BUILDING ENERGY SYSTEMS

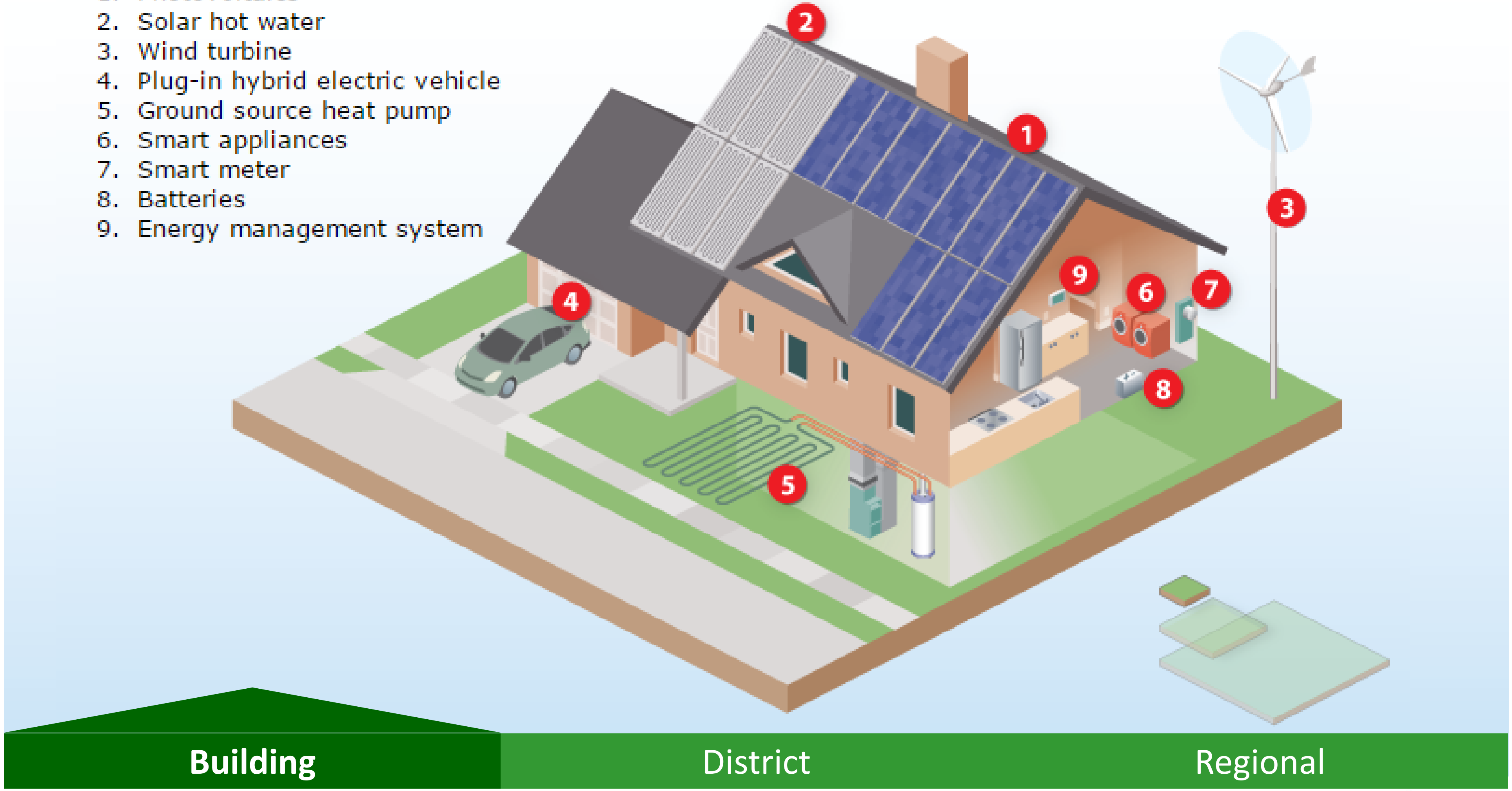
Week 6

7LY3M0
Building performance and energy systems simulation

Where innovation starts

Technologies

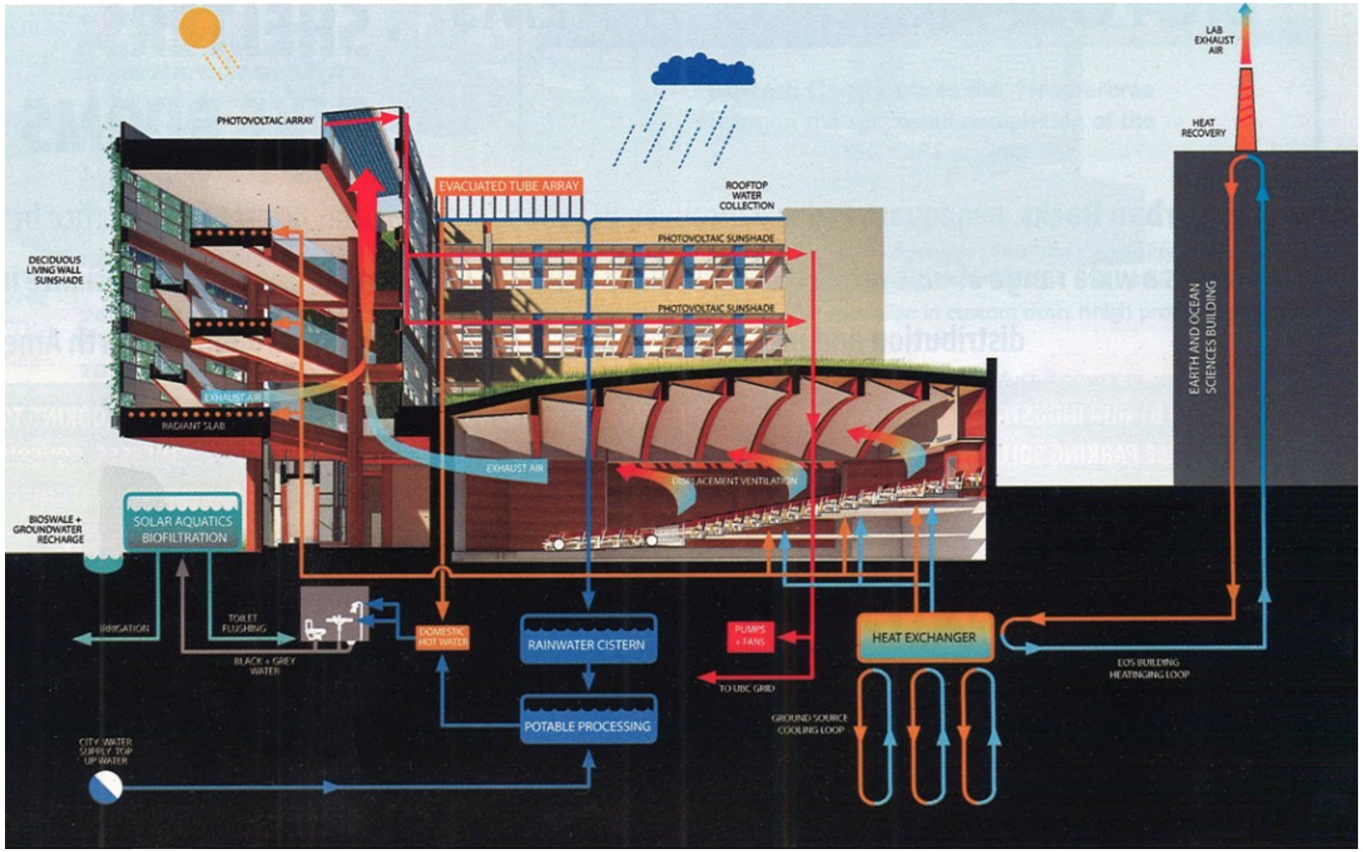
1. Photovoltaics
2. Solar hot water
3. Wind turbine
4. Plug-in hybrid electric vehicle
5. Ground source heat pump
6. Smart appliances
7. Smart meter
8. Batteries
9. Energy management system



Other challenges

» Real challenge: existing buildings

» Building + system → building = system



[Centre for Interactive Research on Sustainability http://cirs.ubc.ca/building]

[http://www.broekbakema.nl}

Energy Academy Europe > 7LY3M0

Daylight

Orientation

Solar chimney

Geothermal energy

BIPV

Climate ceiling

Compact shape

Natural ventilation

Atrium

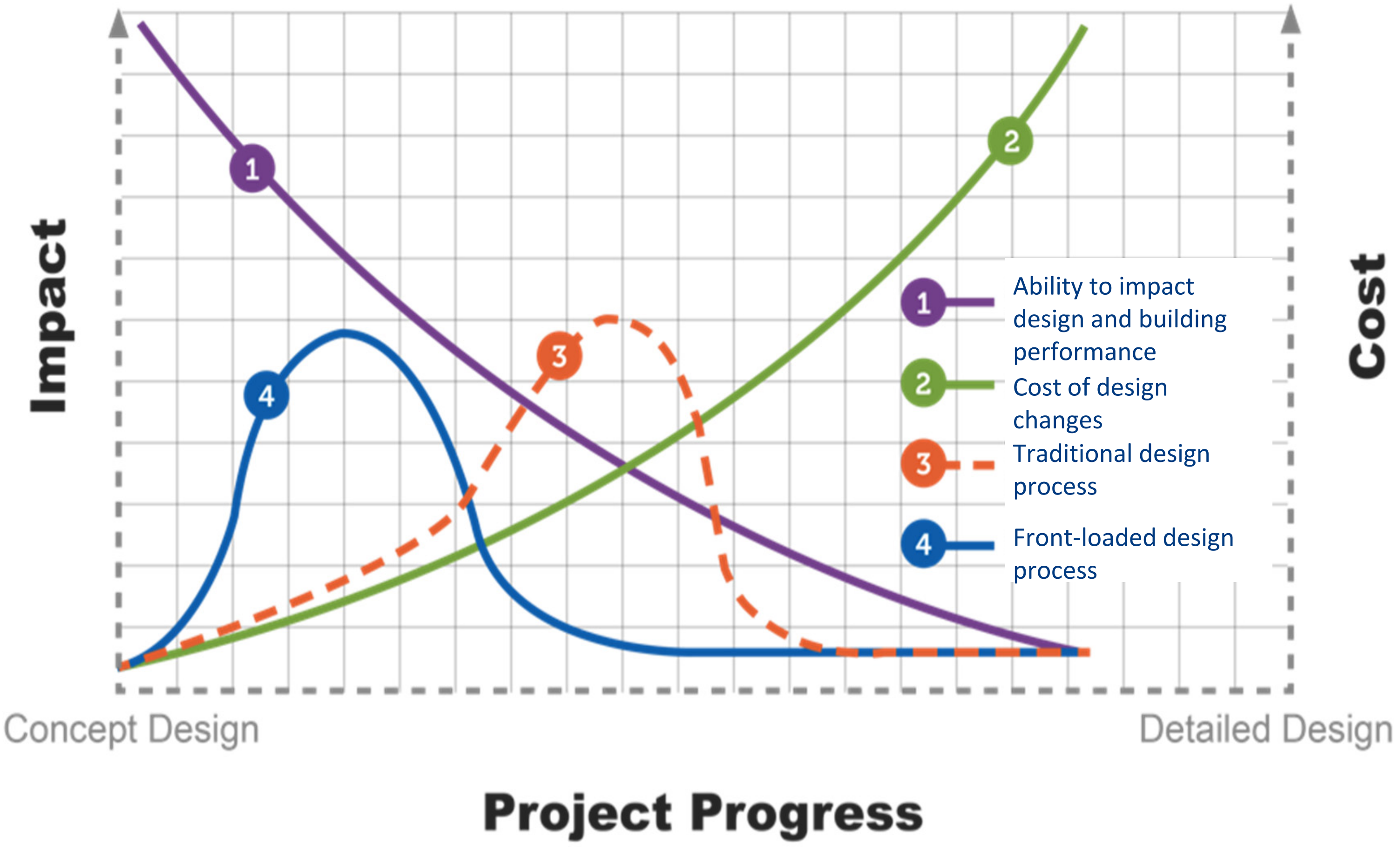
Night cooling

Aquifer thermal storage

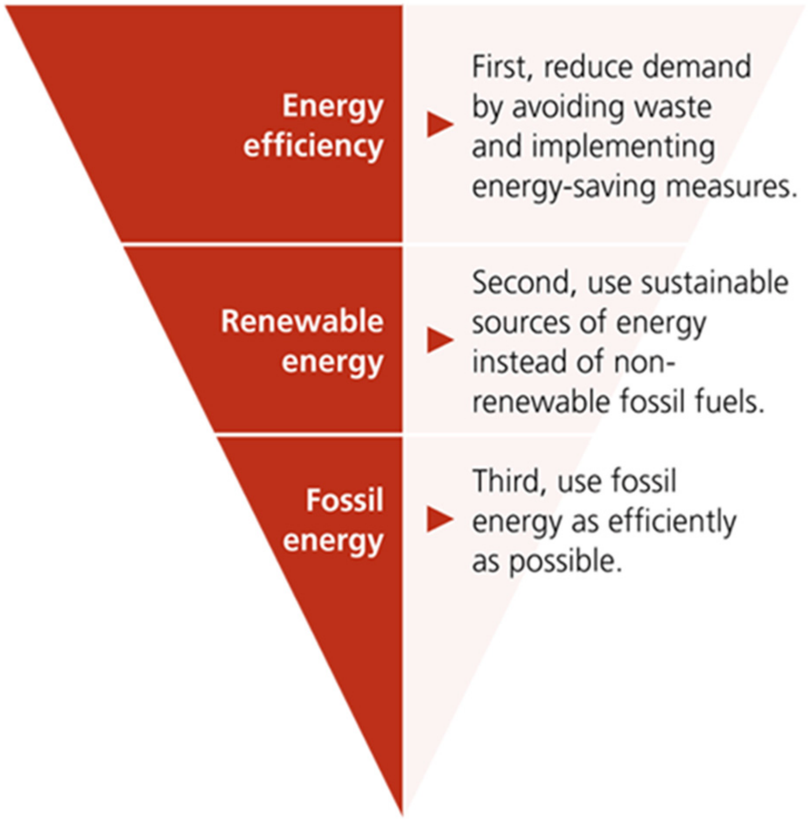
Underfloor heating

Heat pump

Integrated building and systems

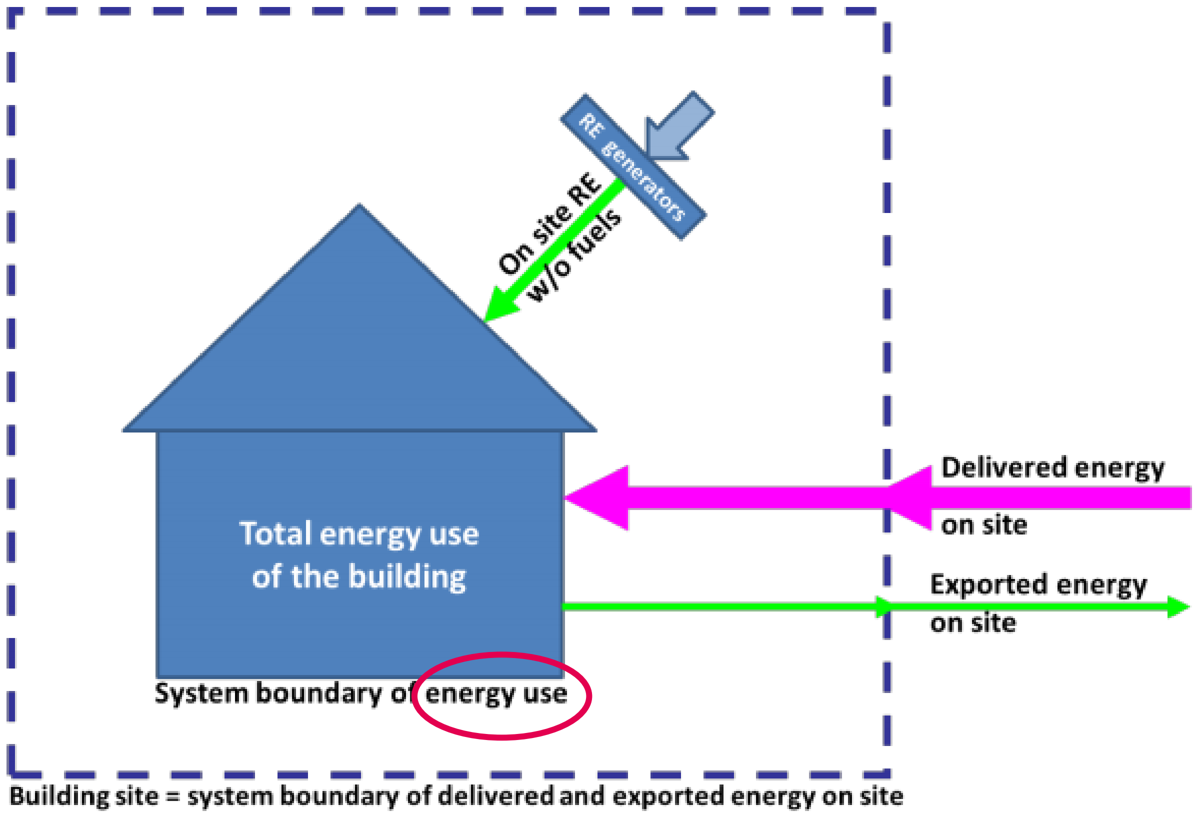


The “trias energetica” concept



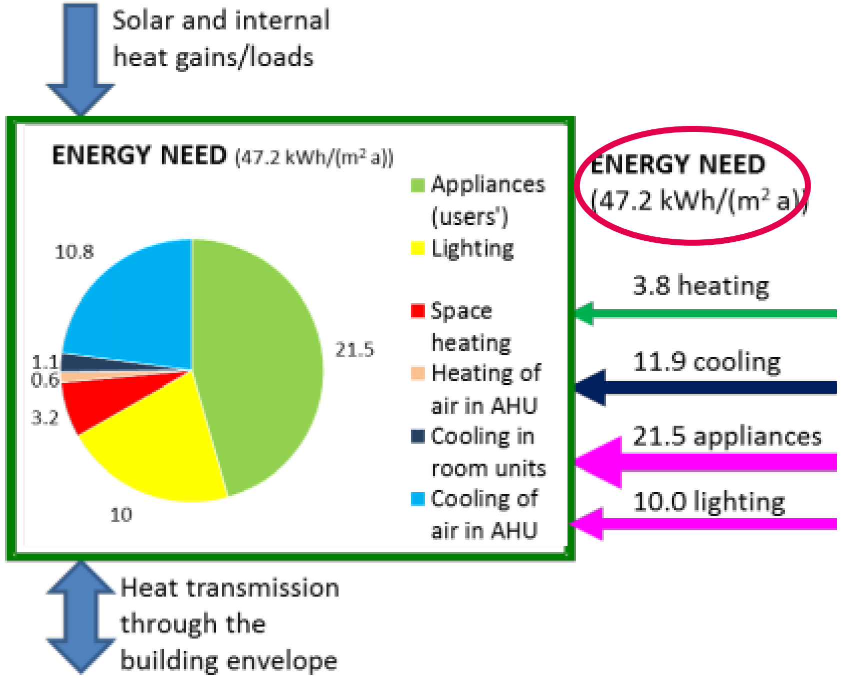
[Sefaira]

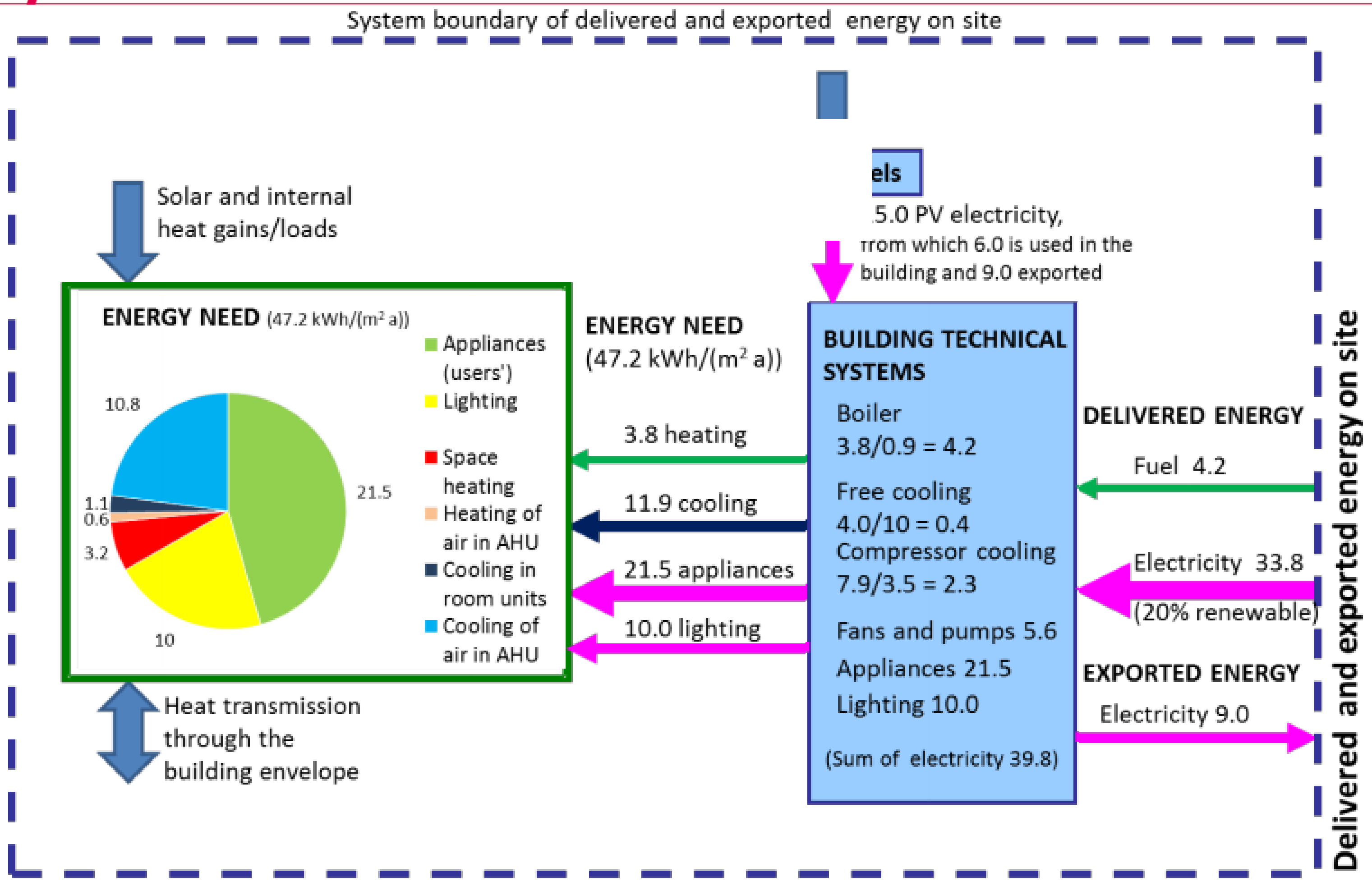
NZEB and system boundaries



Example – demand side

» Consider an office building located in Paris with the following annual energy needs (all values are specific values in kWh/(m² a)):
  – 3.8 kWh/(m² a) energy need for heating (space heating, supply air heating and DHW)
  – 11.9 kWh/(m² a) energy need for cooling
  – 21.5 kWh/(m² a) electricity for appliances
  – 10.0 kWh/(m² a) electricity for lighting





The rest is covered with

kWh/(m² a) electricity.

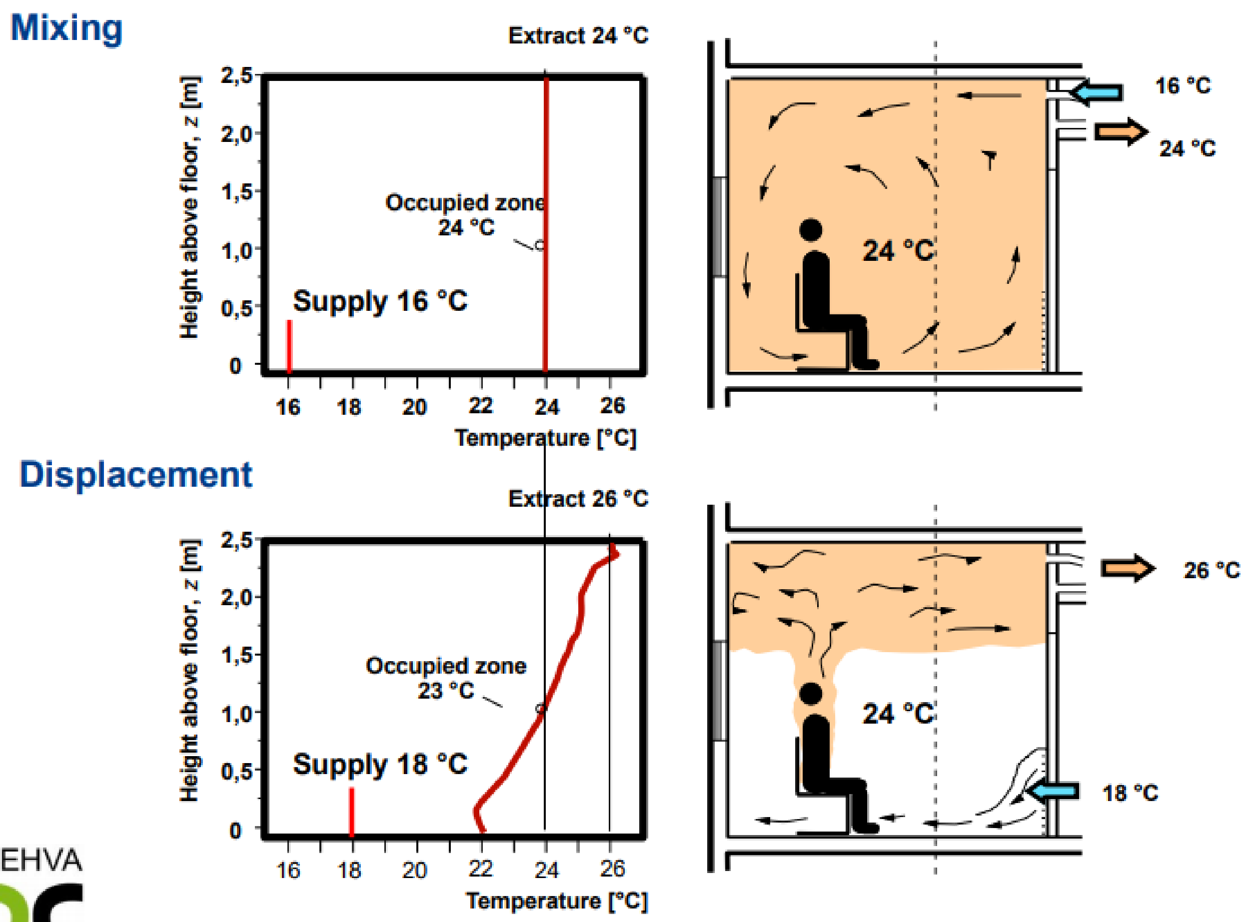
...red fuel energy (caloric value) is 4.2 kWh/(m² a)

How to reduce HVAC energy use?

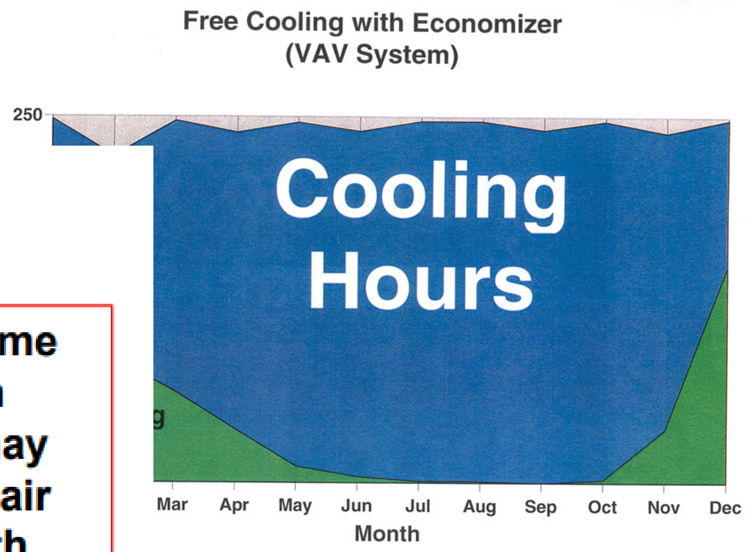
Use energy-efficient systems.

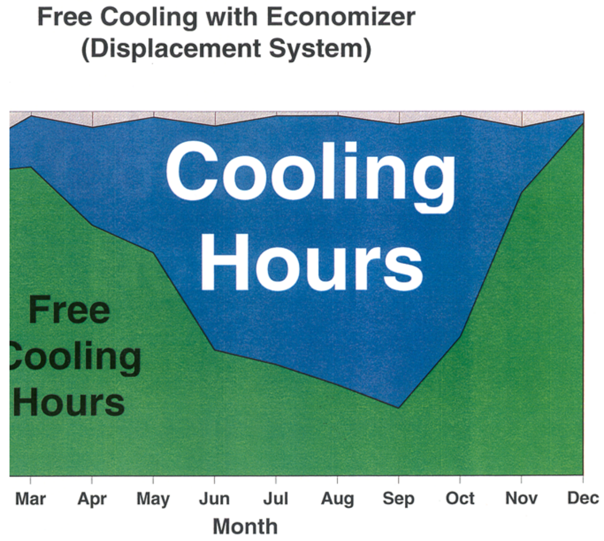
» Displacement Ventilation
» High-temperature cooling systems (e.g., cooling/chilled beam)
» Low-temperature heating systems (e.g., floor heating)
» Phase change materials (PCM)
» Mixed mode ventilation systems
» Double skin facade
» Advanced control systems (e.g. preheating/cooling, demand driven)
» etc.

Displacement Ventilation



For the same ventilation rate, we may get better air quality with displacement ventilation





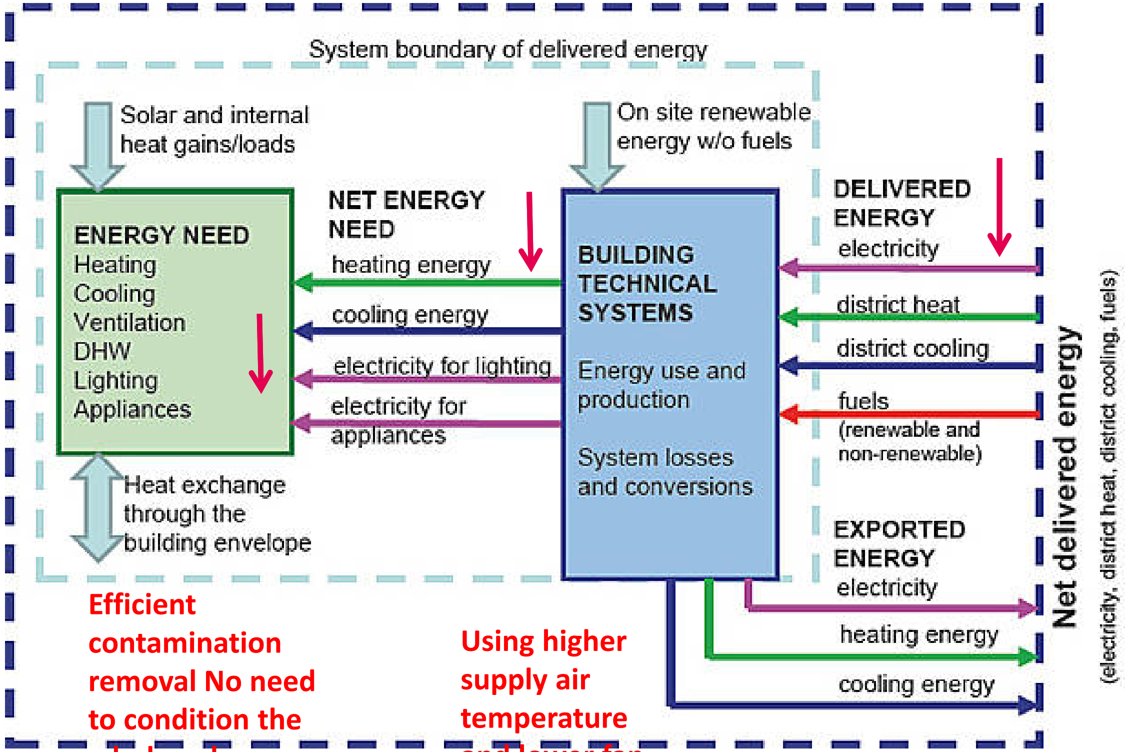
on San Francisco weather files

REHVA

Federation of European Heating, Ventilation and Air-conditioning Associations

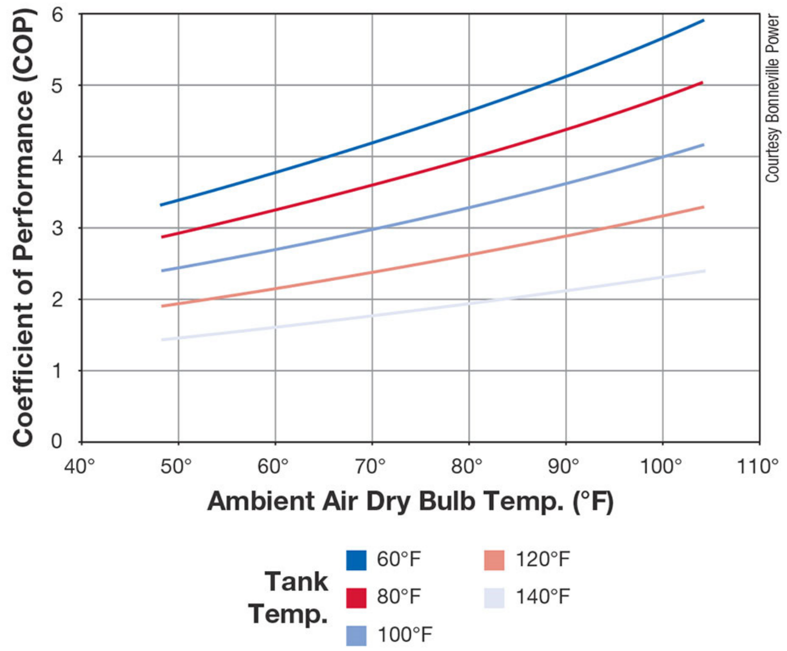
[left: REHVA, right: Rob Pena and Kevin Den, Training Course, Estonia 16th June 2009]

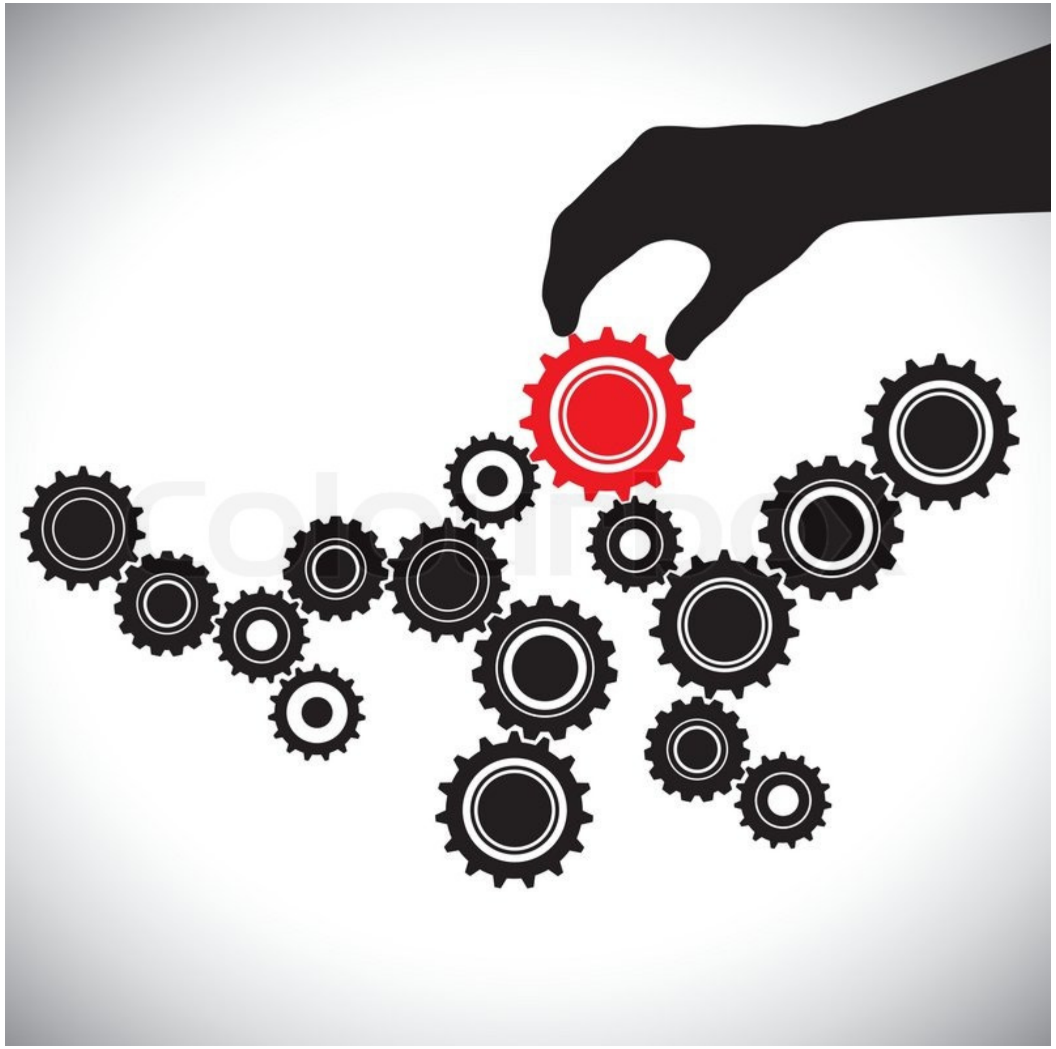
Impact on delivered energy

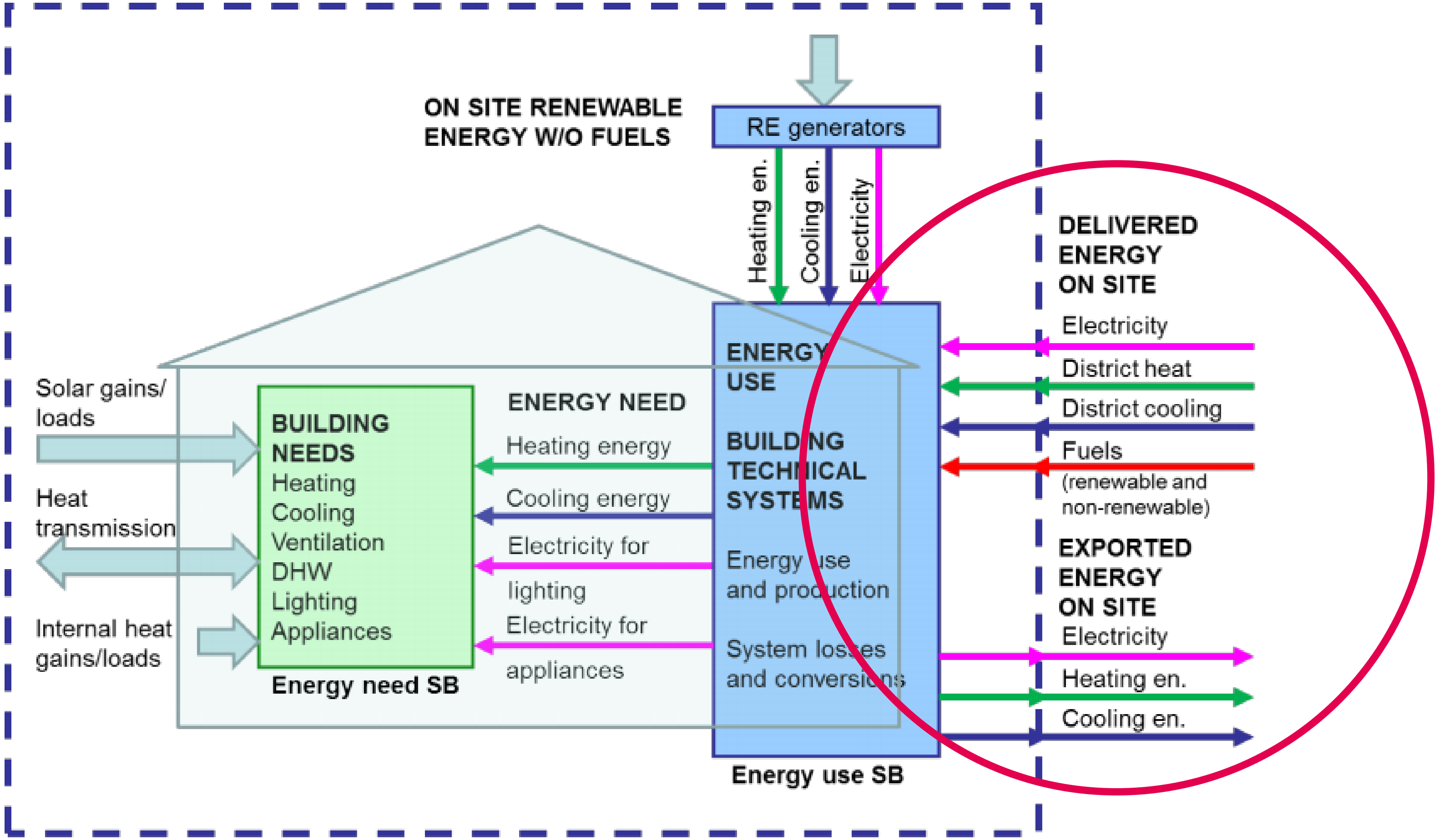


Efficient contamination removal No need to condition the whole volume

Using higher supply air temperature and lower fan power

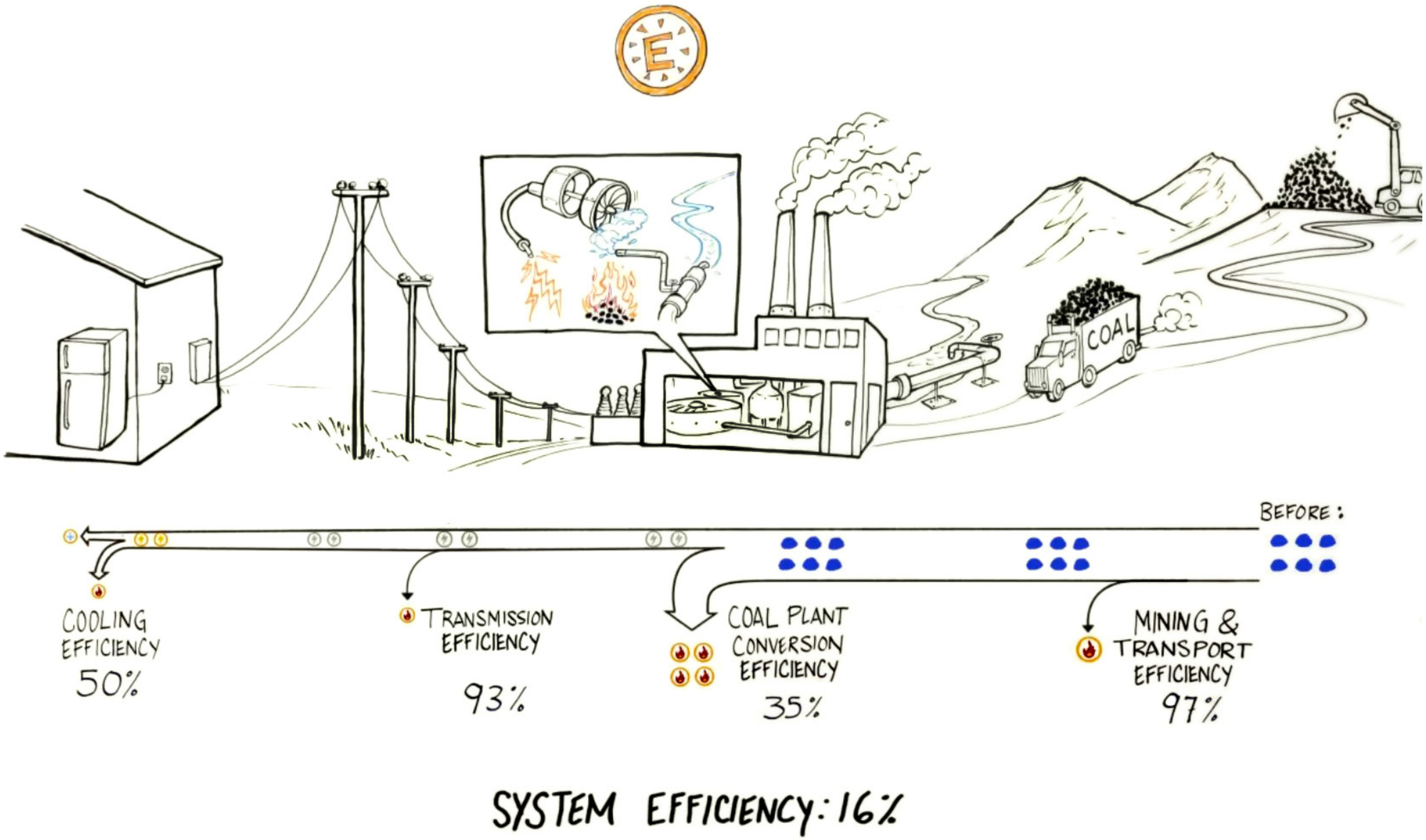






Building site boundary = system boundary of delivered and exported energy on site

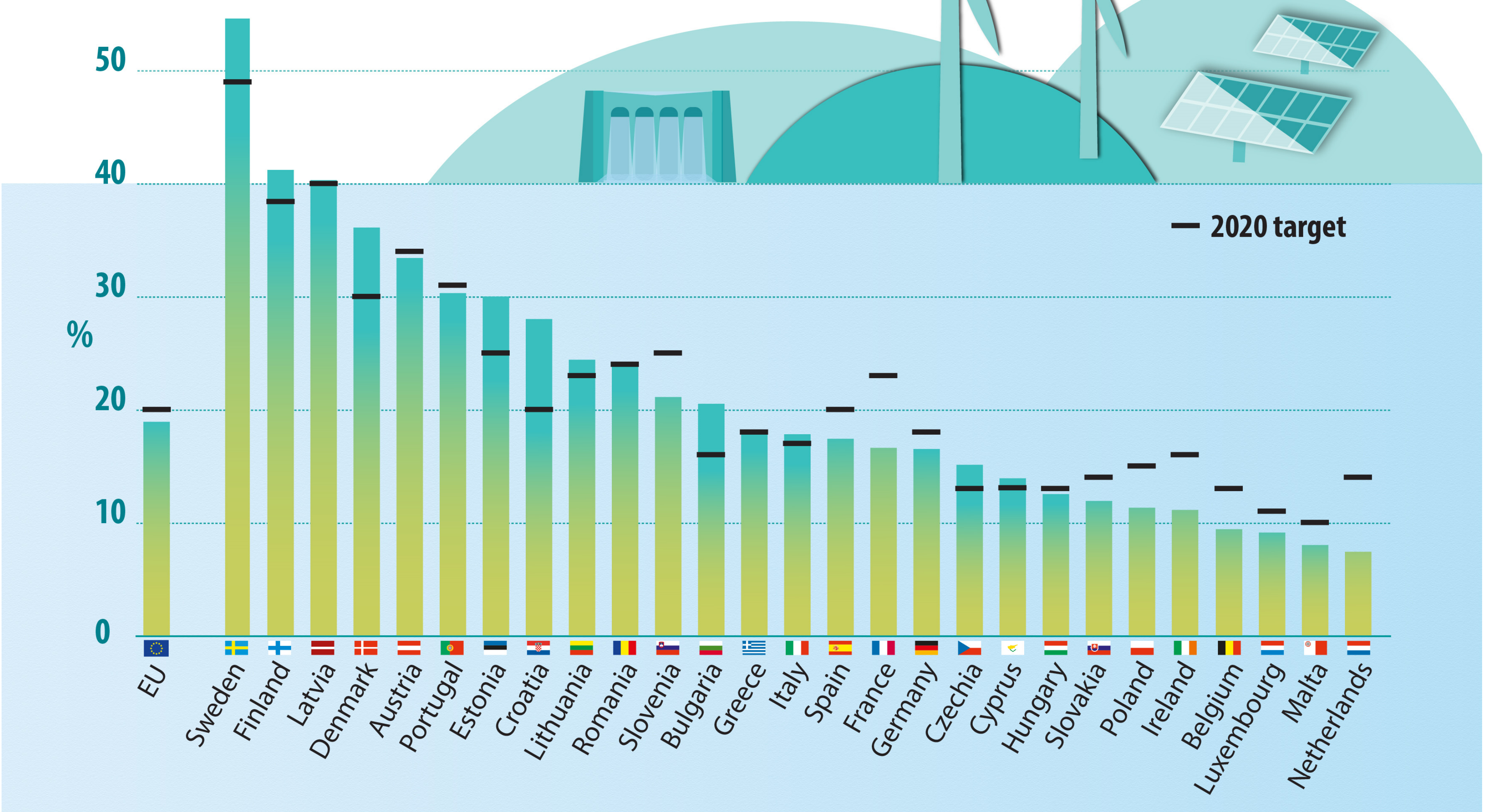
- System boundaries (SB) for energy need, energy use and delivered and exported energy calculation. The last one may be interpreted as the building site boundary.
- Demand reduction measures can be distinguished from RE solutions in the energy use SB, not in the delivered/exported energy SB


COAL
BEFORE:
COOLING EFFICIENCY 50%
TRANSMISSION EFFICIENCY 93%
COAL PLANT CONVERSION EFFICIENCY 35%
MINING & TRANSPORT EFFICIENCY 97%
SYSTEM EFFICIENCY: 16%

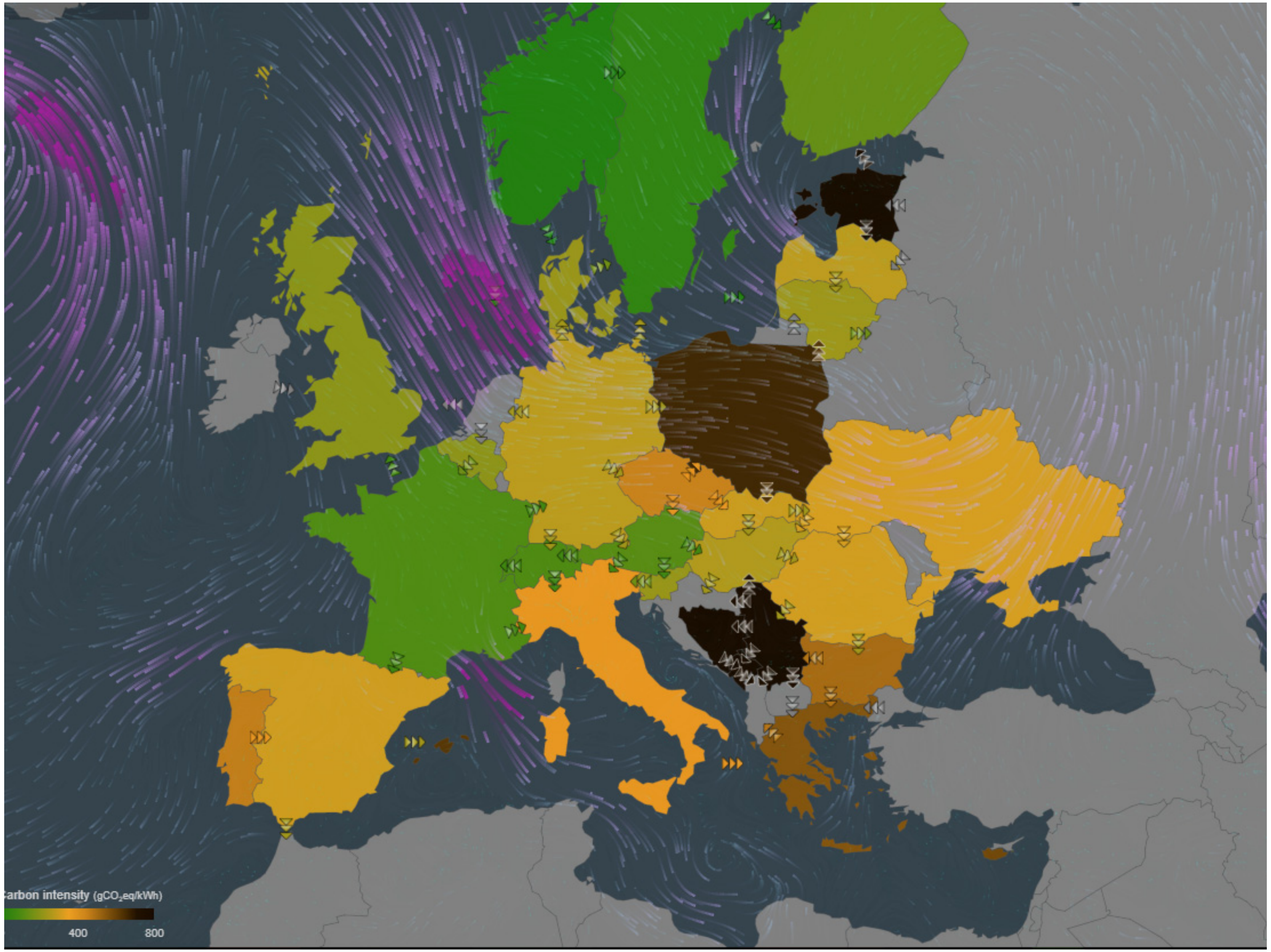
[Autodesk]

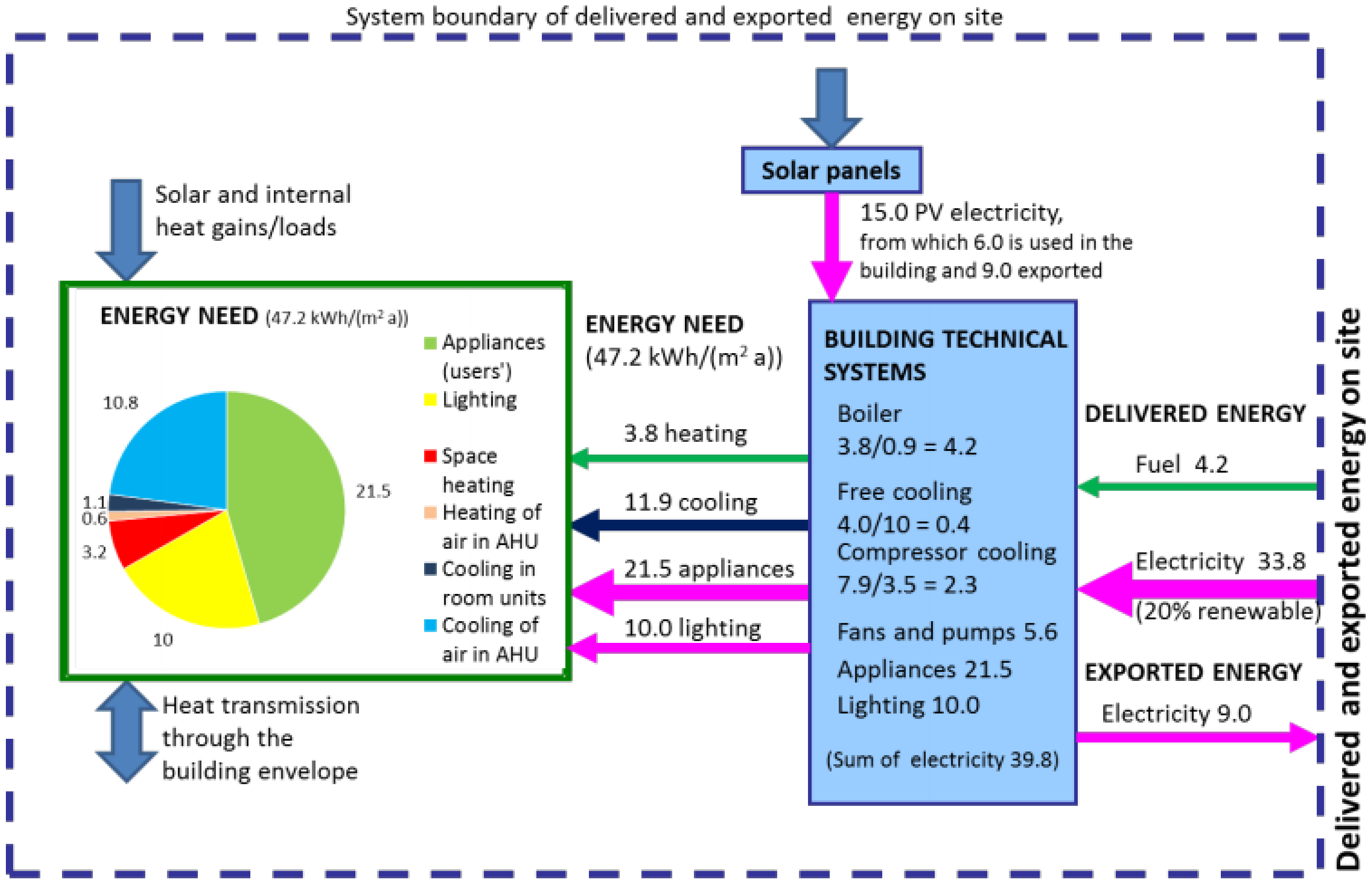
Share of energy from renewable sources in the EU Member States

(2018, in % of gross final energy consumption)

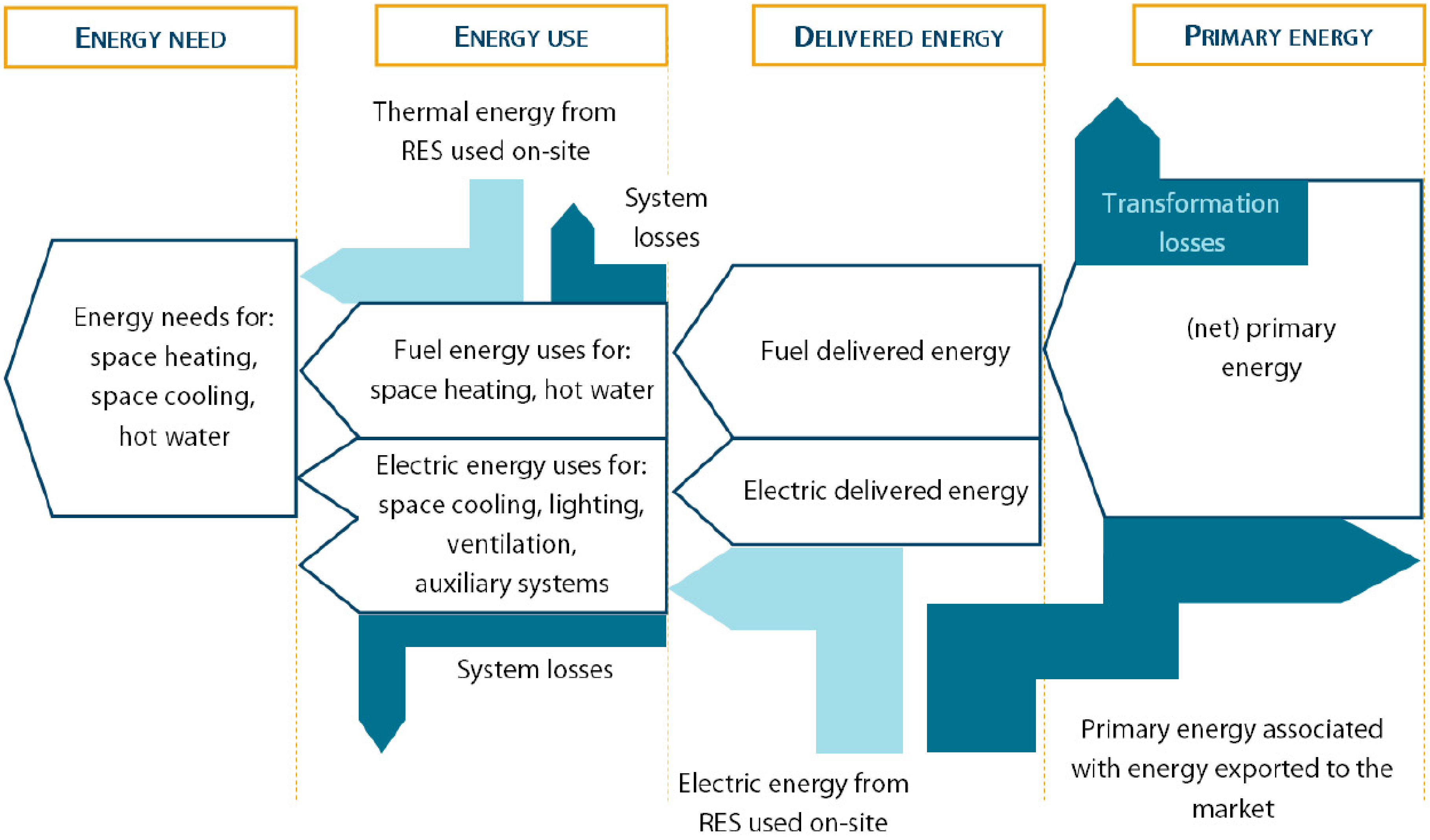


Electricitymap.org





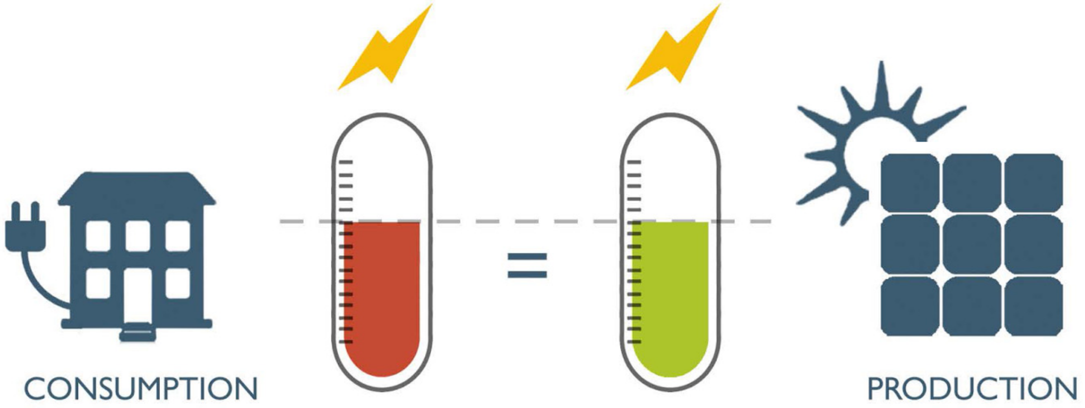
Primary energy: $EP_P = 4.2 \cdot 1.0 + 33.8 \cdot 2.0 - 9.0 \cdot 2.0 = 53.8 \frac{kWh}{m^2 a}$


ENERGY NEED
ENERGY USE
DELIVERED ENERGY
PRIMARY ENERGY
Thermal energy from RES used on-site
System losses
Transformation losses
Energy needs for: space heating, space cooling, hot water
Fuel energy uses for: space heating, hot water
Fuel delivered energy
(net) primary energy
Electric energy uses for: space cooling, lighting, ventilation, auxiliary systems
Electric delivered energy
System losses
Electric energy from RES used on-site
Primary energy associated with energy exported to the market

Different meanings of zero

Net-Zero **Site Energy** Building

A building that generates (at least) as much energy as it uses on-site. This is the most common use of the "net-zero" term.



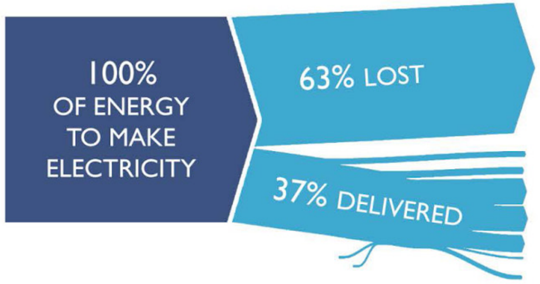
[Browning Day Mullins Dierdorf Architects]

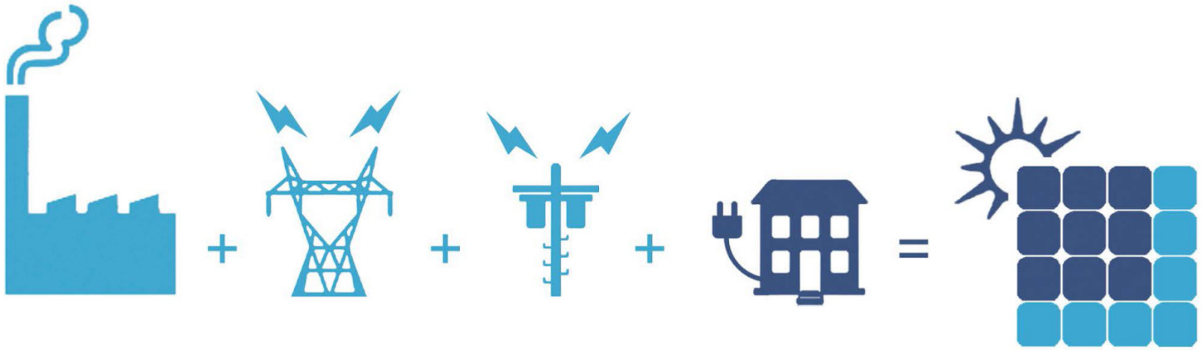
Different meanings of zero

Net-Zero **Source Energy** Building

A building that produces (at least) as much energy as it consumes when compared to the energy used to ***both generate and deliver*** the energy to the site from a remote point of generation (such as a power plant), ***plus the energy consumption*** on the site.

This definition factors in transmission losses and the other inefficiencies.



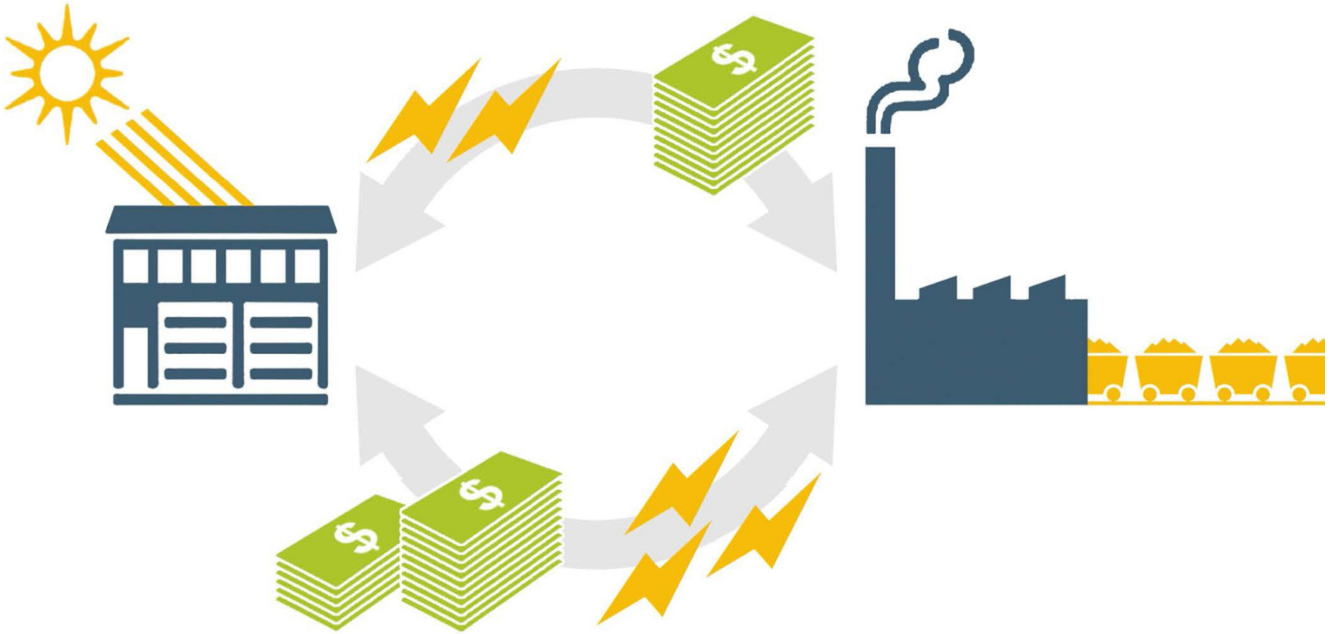


[Browning Day Mullins Dierdorf Architects]

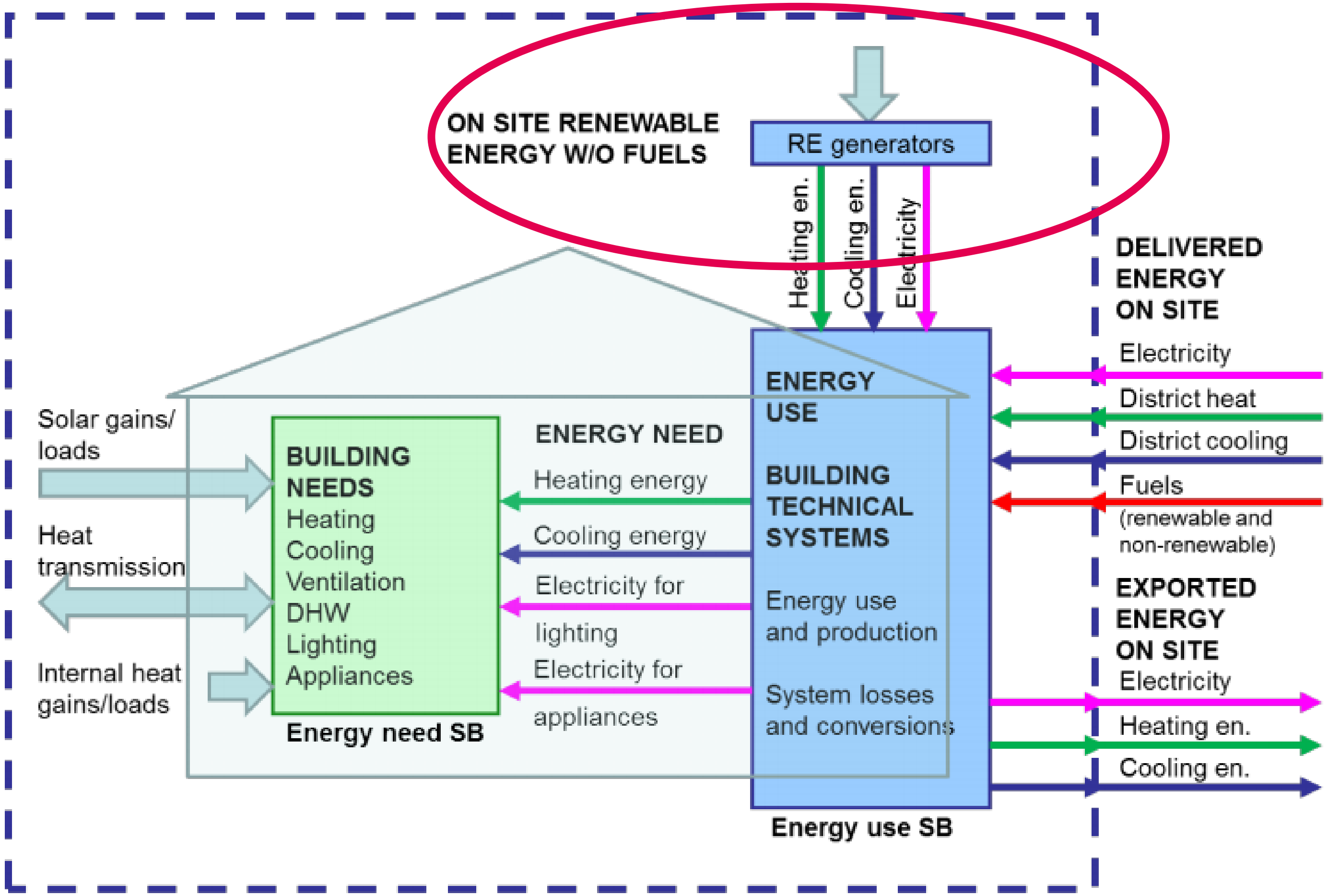
Different meanings of zero

Net-Zero **Energy Cost** Building

A building that sells more power to the utility than it purchases. Utilities generally charge more than they pay for power.



[Browning Day Mullins Dierdorf Architects]



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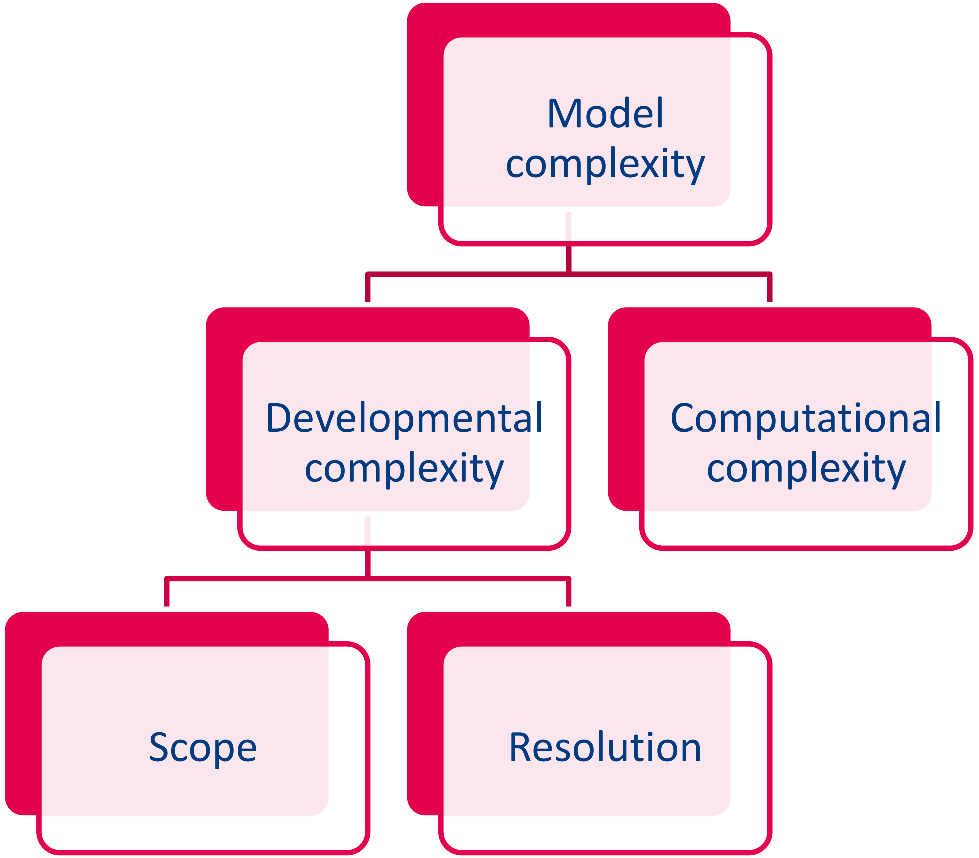
Need for simulation



- » **Scope:** How much of the real world is represented
  - Building, HVAC, renewables
  - Thermal, daylight, airflow, acoustics, …
  - Room, floor, building, district
  - Day … year … decades
- » **Resolution:** The number of variables in the model and their precision or granularity
  - Spatial
  - Temporal

Zeigler, B. P., Praehofer, H., & Kim, T. G. (2000). *Theory of modeling and simulation:*. Academic press.

Need for simulation?

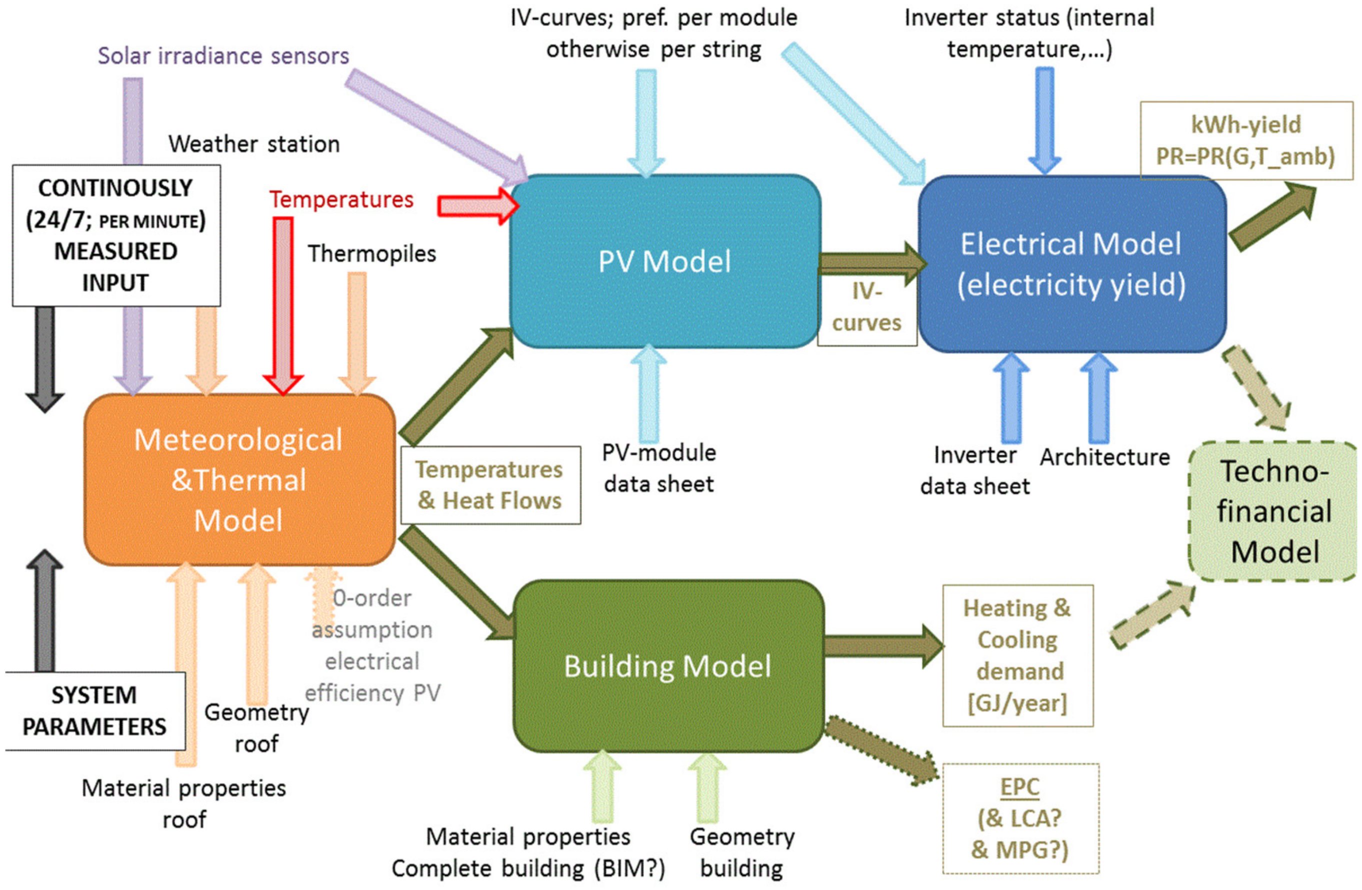
Need for simulation?

» Annual yield

	-90	-85	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
	W				ZWW					ZW				ZZW					Z				ZZO					ZO				ZOO					O	
Horizontaal	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	Horizontaal
5	88	88	89	89	89	90	90	90	91	91	91	91	91	91	91	91	[illegible]	[illegible]	[illegible]	[illegible]	91	91	91	91	91	91	91	91	90	90	90	91	91	91	90	89	89	5
10	89	90	91	91	91	92	92	93	94	94	94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	96	96	96	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	94	94	[illegible]	93	93	93	92	91	91	90	90	10
15	88	89	90	91	92	93	91	94	95	[illegible]	[illegible]	96	96	96	97	97	97	97	97	97	97	97	97	96	96	96	[illegible]	[illegible]	[illegible]	94	94	93	92	91	91	90	89	15
20	87	88	89	90	91	92	93	94	[illegible]	96	96	97	97	97	98	98	98	98	98	98	98	98	98	97	97	97	96	96	96	95	94	93	92	91	90	89	88	20
25	87	88	89	90	91	92	93	94	95	96	97	98	98	98	99	99	99	99	99	99	99	99	99	98	98	97	97	96	96	95	94	93	92	91	89	88	87	25
30	86	87	88	89	90	92	93	94	95	96	97	98	98	98	99	99	99	100	100	100	100	100	100	99	98	98	97	96	96	95	94	93	91	90	89	87	86	30
35	84	85	87	88	89	91	92	93	95	96	97	98	98	98	99	99	99	100	100	100	100	100	100	99	98	98	97	96	95	94	93	92	90	89	88	86	85	35
40	82	83	85	86	87	89	90	[illegible]	94	95	96	97	98	98	99	99	99	100	100	100	99	99	99	98	98	98	97	96	95	93	92	91	89	88	87	85	84	40
45	80	82	84	85	86	88	89	91	93	94	[illegible]	96	97	97	98	98	98	99	99	99	98	[illegible]	98	97	97	96	95	95	93	92	91	89	88	87	85	84	82	45
50	78	80	82	84	85	87	88	89	91	92	93	94	95	95	96	96	96	97	97	97	97	97	97	98	96	95	94	93	92	90	89	88	86	85	84	82	80	50
55	76	78	80	82	83	85	86	87	89	90	91	92	93	93	94	94	94	95	95	95	95	95	95	94	94	93	92	91	90	89	88	86	85	83	82	80	78	55
60	74	76	78	79	81	83	84	85	86	87	88	89	90	90	91	91	92	93	93	93	93	93	93	92	92	91	90	89	88	87	86	85	83	81	80	78	78	60
65	72	74	76	77	78	80	81	82	84	85	86	87	88	88	89	89	89	90	90	90	90	90	90	89	89	88	87	87	85	84	83	82	80	79	77	75	73	65
70	69	71	73	74	75	77	78	79	81	82	83	84	85	85	86	86	86	87	87	87	87	87	87	86	86	86	85	84	83	81	80	79	77	76	74	72	70	70
75	66	68	70	71	72	74	75	76	78	79	80	81	82	82	83	83	83	84	84	84	84	84	84	83	83	82	81	81	79	78	77	76	74	73	71	69	68	75
80	63	65	67	68	69	71	72	73	74	75	76	77	78	78	79	79	79	80	80	80	80	80	80	79	79	79	78	77	76	75	74	73	71	69	68	66	65	80
85	60	61	63	64	65	67	68	69	70	71	72	73	74	74	75	75	75	76	76	76	76	76	76	75	75	75	74	73	72	71	70	68	67	66	64	63	62	85
Vertikaal	56	57	59	60	61	63	64	65	66	67	68	69	69	70	71	71	71	71	71	71	71	71	71	71	71	71	70	69	68	66	65	64	63	62	61	59	58	Vertikaal
	W				ZWW					ZW				ZZW					Z				ZZO					ZO				ZOO					O	
	-90	-85	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	

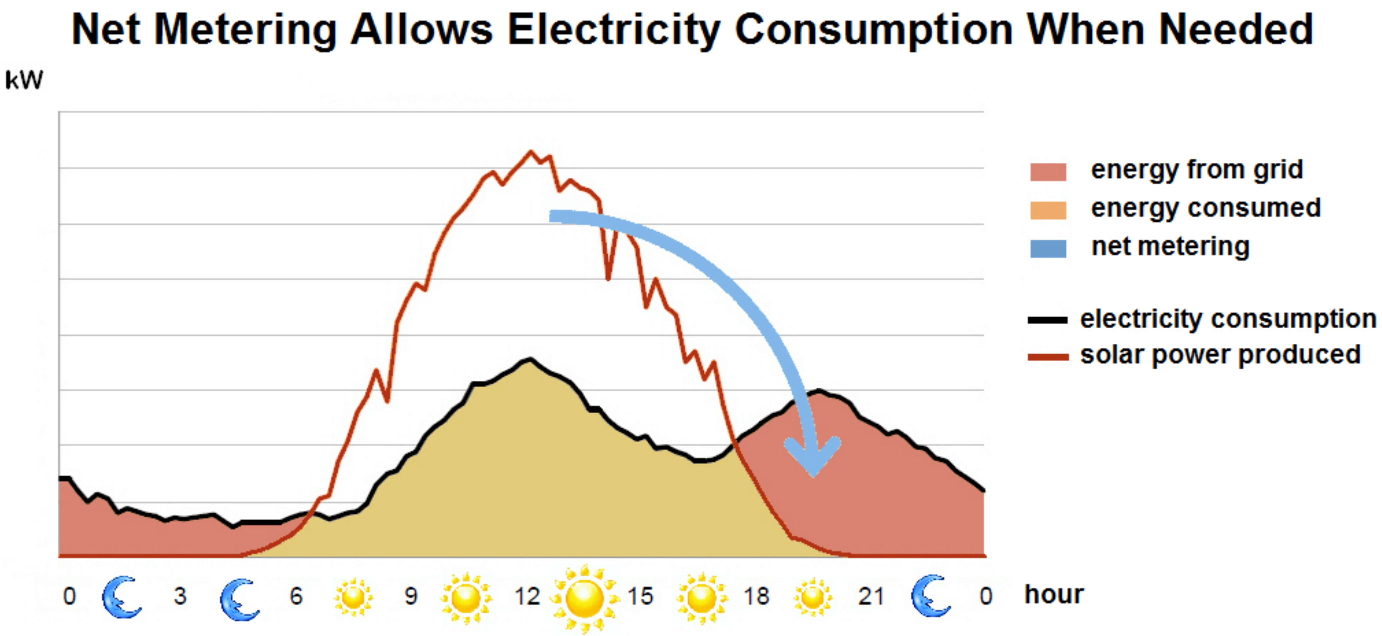
Hellingshoek in graden (0° = horizontaal)

BIPV - Need for simulation



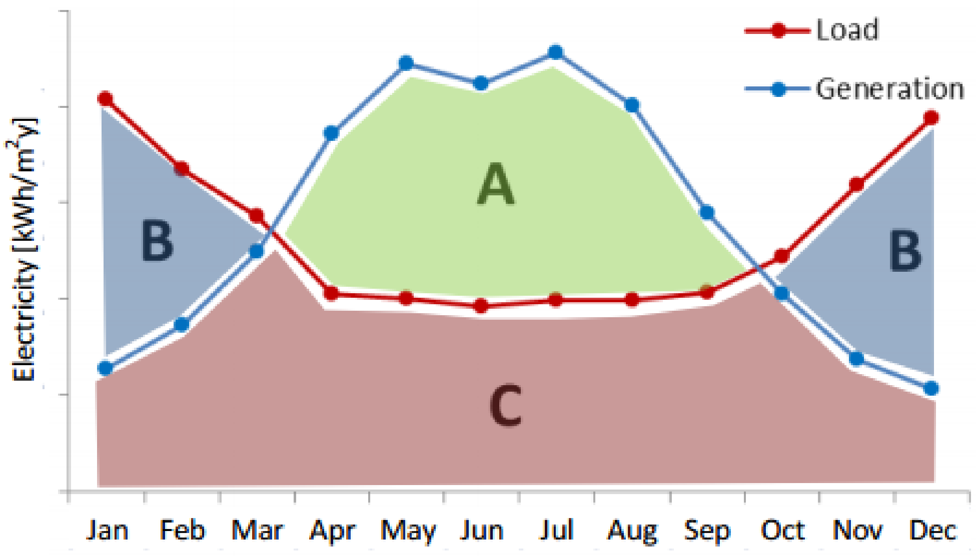
Material and module properties to be validated/checked by off-line methods whenever needed.
Inverter properties to be checked by off-line methods whenever needed.

Net-metering - Need for simulation



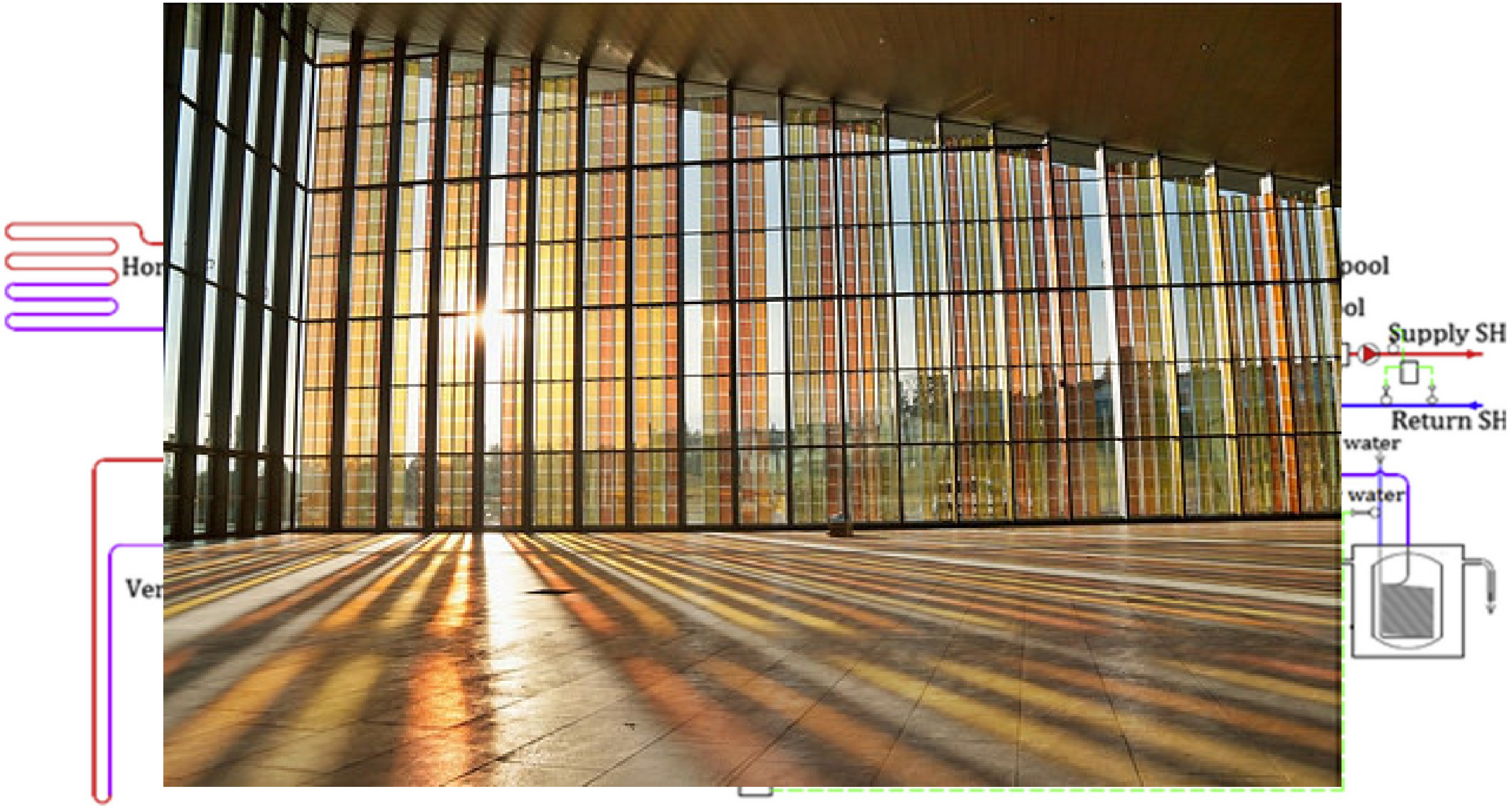
Energy matching – self consumption

- *supply cover factor =* $\frac{C}{B+C}$, also called "self-consumption"
- *load cover factor =* $\frac{C}{A+C}$, also called "self-generation"



Scope and resolution

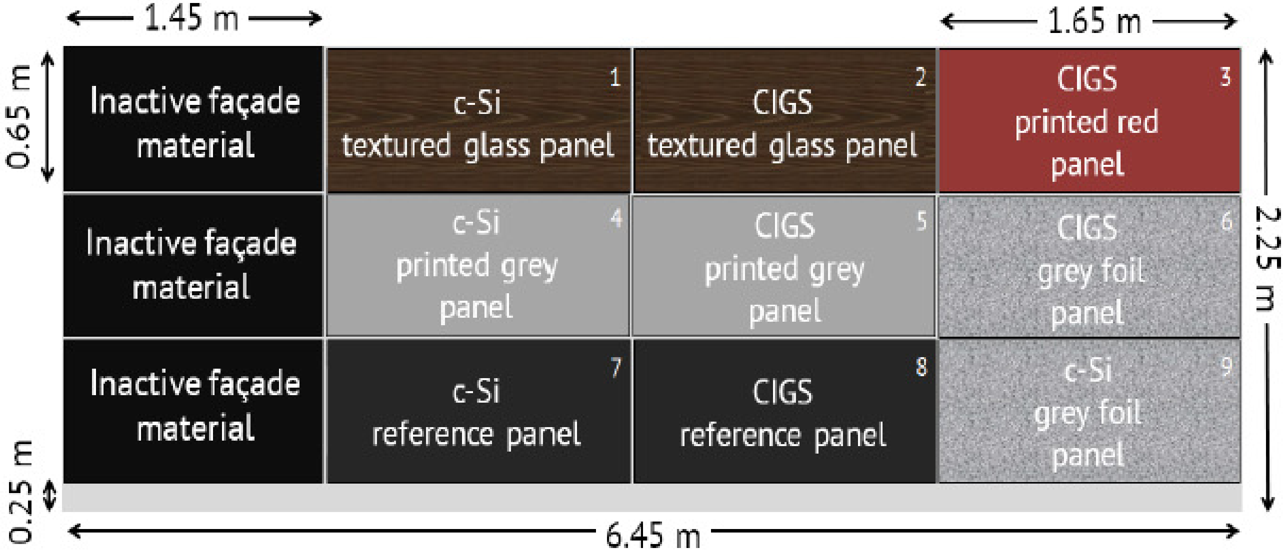
- Systems integration
- Spectral properties



Energy supply system with solar thermal system, GSHP, and EAHP.

Source: Natasa Nord, Live Holmedal Qvistgaard, Guangyu Cao, Identifying key design parameters of the integrated energy system for a residential Zero Emission Building in Norway, Renewable Energy

- This project intends to make efficient, aesthetic and cheap PV panels.
- A demonstrator was installed at the Solar Beat.



Measurements
- Irradiance
- Operating temperature
- Voltage
- Current
- Solar spectra

seac

TU/e Technische Universiteit Eindhoven University of Technology

SOLLIANCE SOLAR RESEARCH

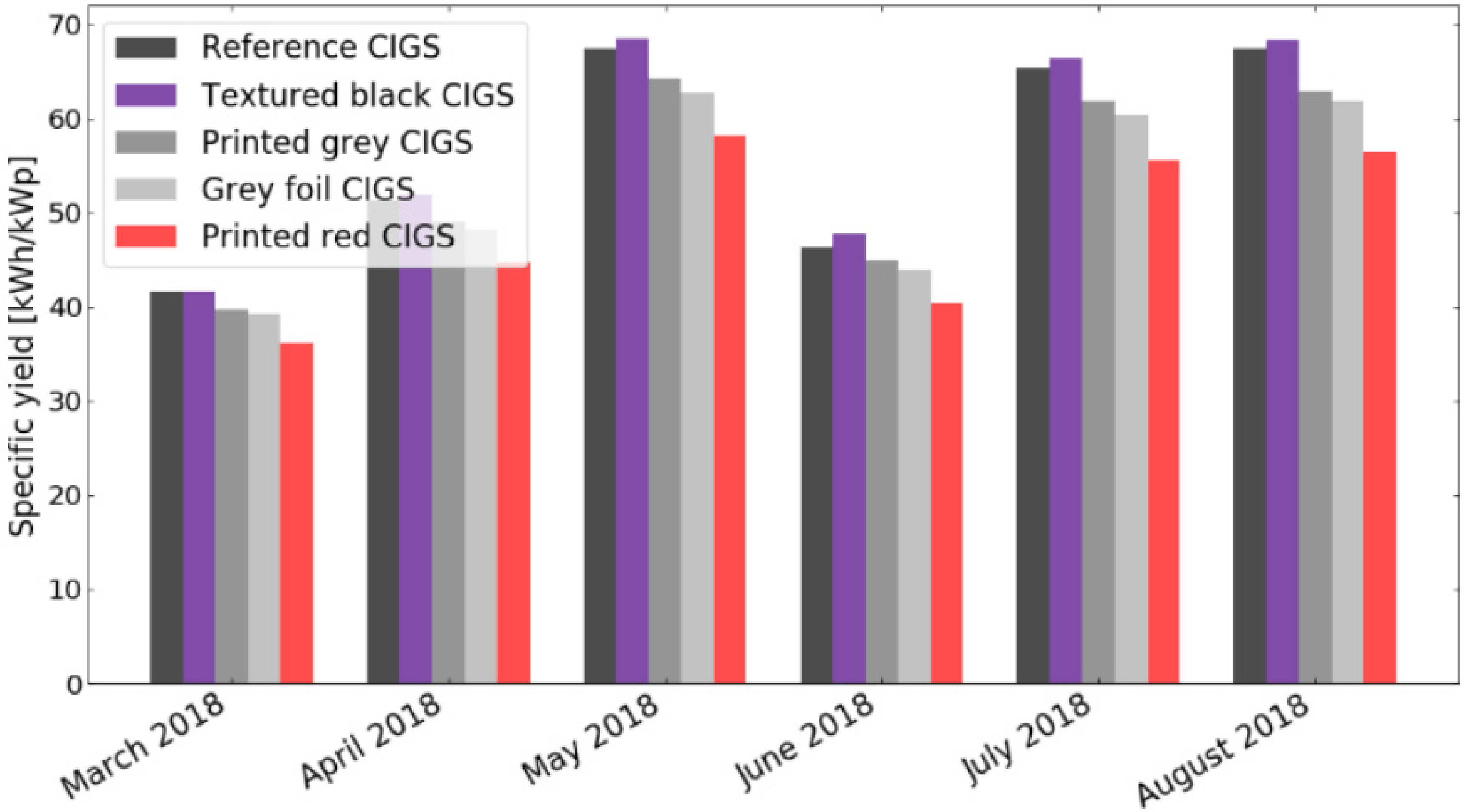
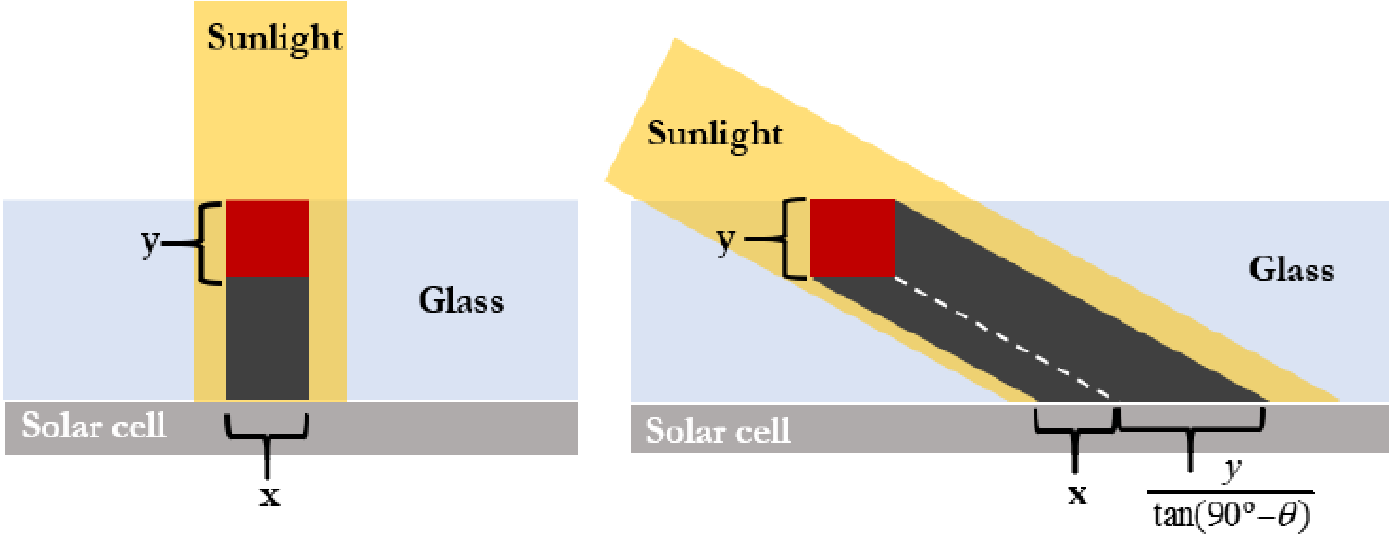


Figure 8: Monthly specific yield of the CIGS PV panels.

Panels with foils and textures exhibit a lower performance at high solar incidence angles, both with direct and diffuse irradiance.

Possible explanation: increased specular reflection losses and/or shadowing of the prints.



Introducing custom IAM profiles

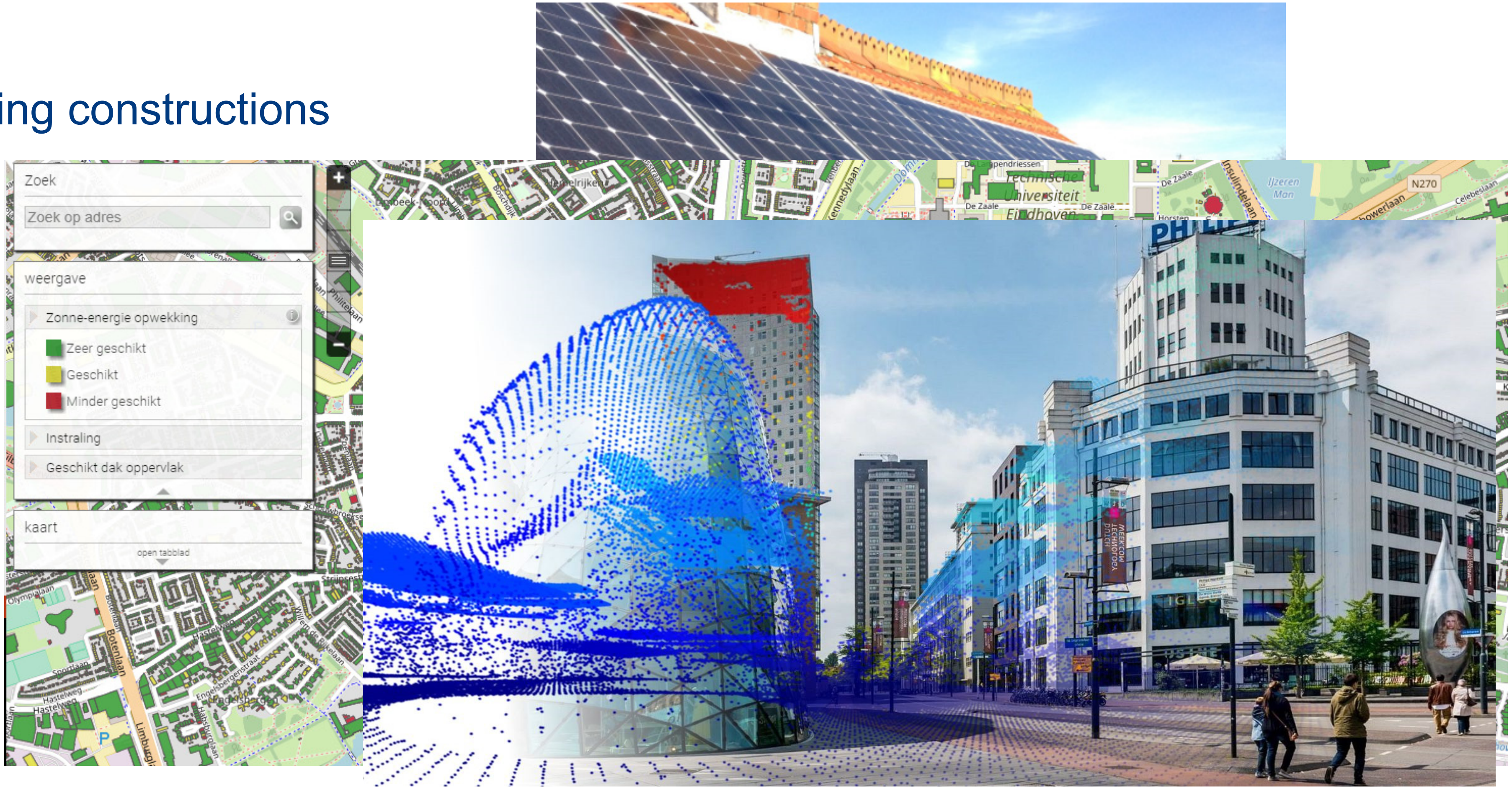
Modelling the effective irradiance as traditional simulation tools do (Helioscope, SAM, etc).

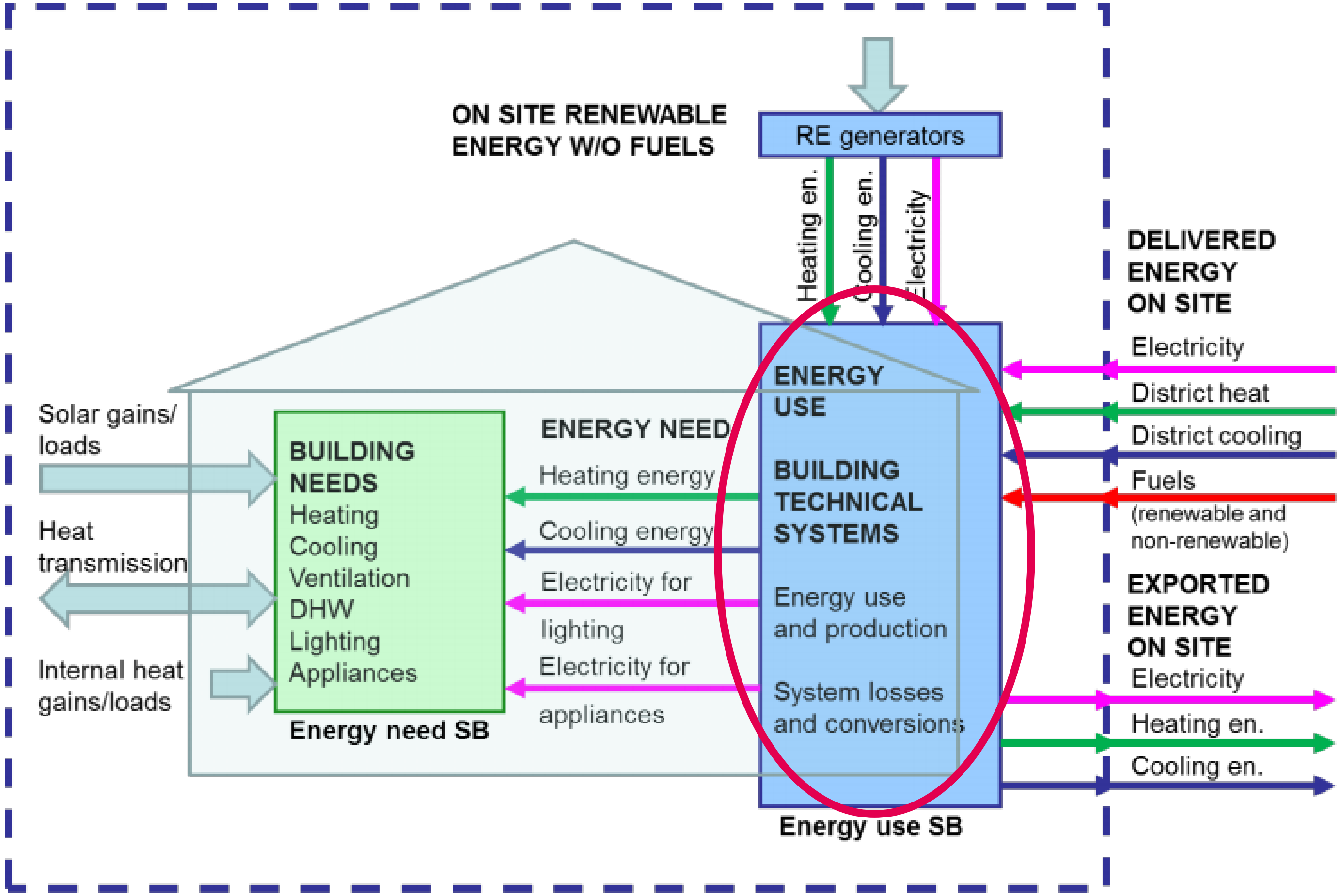
Assuming no non-linear losses at the solar surface.

Technology	Prototype	No losses	Traditional PV	Custom IAM
c-Si	Reference	7.80%	1.43%	1.39%
	White Print	6.58%	0.24%	-0.22%
	White Foil	15.65%	8.78%	1.28%
	Red Print	-	-	-
	Textured	9.28%	2.77%	0.02%
CIGS	Reference	10.25%	3.72%	2.98%
	White Print	8.32%	1.90%	0.71%
	White Foil	15.64%	8.67%	0.58%
	Red Print	9.34%	2.85%	1.65%
	Textured	10.52%	3.96%	1.67%

Scope and resolution

- Systems integration
- Spectral properties
- Shading from neighboring constructions
- Reflected radiation
- City scale





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(HVAC) System simulation

- Definition:
  "... predicting the operating quantities within a system (pressures, temperatures, energy and fluid flow rates) at the condition where all energy and material balances, all equations of state of working substances, and all performance characteristics of individual components are satisfied.“ (ASHRAE 1975)

- Consider building dynamics vs. system dynamics

Approaches for modeling energy systems

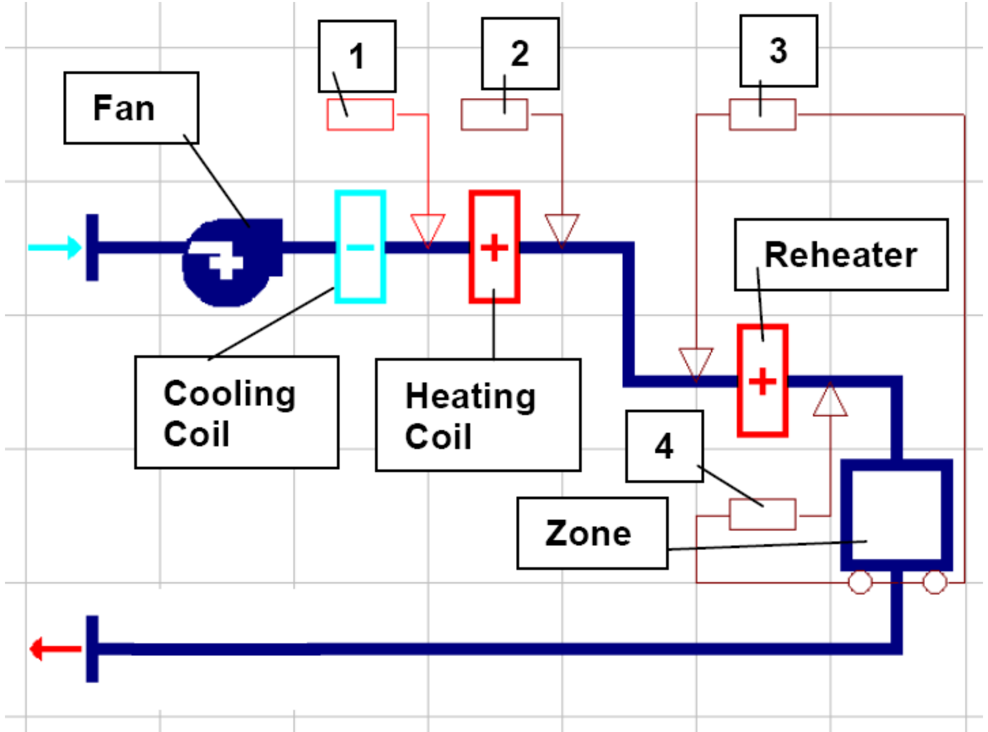
A. Ideal system
B. System based efficiencies (e.g. VAV)
C. Component based
D. Component based in multidomain
E. Equation based

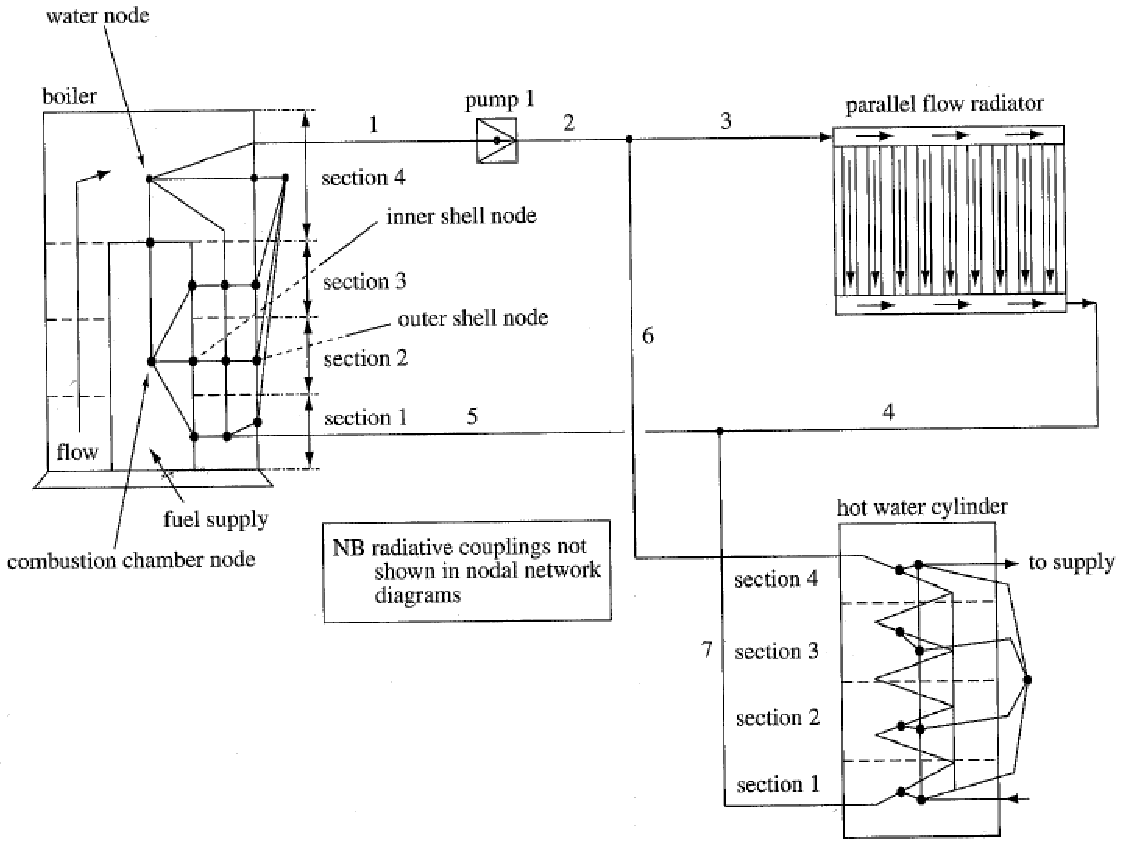
Conceptual

↓

Explicit

Examples

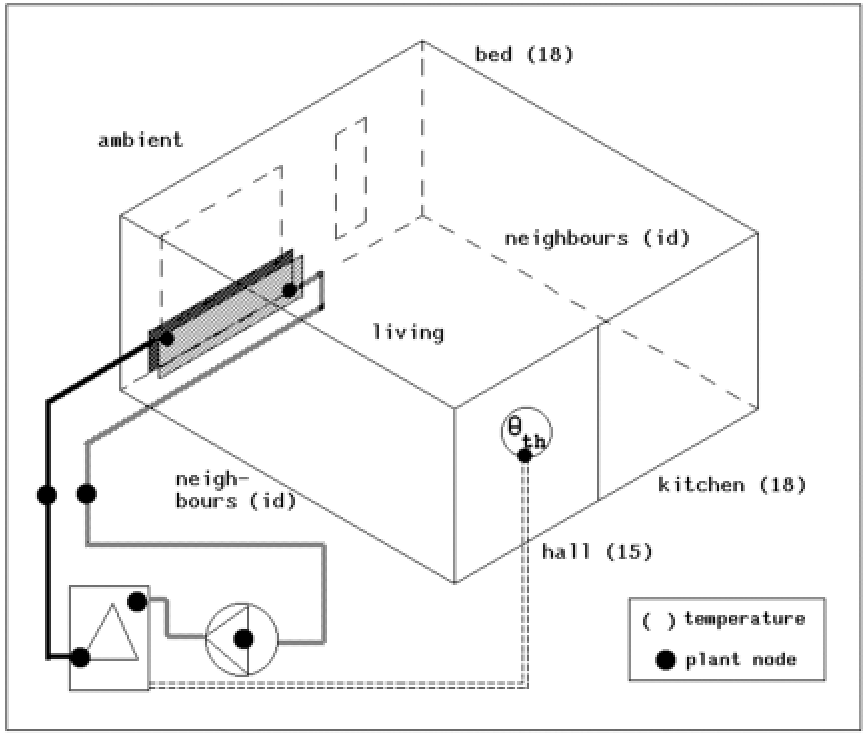

1
2
3
Fan
Reheater
Cooling Coil
Heating Coil
4
Zone

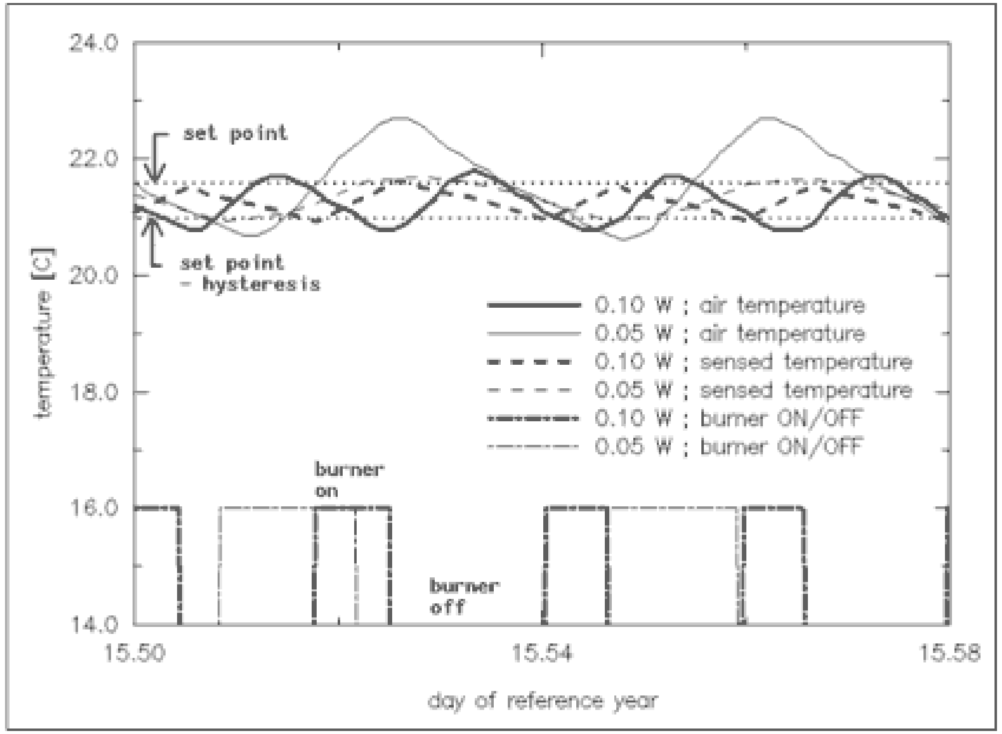

water node
boiler
1
pump 1
2
3
parallel flow radiator
section 4
inner shell node
section 3
outer shell node
section 2
section 1
5
6
4
flow
fuel supply
combustion chamber node
NB radiative couplings not shown in nodal network diagrams
hot water cylinder
section 4
to supply
7
section 3
section 2
section 1

Case: room thermostat

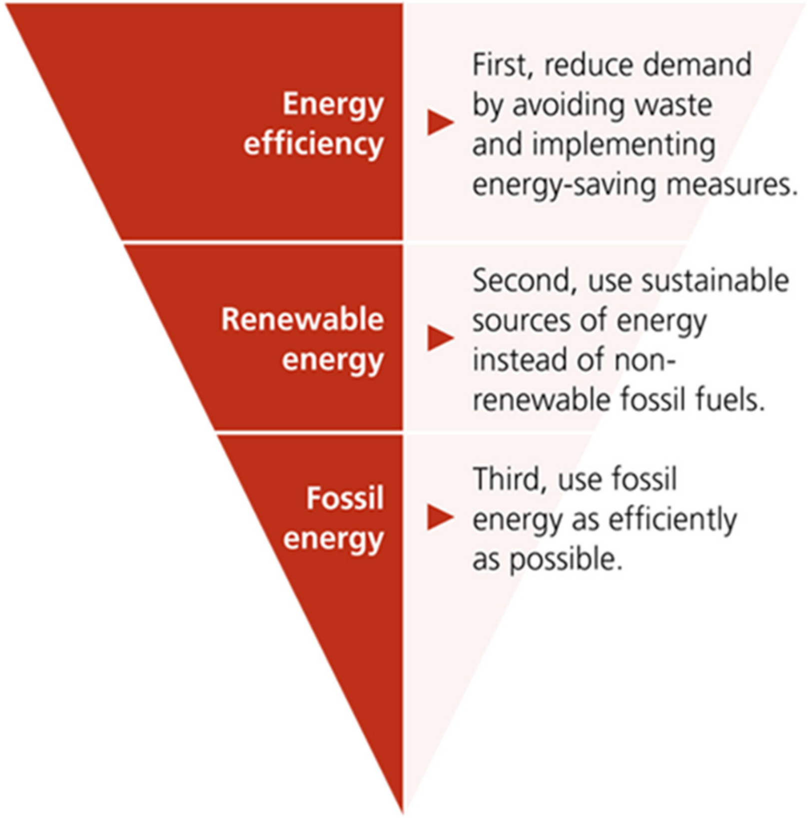
Plant

- 6 components
- 51 parameters

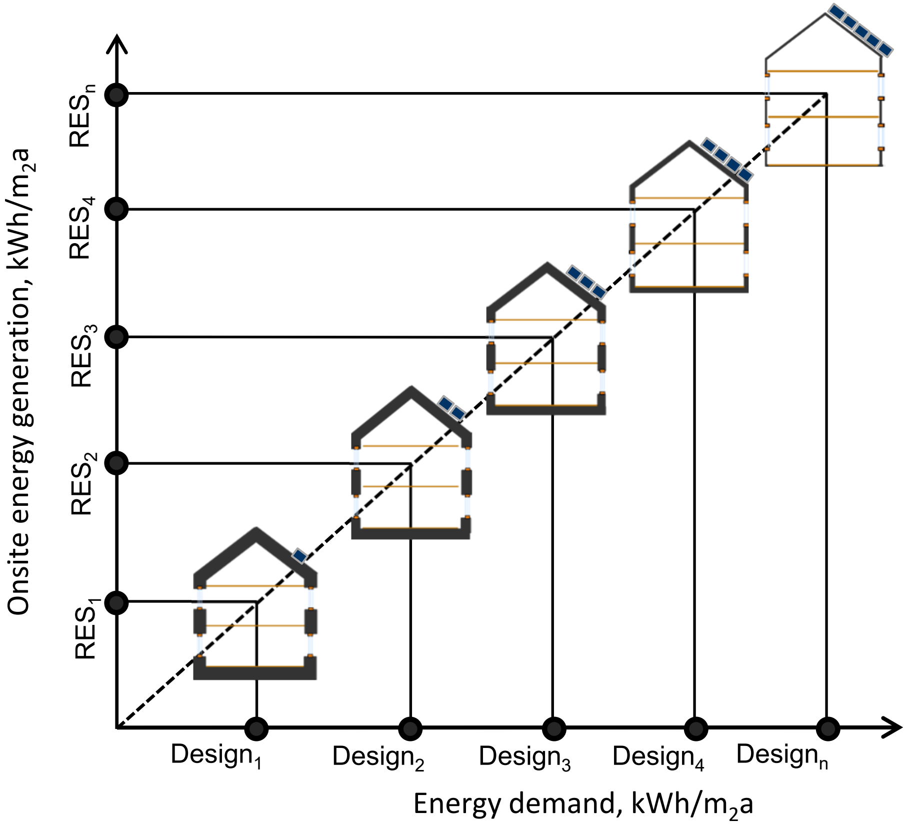




The "trias energetica" concept

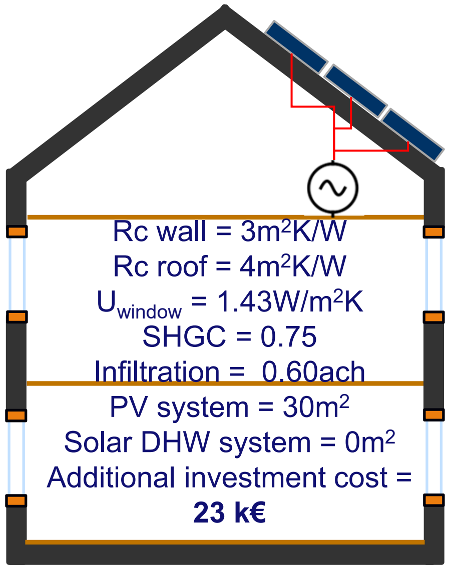


Energy demand vs. generation

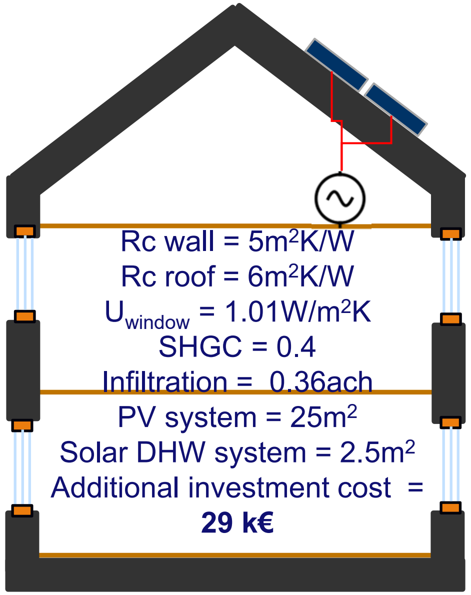


Selected renovation options

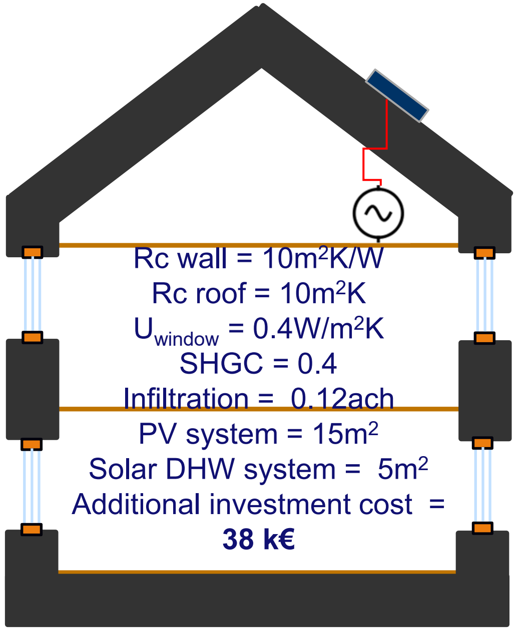
Low insulation



Medium insulation



Very high insulation



Scenarios

Scenarios

1 - 4

Working, retired

18 - 22° C
14 - 18° C

0.9 - 1.5 ach

1 - 3 W/m²

60 - 180 L/p/day

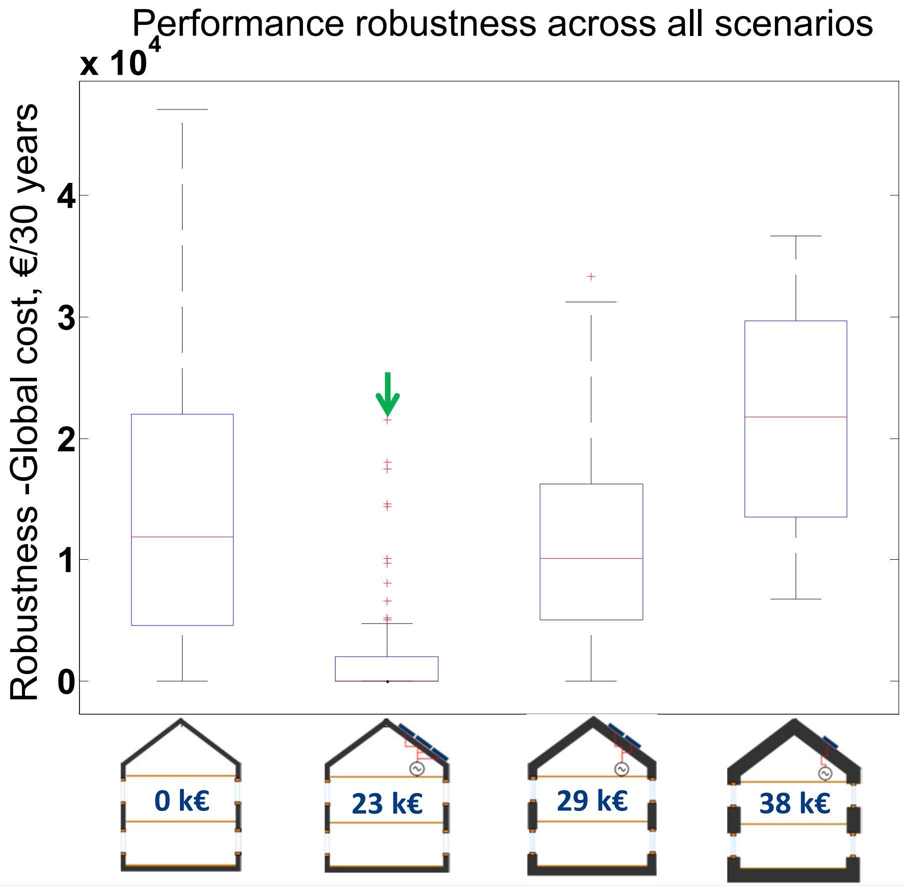
1 - 3 W/m²

ON/OFF
Radiation (200-350 W/m²)
Tindoor > 24° C

NEN 5060-2008
G, W, G+, W+

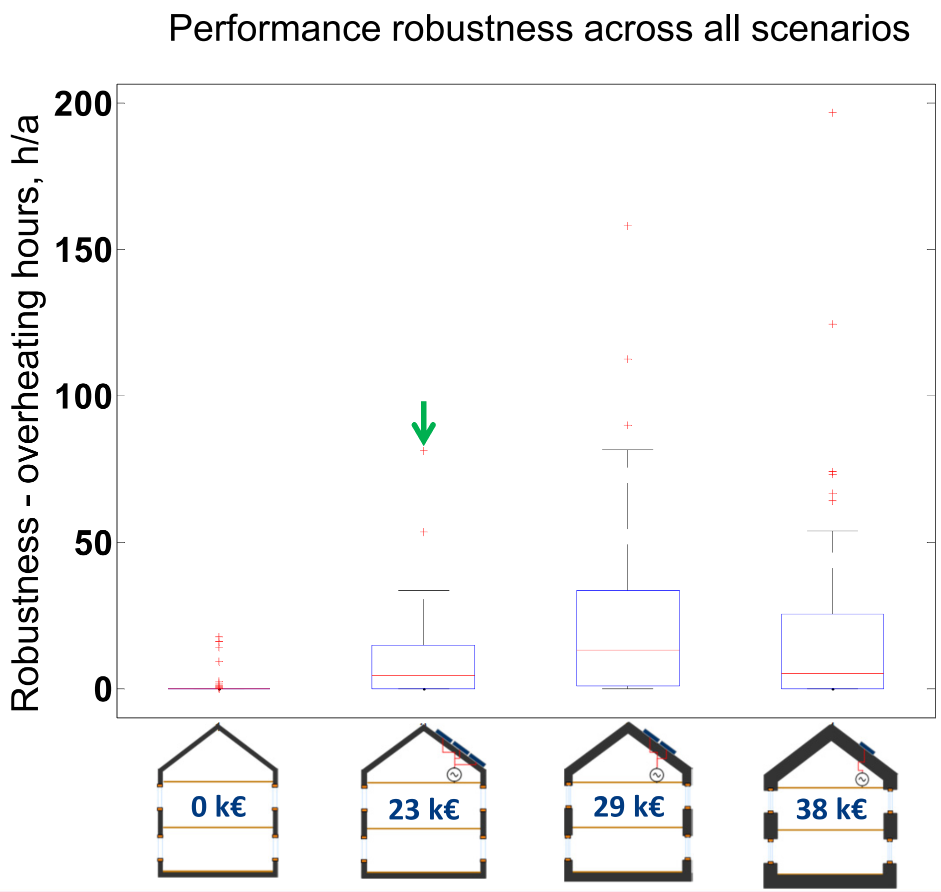
Global cost

- Cost of investment, replacement and operational
- Calculated for period of 30 years – service life span of energy systems



Thermal comfort

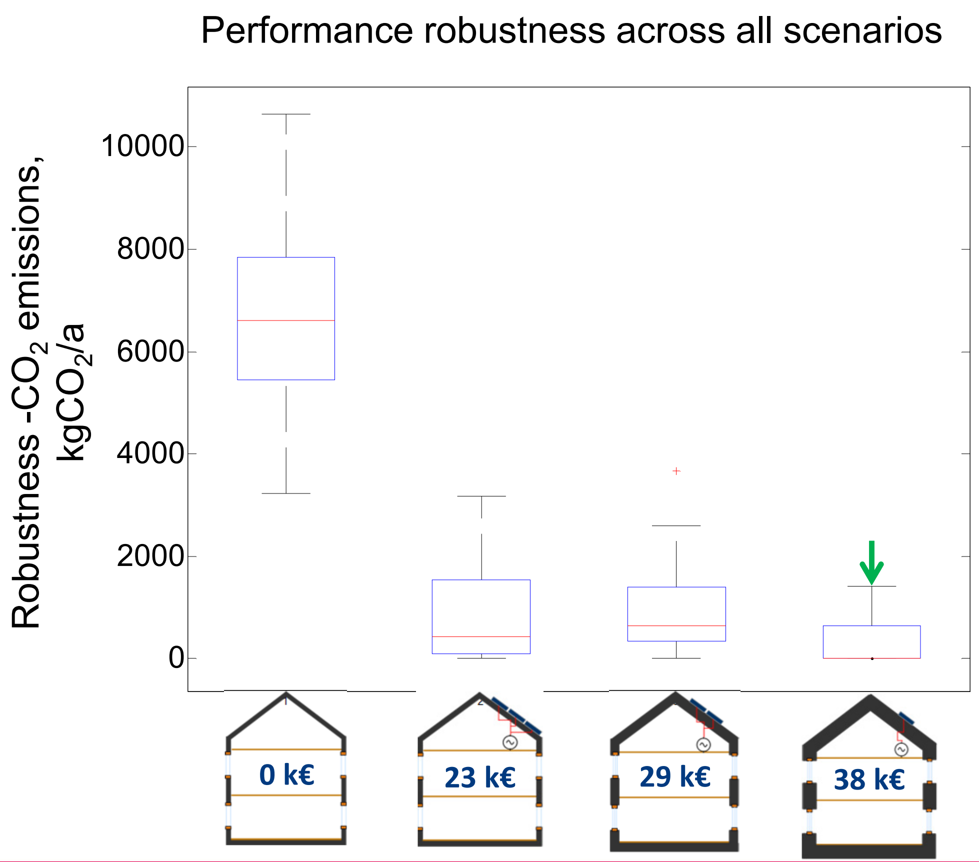
- Hours above adaptive temperature limits proposed by *Peeters et al., 2009*
- Calculated for occupancy hours in a year



CO2 emissions

$$CO_2\ emissions = Energy\ consumption \times EF - Energy\ generation \times EF$$

- EF = CO_2 emission factor
- Embodied emissions are not taken into account



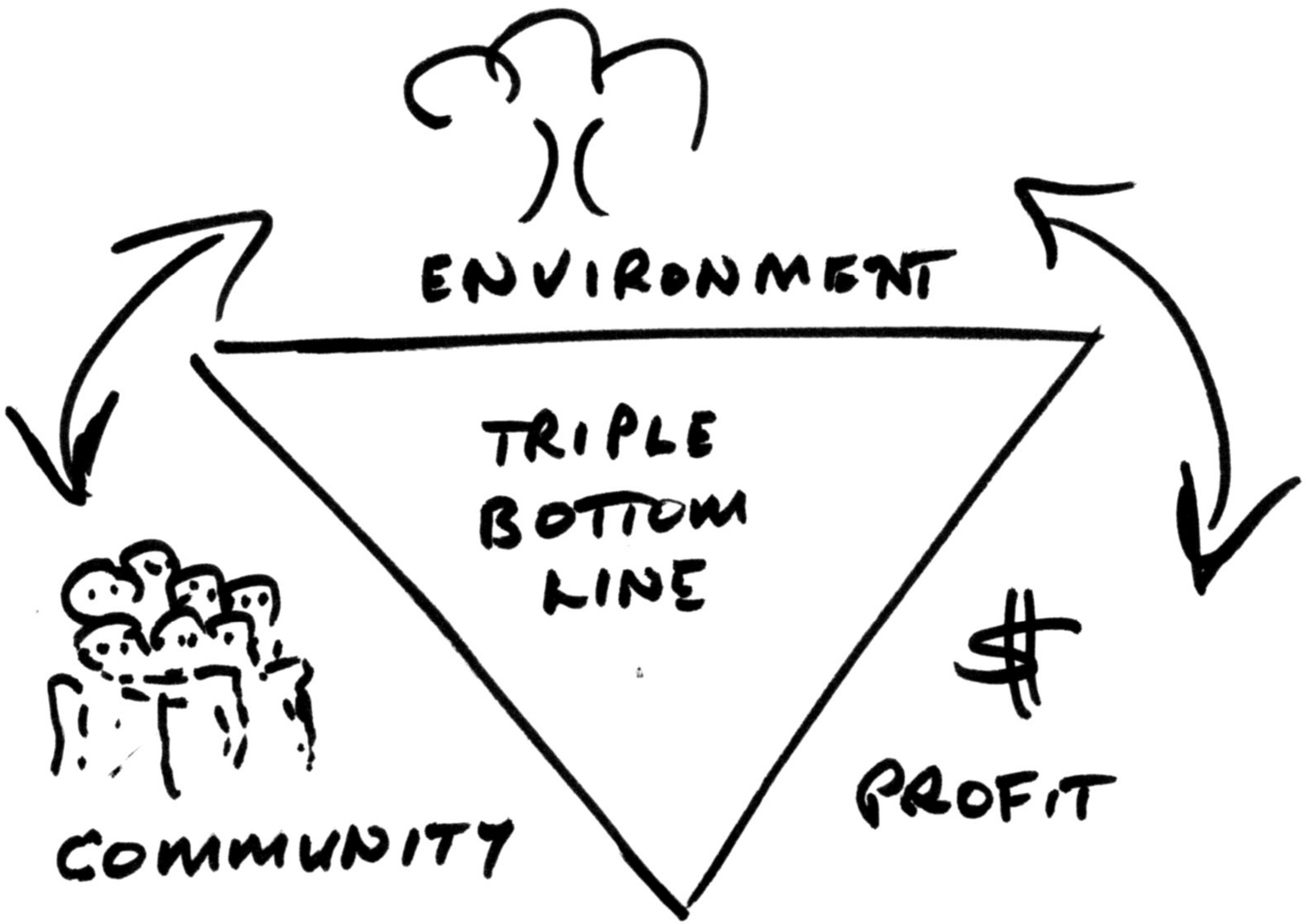
Summary - Design considerations

- Form of Energy —electricity? thermal energy? Site vs. source energy?

- Generation Characteristics
  - environment dependent — solar radiation, wind availability, soil properties

- Design Objectives / Evaluation Criteria
  - Energy generation
  - Life-cycle cost-effectiveness (unit cost, life-span, energy price ...)
  - Life-cycle carbon footprint (embodied carbon, life-span, comparative advantages ...)
  - Environmental Impact

- Design Limitation / Trade-off
  - financial resource — limits the amount of capital investment
  - land availability — limits the project size


ENVIRONMENT
TRIPLE
BOTTOM
LINE
$
PROFIT
COMMUNITY

Helioscope or PVWatts