6	530	17.7	1.32	13.2	100.9	3.93
				700	21.9	15.8	0.72	0.81	24.6	27.1	700	18.2	1.22	14.1	94.1	4.38
	5.5	2.8	6.5	530	21.2	13.6	0.64	0.74	23.7	28.7	530	18.1	1.32	13.6	101.6	4.00
				700	22.0	15.8	0.72	0.78	24.7	28.2	700	18.6	1.22	14.5	94.7	4.47
60	2.8	0.3	0.7	530	19.8	13.3	0.67	0.92	22.9	21.5	530	19.1	1.34	14.6	103.4	4.19
				700	20.5	15.4	0.75	0.97	23.9	21.1	700	19.7	1.23	15.5	96.1	4.68
	4.1	1.5	3.5	530	20.3	13.5	0.66	0.86	23.2	23.7	530	20.0	1.34	15.4	104.9	4.36
				700	21.2	15.7	0.74	0.91	24.2	23.3	700	20.6	1.24	16.4	97.3	4.86
	5.5	2.6	6.0	530	20.6	13.5	0.66	0.83	23.4	24.9	530	20.5	1.35	15.8	105.7	4.44
				700	21.4	15.7	0.74	0.88	24.4	24.4	700	21.1	1.25	16.8	97.9	4.96
70	2.8	0.3	0.7													
	4.1	1.4	3.2													
	5.5	2.4	5.5													
80	2.8	0.2	0.5													
	4.1	1.2	2.8													
	5.5	2.2	5.1													
85	2.8	0.2	0.5													
	4.1	1.2	2.7													
	5.5	2.1	4.9													
90	2.8	0.2	0.5													
	4.1	1.1	2.5													
	5.5	2.0	4.6													
100	2.8	0.2	0.5													
	4.1	1.1	2.5													
	5.5	1.9	4.4													
110	2.8	0.1	0.2													
	4.1	0.9	2.1													
	5.5	1.7	3.9													
120	2.8	0.1	0.2													
	4.1	0.8	1.8													
	5.5	1.6	3.7													

AIR FLOW CORRECTION TABLE

Full Load Cooling Corrections 400 CFM per Ton

Ent Air WB F	Total Clg Cap	Sens Clg Cap Multipliers- Entering DB °F: 60	65	70	75	80	80.6	85	90	95	100	Power	Heat of Rej
45	0.8650	*	*	*	*	*	*	*	*	*	*	0.9660	0.7266
50	0.7432	0.9111	*	*	*	*	*	*	*	*	*	0.9866	0.7901
55	0.8202	0.7709	0.8820	1.0192	*	*	*	*	*	*	*	0.9887	0.8527
60	0.8960		0.6702	0.8540	1.0473	*	*	*	*	*	*	0.9924	0.9146
65	0.9705			0.6491	0.8657	1.0809	1.1066	*	*	*	*	0.9975	0.9757
66.2	0.9882			0.5939	0.8152	1.0333	1.0592	1.2481	*	*	*	0.9990	0.9903
67	1.0000			0.5559	0.7801	1.0000	1.0261	1.2158	*	*	*	1.0000	1.0000
70	1.0438				0.6377	0.8645	0.8913	1.0847	1.2983	*	*	1.0042	1.0362
75	1.1159					0.6008	0.6289	0.8323	1.0578	1.2773	*	1.0123	1.0959

* Sensible capacity equals total capacity.

ENTERING AIR CORRECTION TABLE

Heating Corrections: Ent Air DB F	Htg Cap	Power	Heat of Ext
20	1.0782	0.6820	1.1821
25	1.0756	0.6871	1.1775
30	1.0716	0.6994	1.1692
35	1.0661	0.7185	1.1572
40	1.0593	0.7438	1.1421
45	1.0514	0.7749	1.1240
50	1.0426	0.8113	1.1032
55	1.0329	0.8525	1.0802
60	1.0224	0.8980	1.0551
65	1.0114	0.9473	1.0282
68	1.0046	0.9788	1.0115
70	1.0000	1.0000	1.0000
75	0.9883	1.0556	0.9706
80	0.9764	1.1135	0.9404

ECM Airflow: CFM Per Ton of Clg	% of Nominal	Heating: Htg Cap	Power	Heat of Ext	Cooling: Total Cap	Sens Cap	S/T	Power	Heat of Rej
240	60.00	0.9518	1.1724	0.8848	0.9224	0.7856	0.8519	0.9286	0.9232
275	68.75	0.9624	1.1161	0.9228	0.9470	0.8265	0.8727	0.9363	0.9449
300	75.00	0.9700	1.0822	0.9410	0.9619	0.8583	0.8933	0.9455	0.9587
325	81.25	0.9775	1.0538	0.9579	0.9747	0.8943	0.9175	0.9564	0.9711
350	87.50	0.9851	1.0304	0.9733	0.9853	0.9302	0.9441	0.9691	0.9821
375	93.75	0.9925	1.0125	0.9874	0.9938	0.9659	0.9719	0.9837	0.9918
400	100.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
425	106.25	1.0074	0.9928	1.0112	1.0041	1.0313	1.0271	1.0181	1.0069
450	112.50	1.0148	0.9909	1.0210	1.0060	1.0584	1.0522	1.0381	1.0123
475	118.75	1.0222	0.9622	1.0377	1.0070	1.0815	1.0740	1.0598	1.0174
500	125.00	1.0295	0.8681	1.0712	1.0076	1.0998	1.0916	1.0834	1.0225
520	130.00	1.0354	0.8456	1.0844	1.0083	1.1110	1.1018	1.1035	1.0271

PSC Airflow: CFM Per Ton of Clg	% of Nominal	Heating: Htg Cap	Power	Heat of Ext	Cooling: Total Cap	Sens Cap	S/T	Power	Heat of Rej
240	60.00	0.9561	1.1841	0.8959	0.9248	0.7674	0.8298	0.9542	0.9309
275	68.75	0.9668	1.1282	0.9242	0.9465	0.8019	0.8472	0.9614	0.9496
300	75.00	0.9740	1.0936	0.9425	0.9602	0.8350	0.8696	0.9673	0.9617
325	81.25	0.9810	1.0635	0.9592	0.9724	0.8733	0.8981	0.9744	0.9728
350	87.50	0.9876	1.0379	0.9744	0.9831	0.9149	0.9306	0.9821	0.9829
375	93.75	0.9940	1.0167	0.9880	0.9923	0.9579	0.9653	0.9906	0.9920
400	100.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
425	106.25	1.0057	0.9878	1.0105	1.0062	1.0392	1.0328	1.0102	1.0070
450	112.50	1.0112	0.9800	1.0194	1.0109	1.0733	1.0617	1.0211	1.0130
475	118.75	1.0163	0.9705	1.0284	1.0141	1.1001	1.0848	1.0329	1.0180
500	125.00	1.0211	0.9614	1.0368	1.0159	1.1174	1.0999	1.0455	1.0220
520	130.00	1.0247	0.9554	1.0430	1.0161	1.1229	1.1050	1.0562	1.0244

Outputs

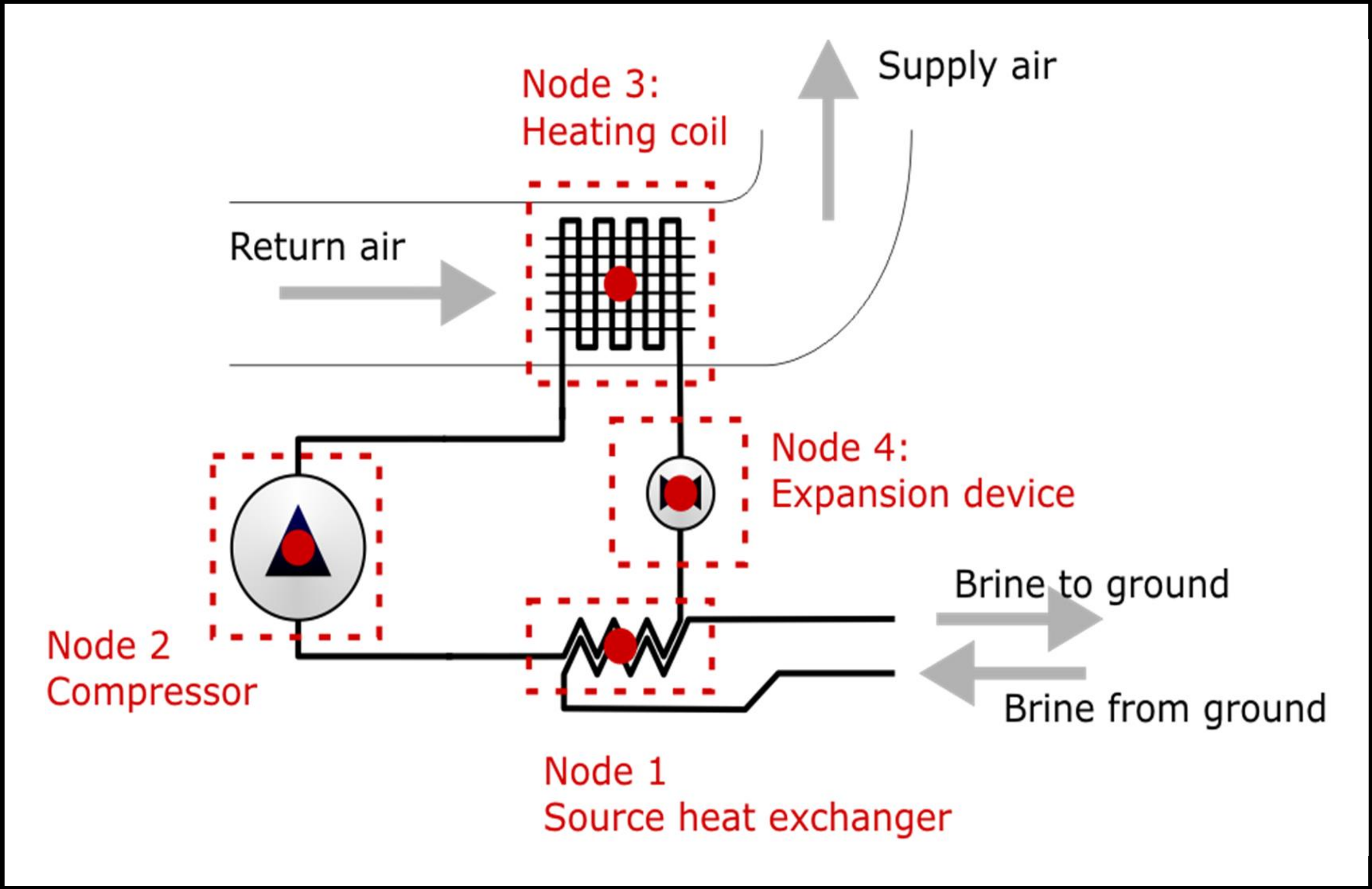
Leaving water temperature

Leaving air temperature & humidity

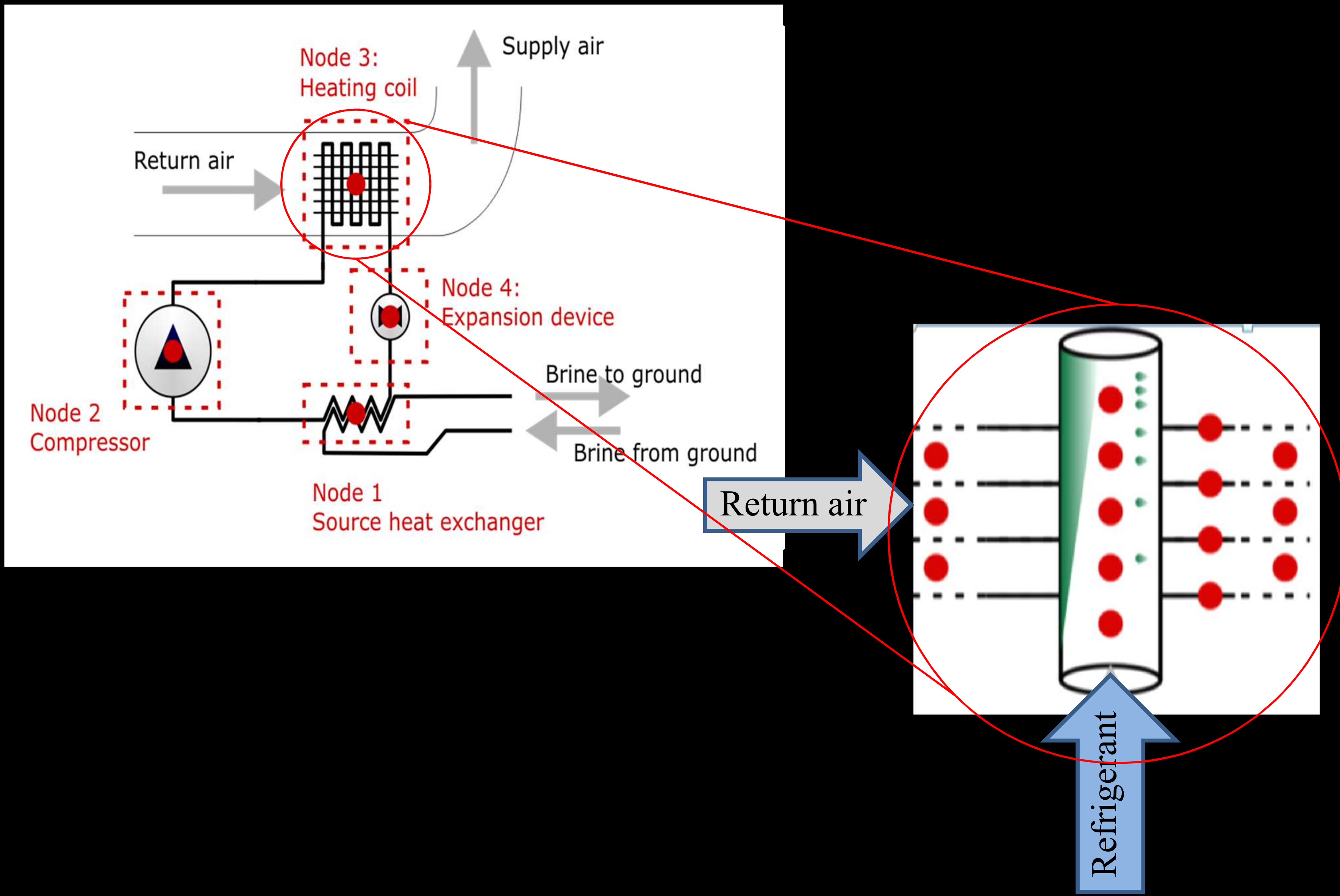
Electrical power

Heat flows

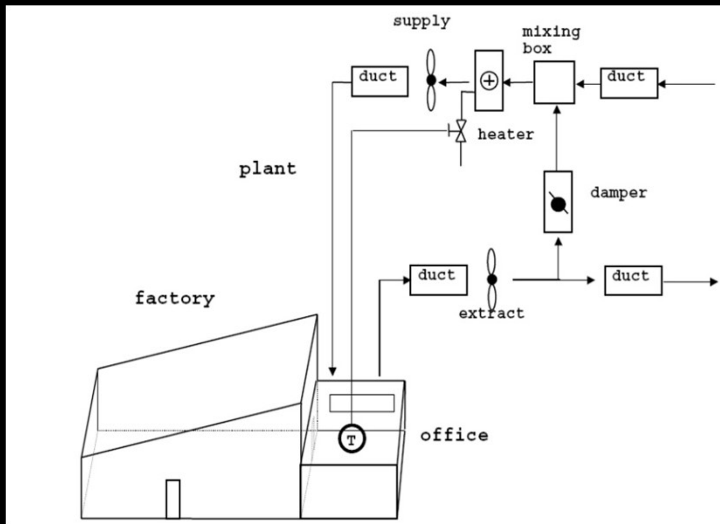
Heat pump: simultaneous approach

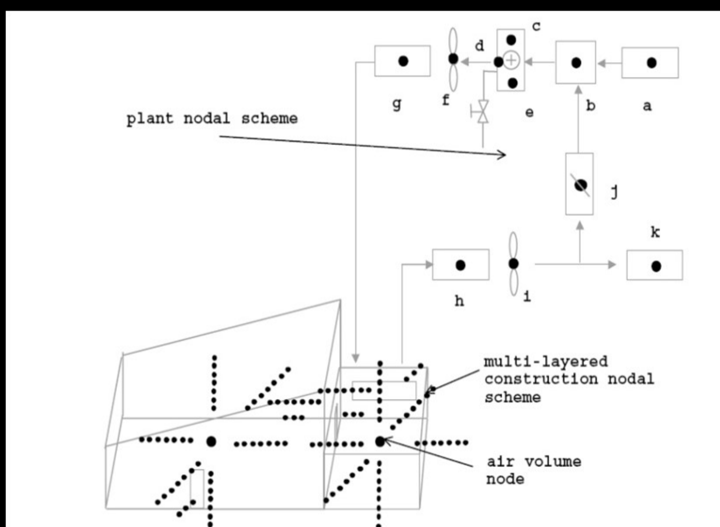


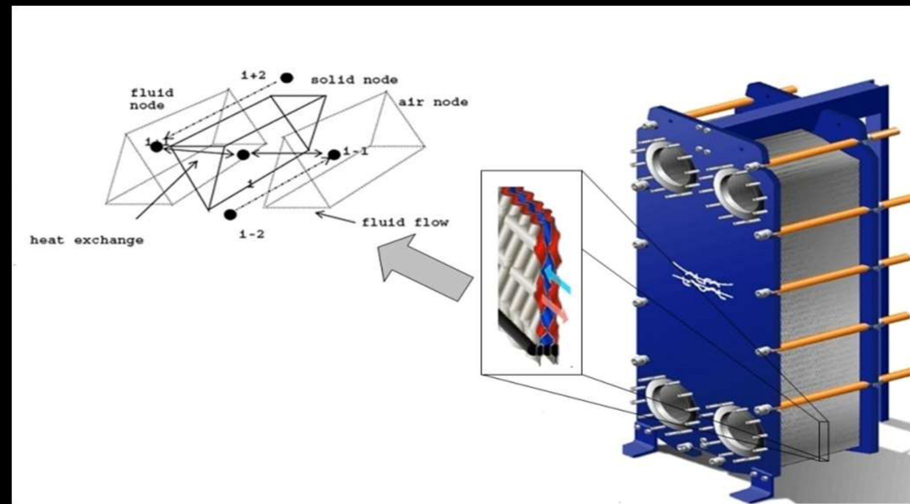
Variable discretisation levels

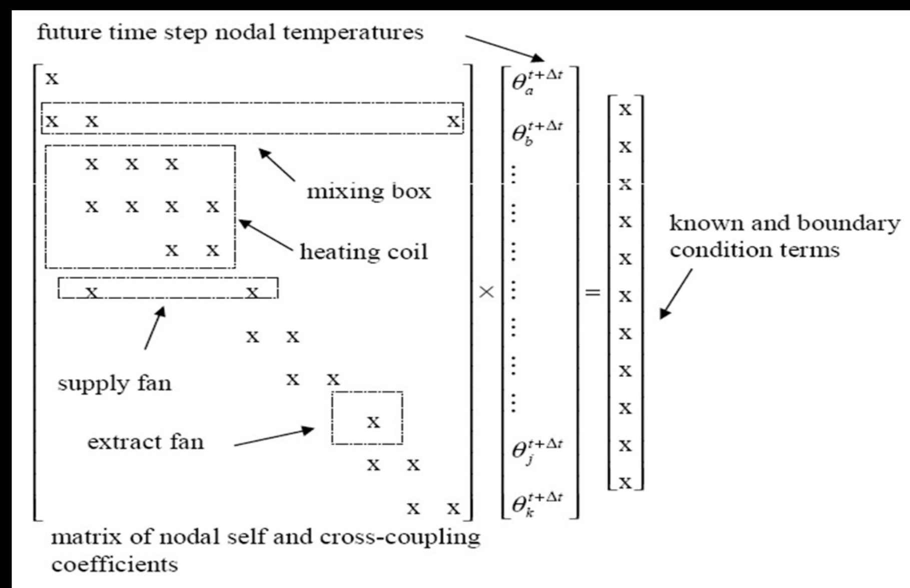


Discretising plant









Gas central heating system

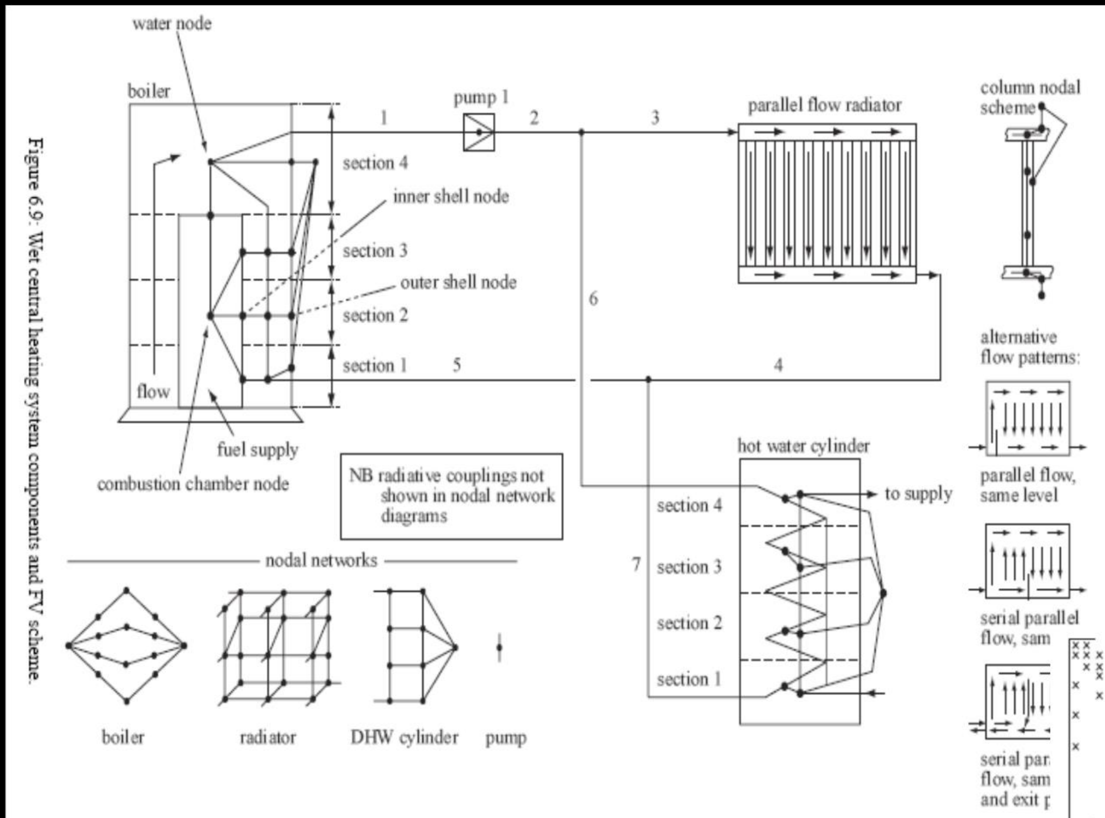


Figure 6.9: Wet central heating system components and FV scheme.

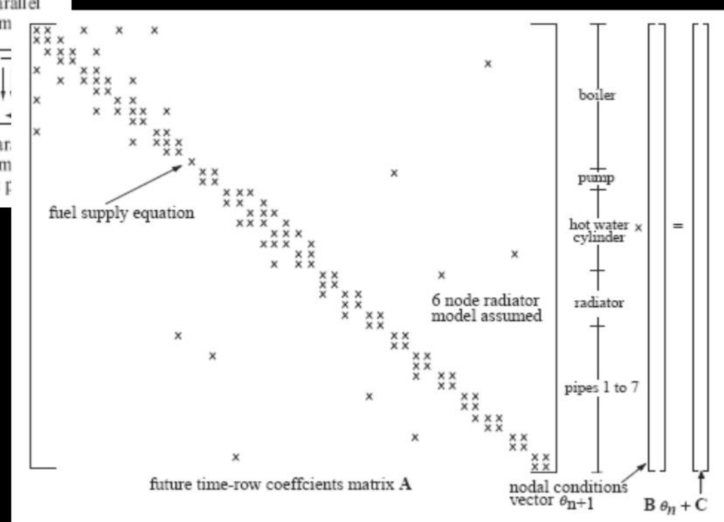


Figure 6.11: Wet central heating system energy balance matrix equation.

Solar energy collector with energy storage

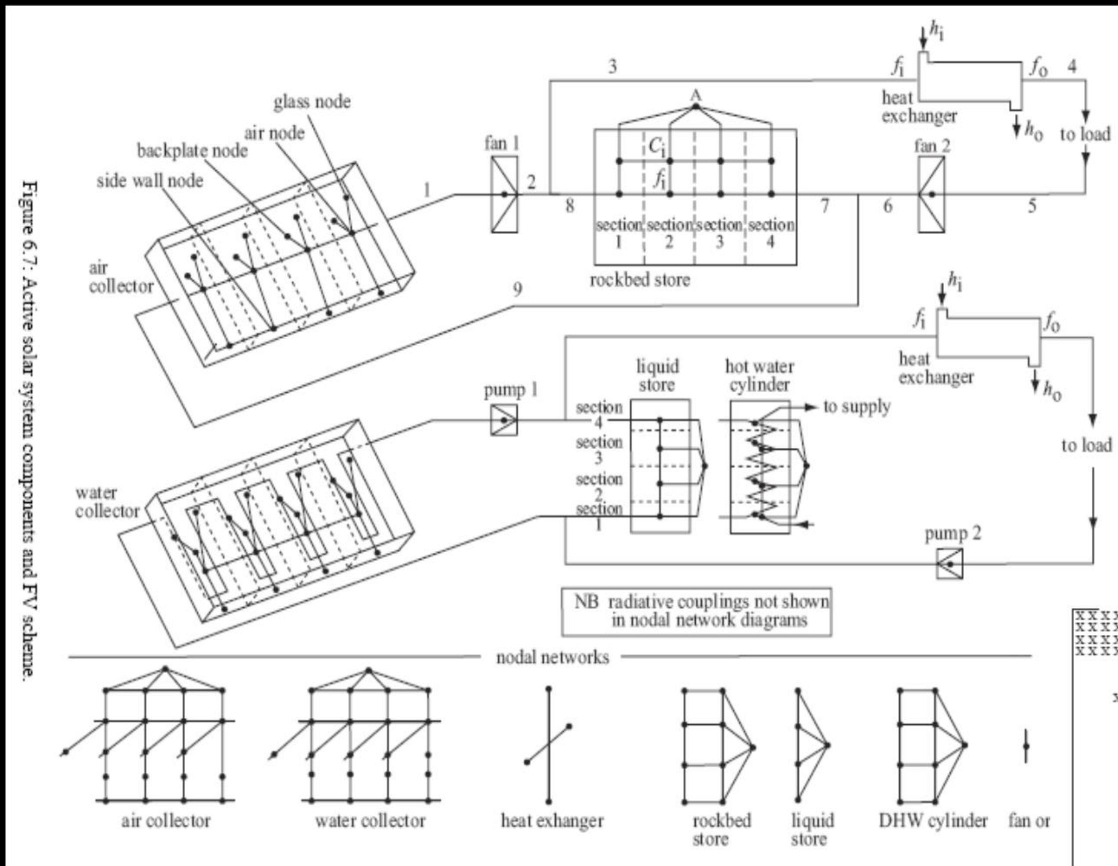


Figure 6.7: Active solar system components and FV scheme.

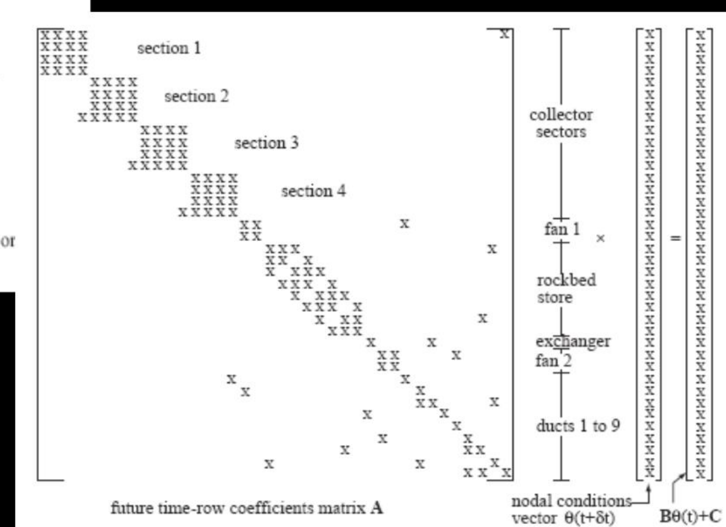
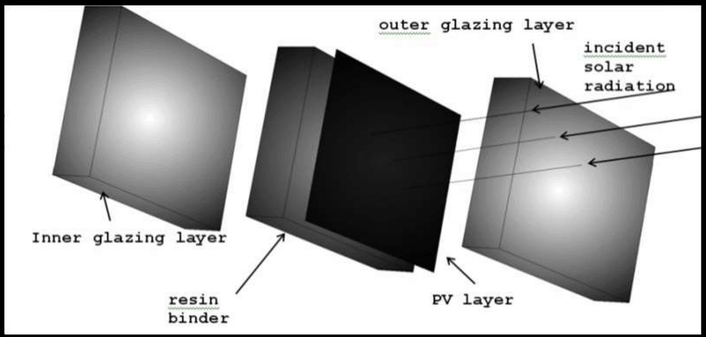
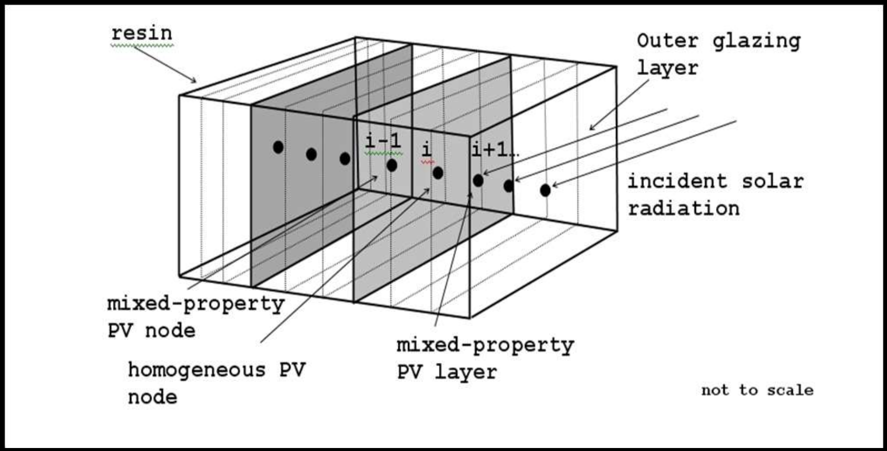
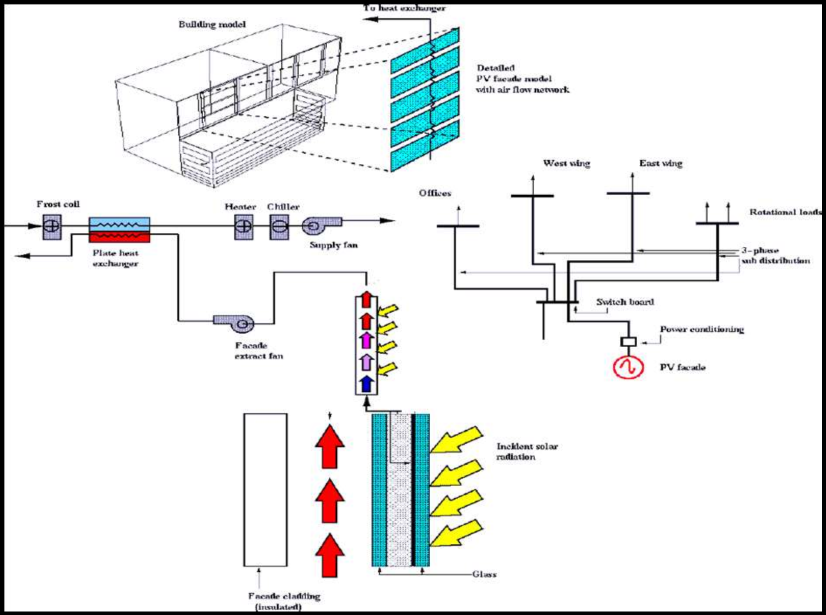


Figure 6.8: Active solar system energy balance matrix equation.

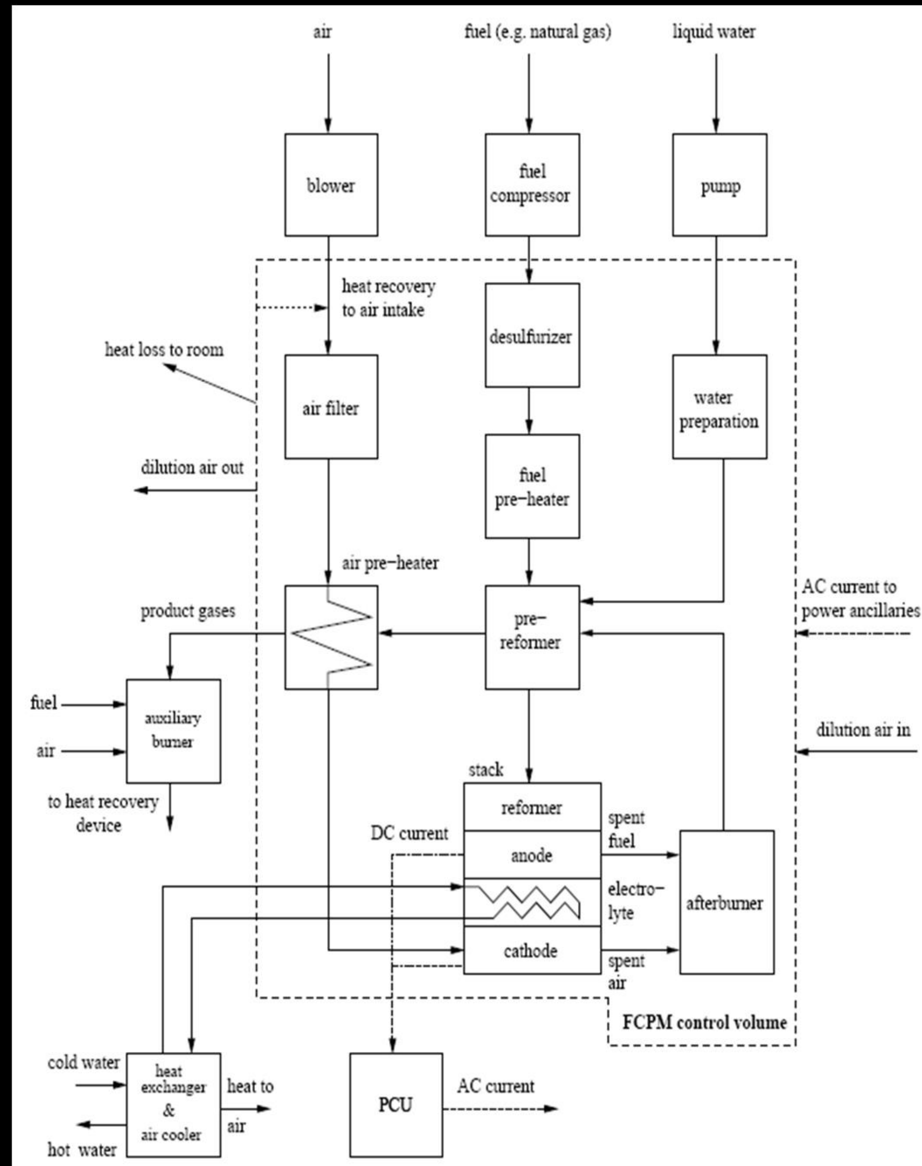
Building-integrated photovoltaic system



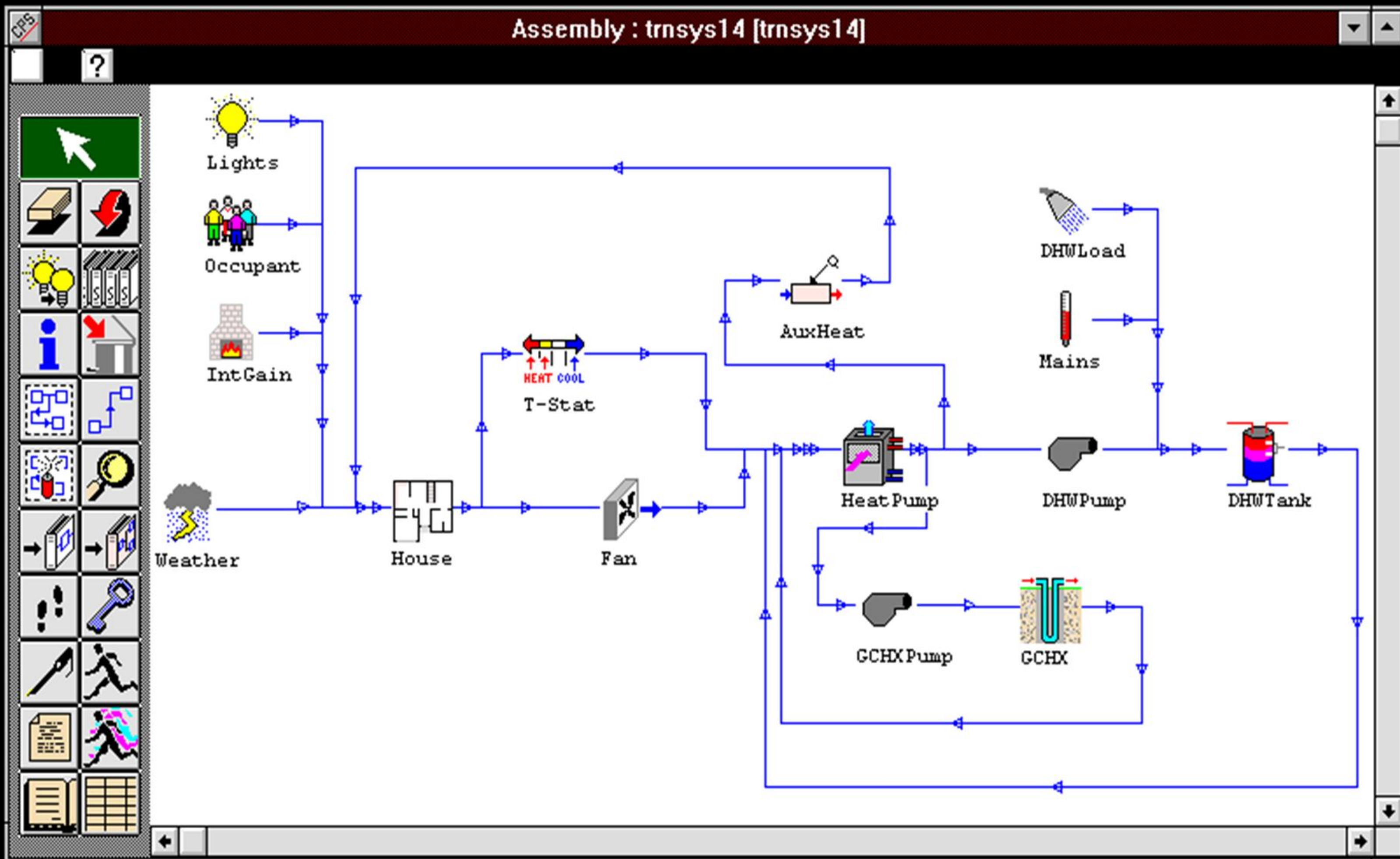




Fuel cell system

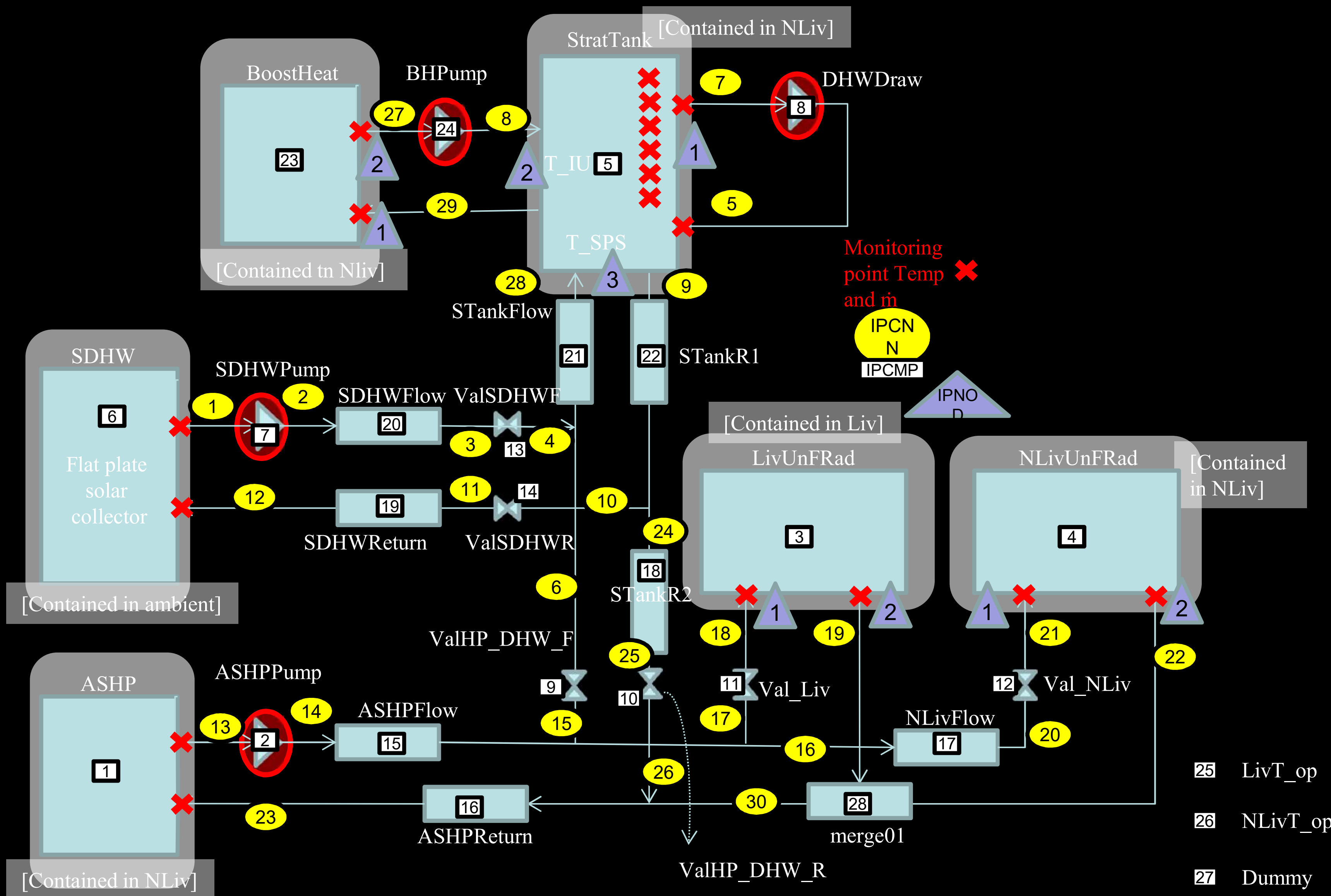


TRNSYS – low energy house with heat pump

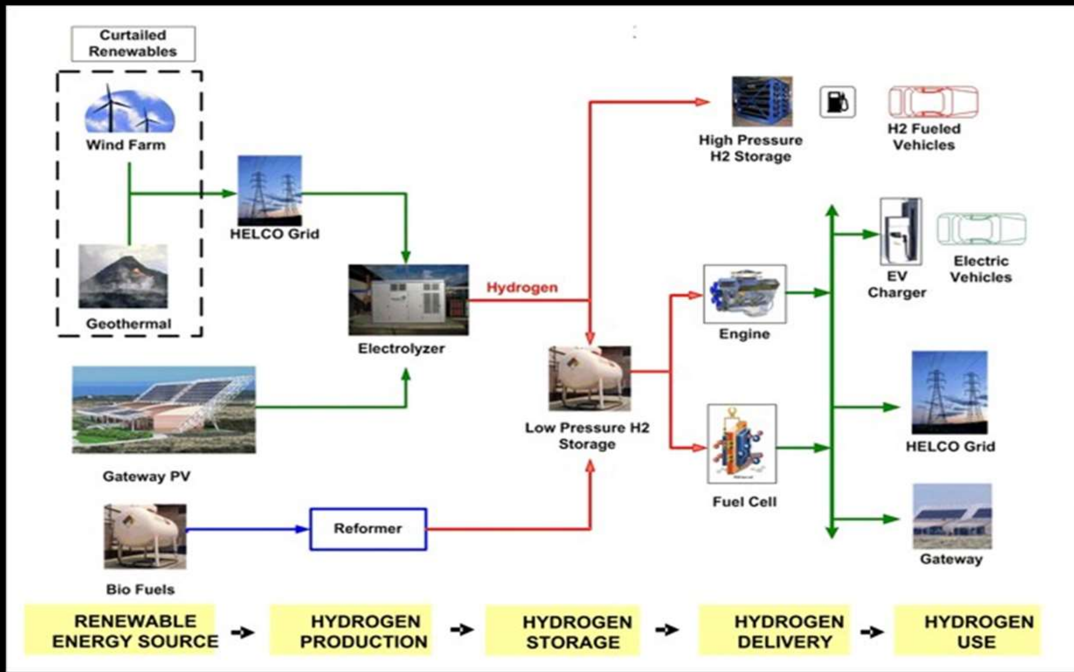


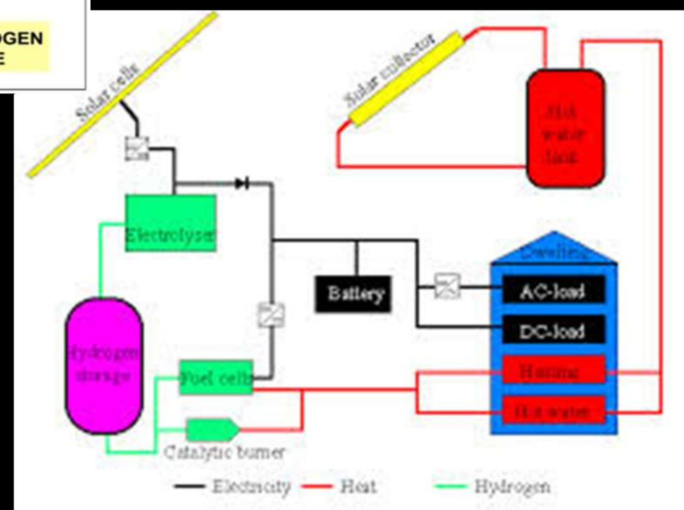
http://www.trnsys.com/

ESP-r: linked building, plant and air/water flow network

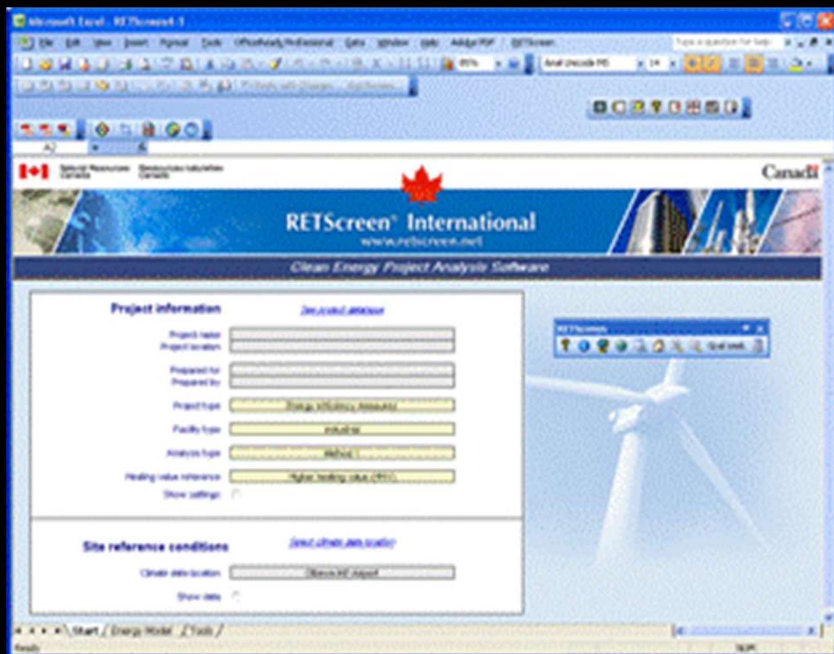


Hydrogen fuel cells



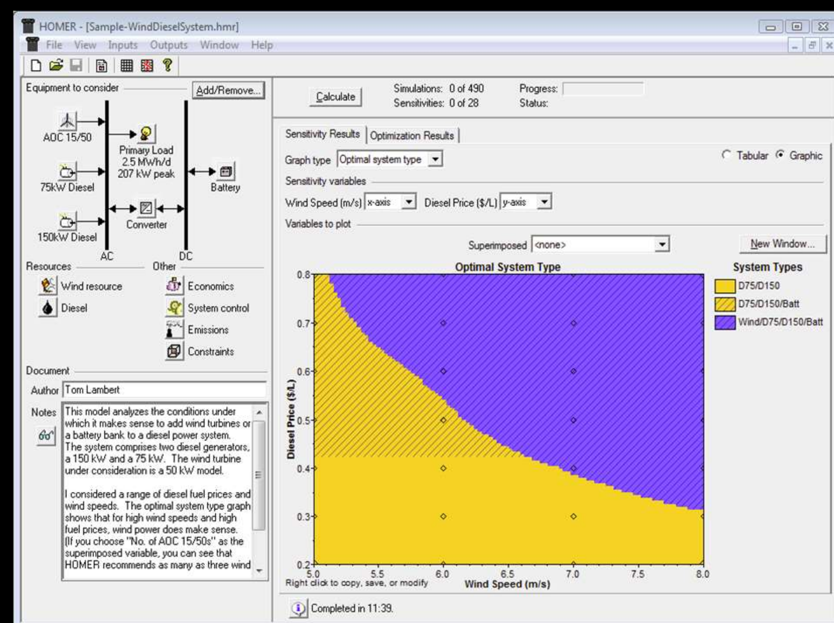


Renewable energy



Retscreen (https://www.nrcan.gc.ca/energy/software-tools/7465)

Homer (http://homer.ucsd.edu/homer/)



Distributed/embedded generation

Power station ………… 1 @ 2000 MW
Wind ……. ………… 100 @ 20 MW
Marine …………… 4,000 @ 0.5 MW
CHP …………… 40,000 @ 0.05 MW
Urban RE ……… 200,000 @ 0.01 MW

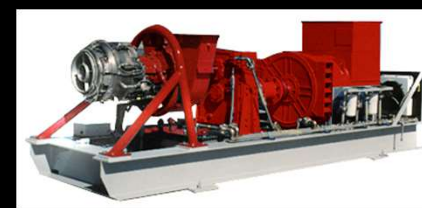
RE systems 3-5 times greater if the requirement is to match energy production. Requires a combined buildings/systems model.

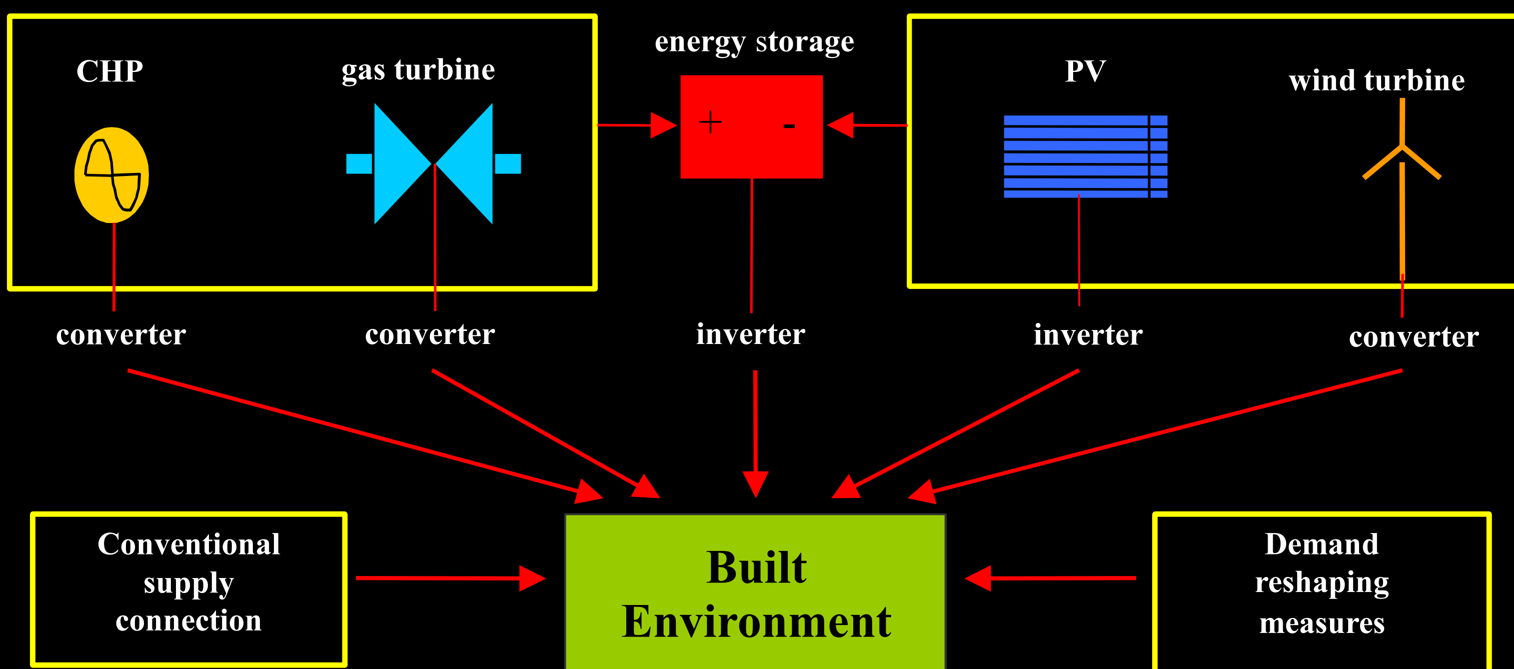

Combined heat & power


heat pump

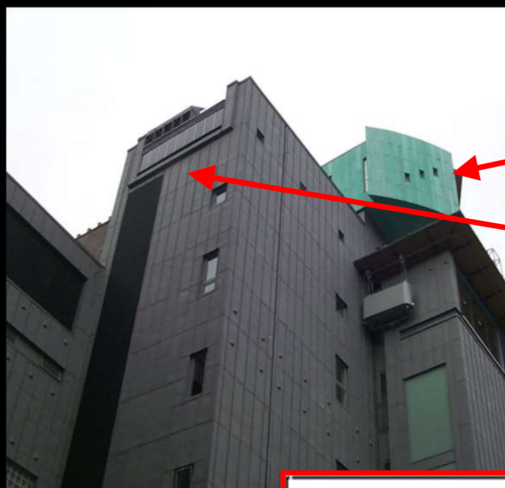

ducted wind turbines


photovoltaic cells


gas turbine



Embedded generation, Lighthouse Building in Glasgow

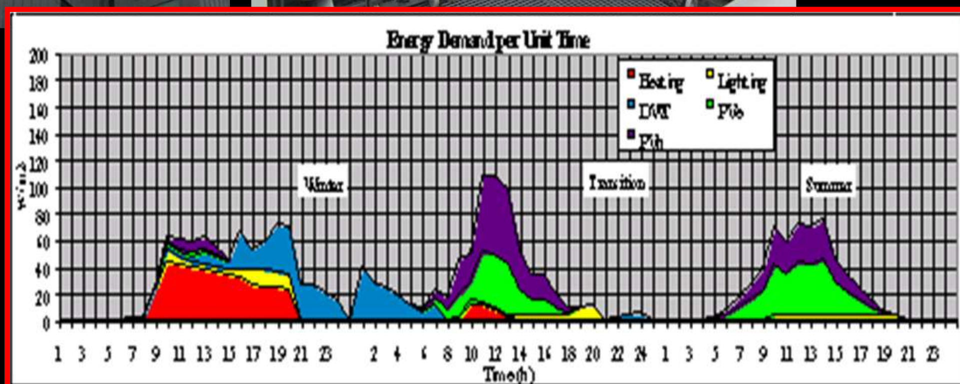


Demand reduction through transparent insulation, advanced glazing and smart control.

PV: 0.7 kW_e

DWT: 0.6 kW_e

PV hybrid: 0.8 kW_e / 1.5 kW_h



total demand:
68 $kWh/m^2.yr$

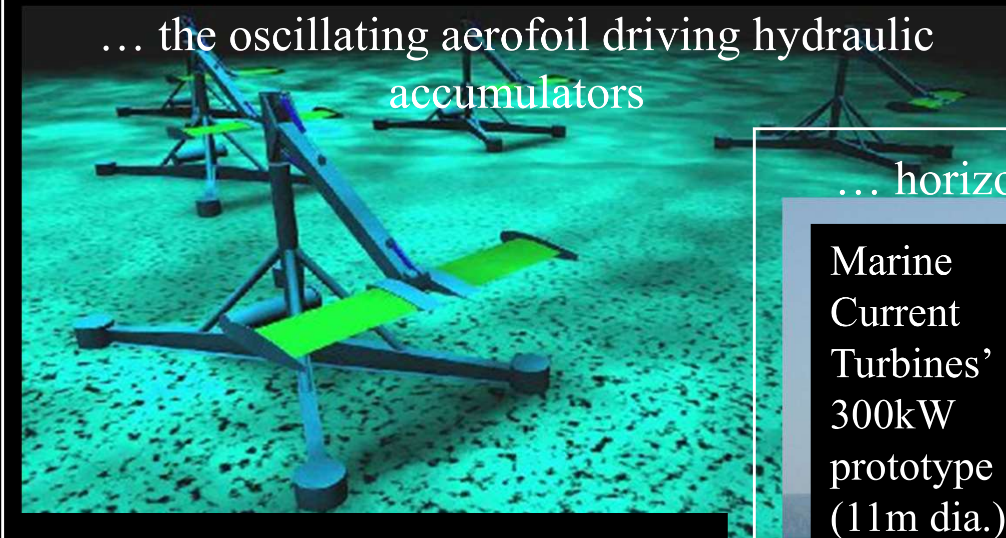
total RE supply:
98 $kWh/m^2.yr$

Issues:

- ❑ accommodating the grade, variability and unpredictability of energy sources/demands;
- ❑ hybrid systems sizing and maintenance;
- ❑ strategies for co-operative control of stochastic demand and supply;
- ❑ active network management for network balancing, fault handling and power quality maintenance.

Tidal stream energy

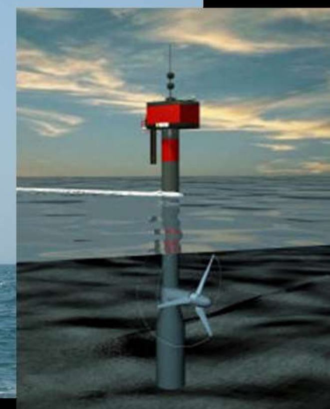
… the oscillating aerofoil driving hydraulic accumulators



Engineering Business' Stingray device

… horizontal axis turbines evolved from wind power technology

Marine Current Turbines' 300kW prototype (11m dia.)



… and contra-rotating devices

minimises the reaction torque on the structure

Nautricity's 500 kW prototype

Challenges:

- ❑ aquaculture impact
- ❑ reduced reactive torque
- ❑ simplify moorings
- ❑ limit corrosion and abrasion
- ❑ maintenance and safety issues
- ❑ power take-off at low rotation speed
- ❑ gearing reduction/elimination
- ❑ power transmission/grid access
- ❑ land access and use
- ❑ phased operation of different sites

Approch is universally applicable