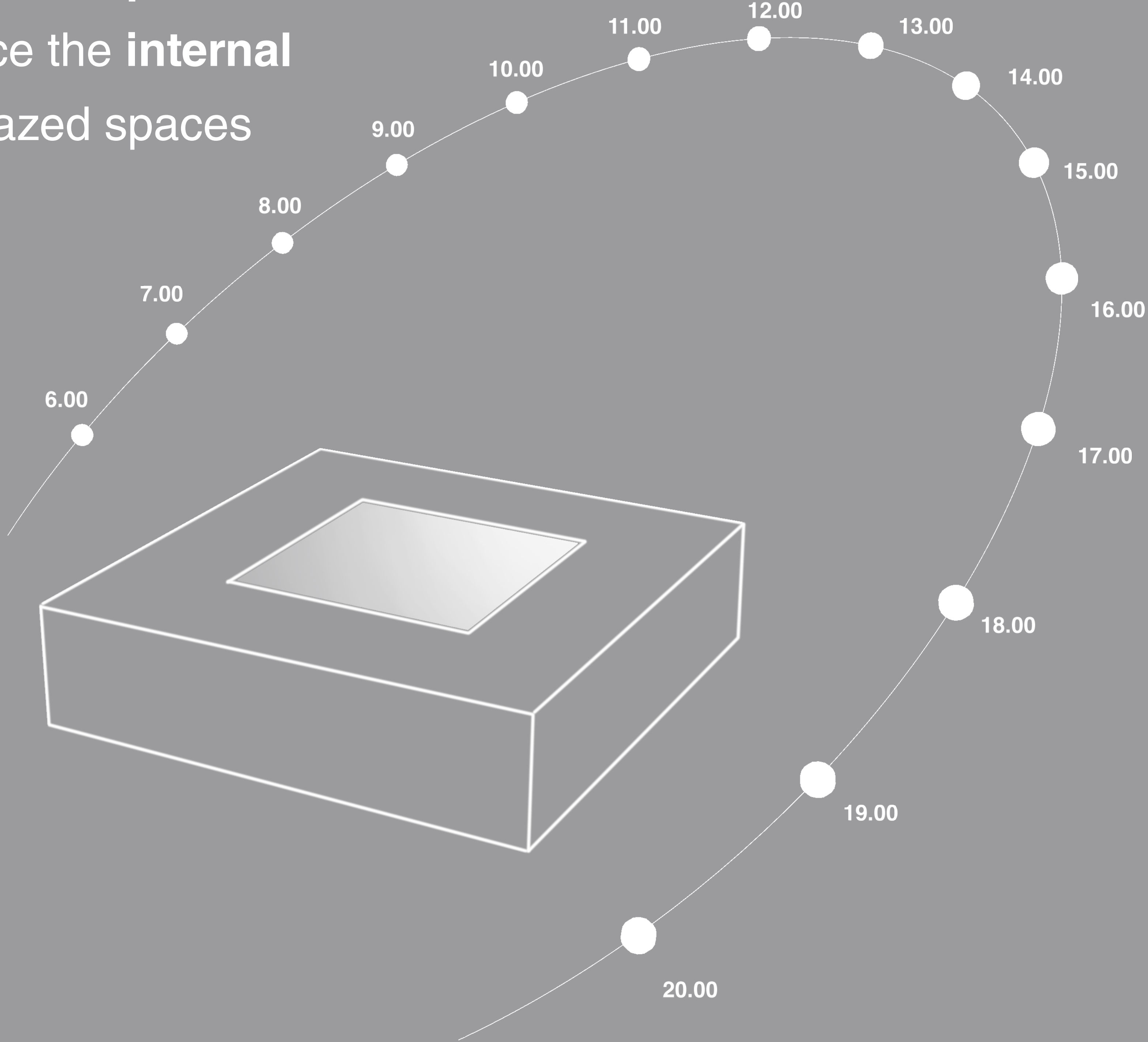
The use of **solar cells** to **produce energy** and enhance the **internal comfort** of large glazed spaces



MILAN VOORHORST - P5 - 27/6/2017

The use of **solar cells** to produce energy and enhance the **internal comfort** of **large glazed spaces**

In what way, can the integration of solar cells in the skin of large glazed spaces be applied effectively and contribute positively to the internal thermal comfort?

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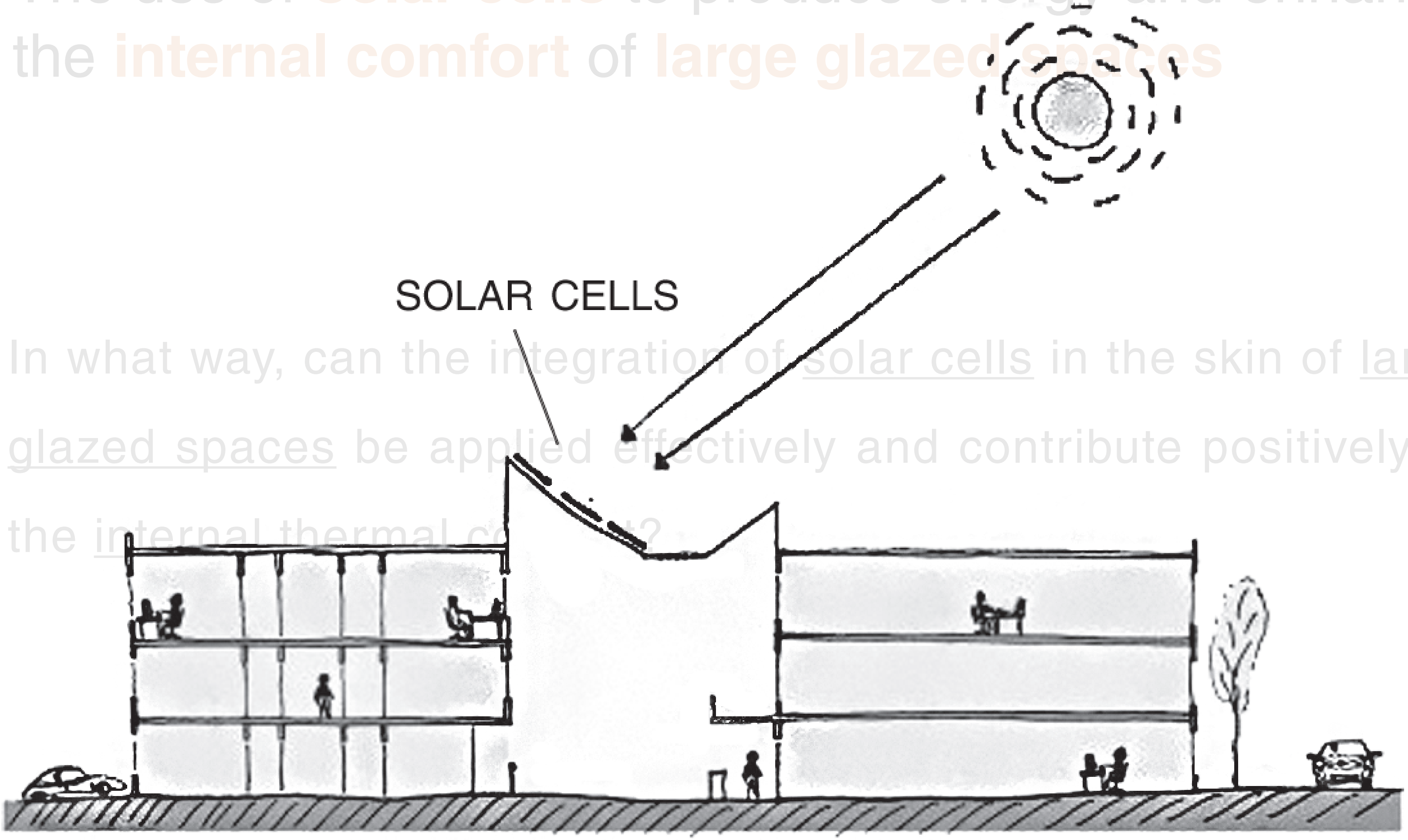
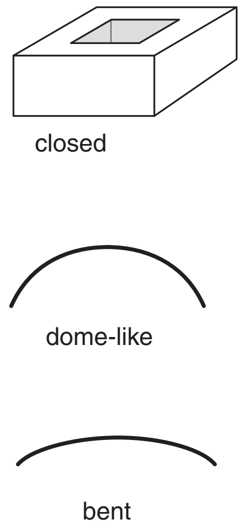
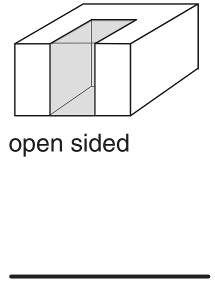


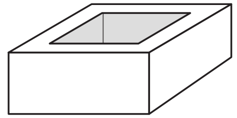
MUSEUM FÜR HAMBURGISCHE GESCHICHTE - HAMBURG



AVRO, KRO EN NCRV - HILVERSUM



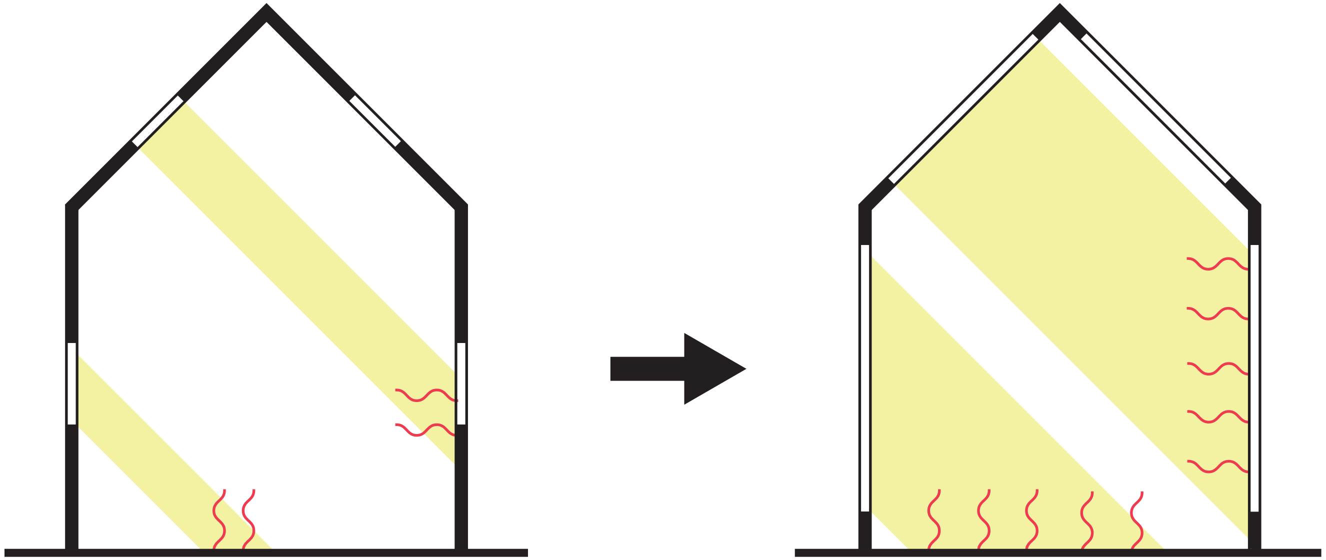
SCHEEPVAARTMUSEUM - AMSTERDAM



large closed

dome-like

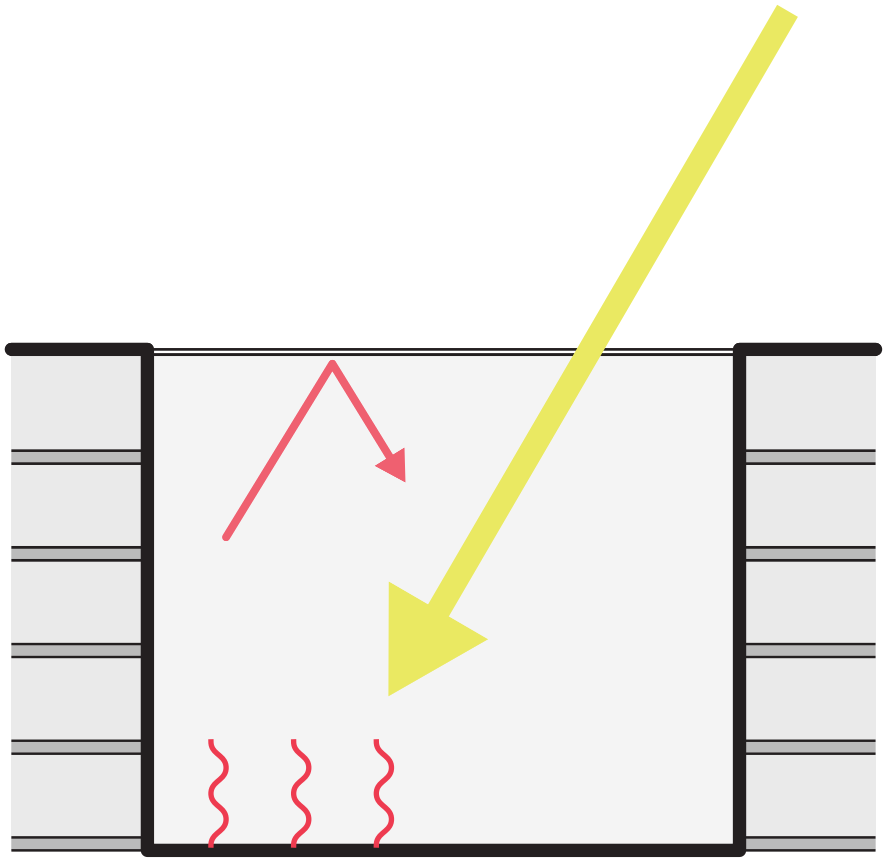
bent



heat gain glazed spaces:

- increase transparent architecture
- insulation values

focus = thermal comfort summer



heat gain glazed spaces:

- increase transparent architecture
- insulation values

focus = thermal comfort summer

thermal comfort:

How can you prevent overheating in
a large glazed space (passively)?

focus = thermal inside comfort summer

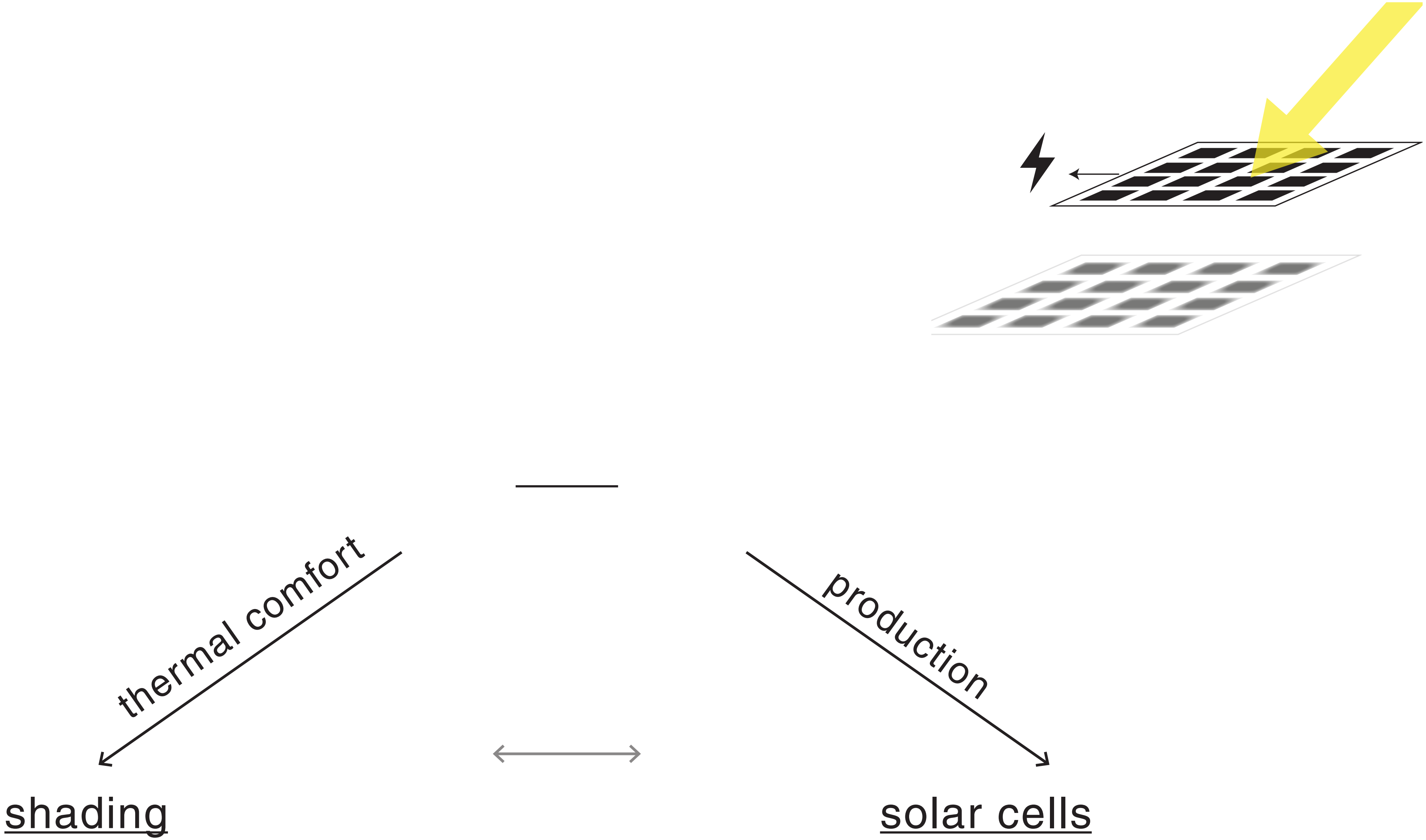
thermal comfort:

How can you prevent overheating in
a large glazed space (passively)?

shading

focus = thermal inside comfort summer

why sola rcells



double profit

sustainable goal

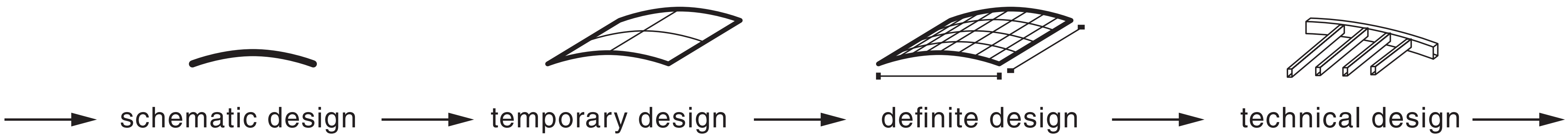
to reduce the energy consumption

from non-renewable resources

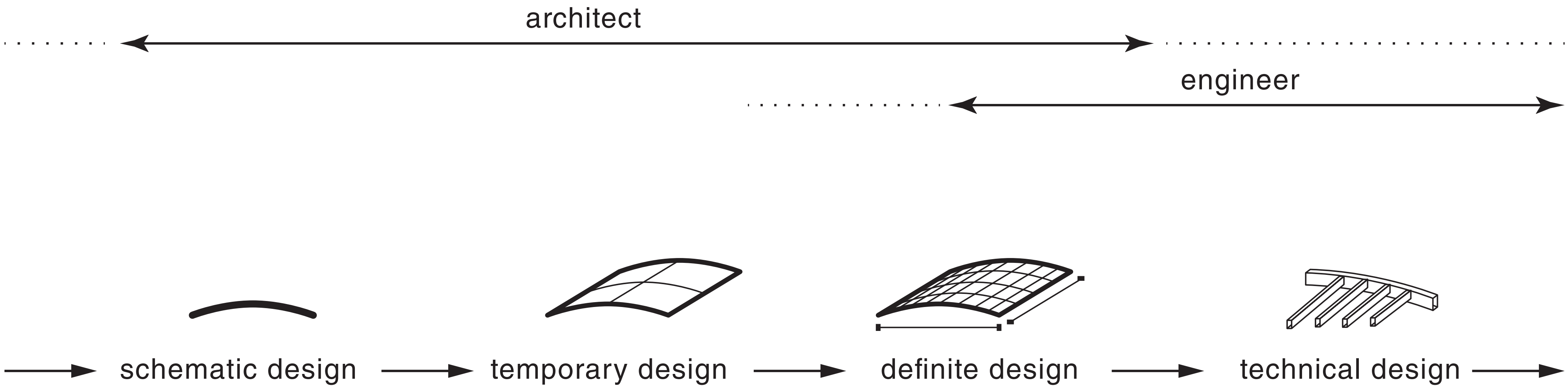
CONTENT:

- ~~INTRODUCTION~~
- THERMAL COMFORT
- PARAMETRIC MODEL AND CALCULATION RESULTS
- ENERGY PRODUCTION WITH SOLAR CELLS
- MORPHOLOGICAL DESIGN OVERVIEW
- DESIGN CASES
- CONCLUSIONS

goal

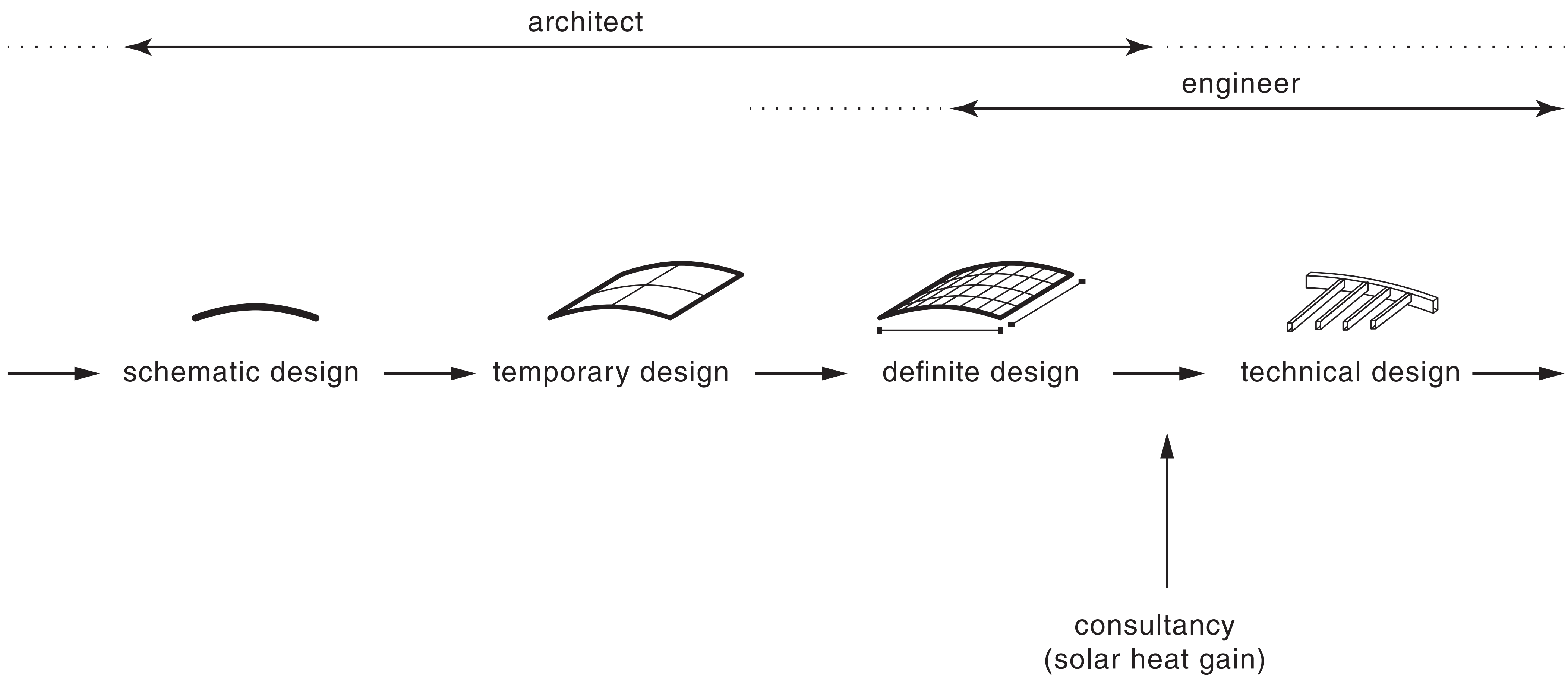

schematic design
temporary design
definite design
technical design

goal

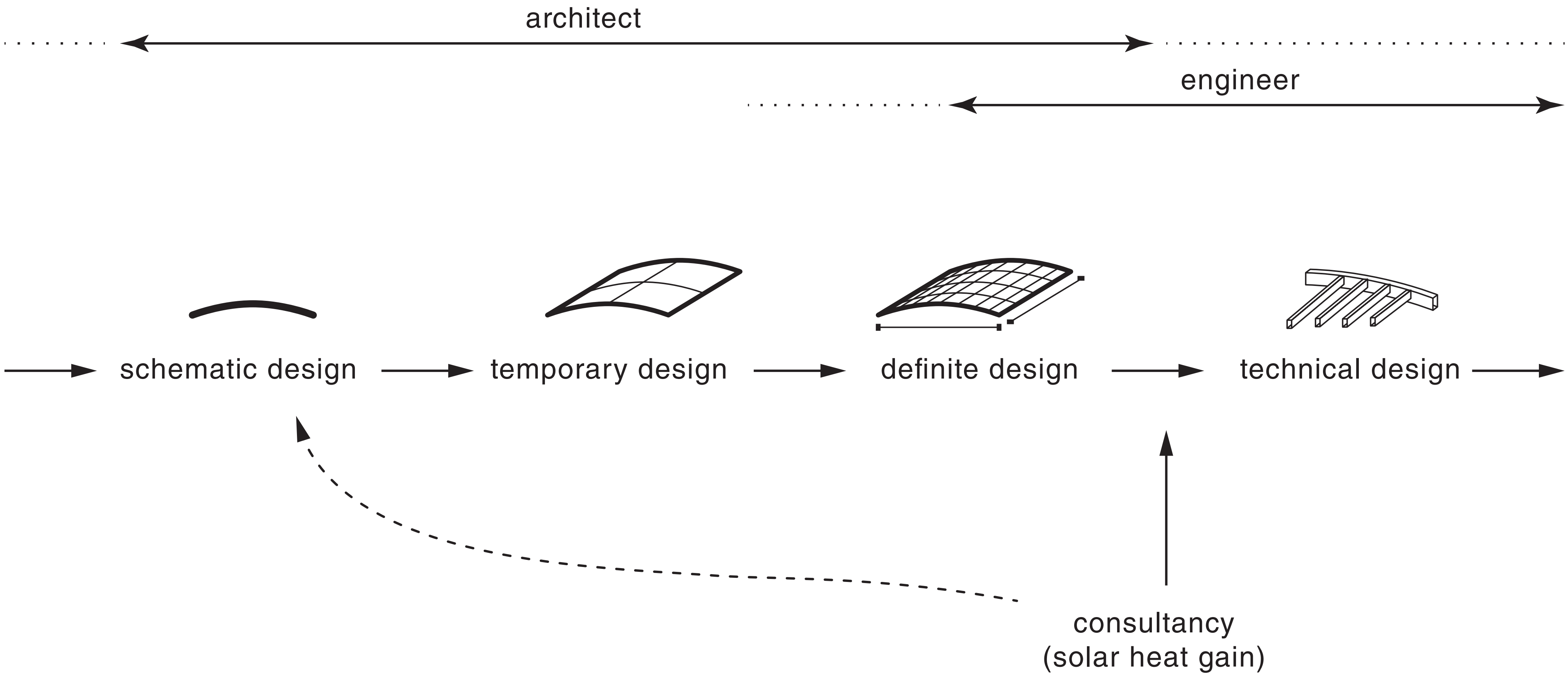


architect
engineer
schematic design
temporary design
definite design
technical design

goal


architect
engineer
schematic design
temporary design
definite design
technical design
consultancy
(solar heat gain)

goal


architect
engineer
schematic design
temporary design
definite design
technical design
consultancy
(solar heat gain)

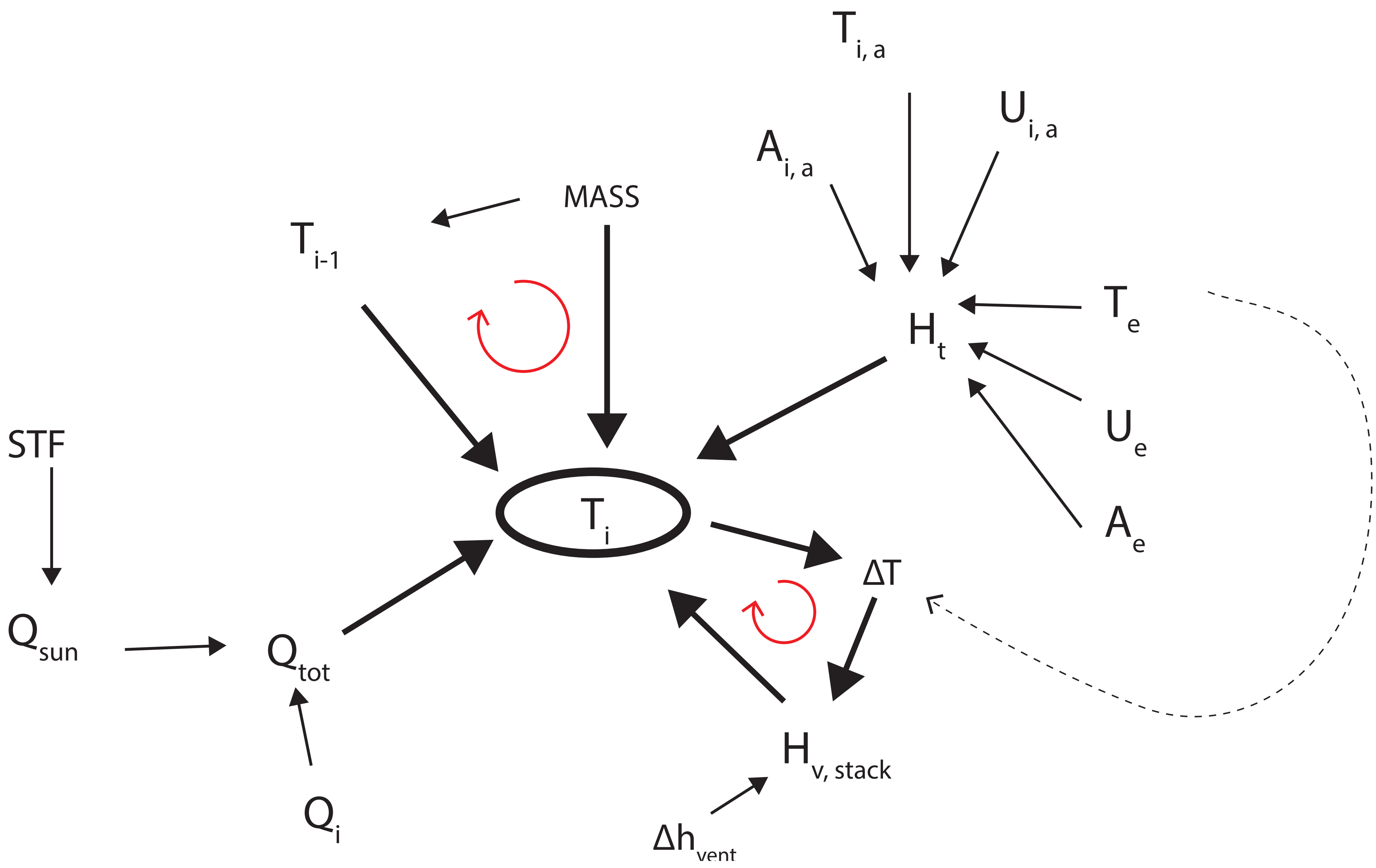
INSIDE TEMPERATURE CALCULATION

$$T_i = \frac{\left(H \cdot T_e + \frac{M}{3600} \cdot T_{(i-1)} + (Q_{sun} + Q_i) \right)}{\left(H + \frac{M}{3600} \right)}$$

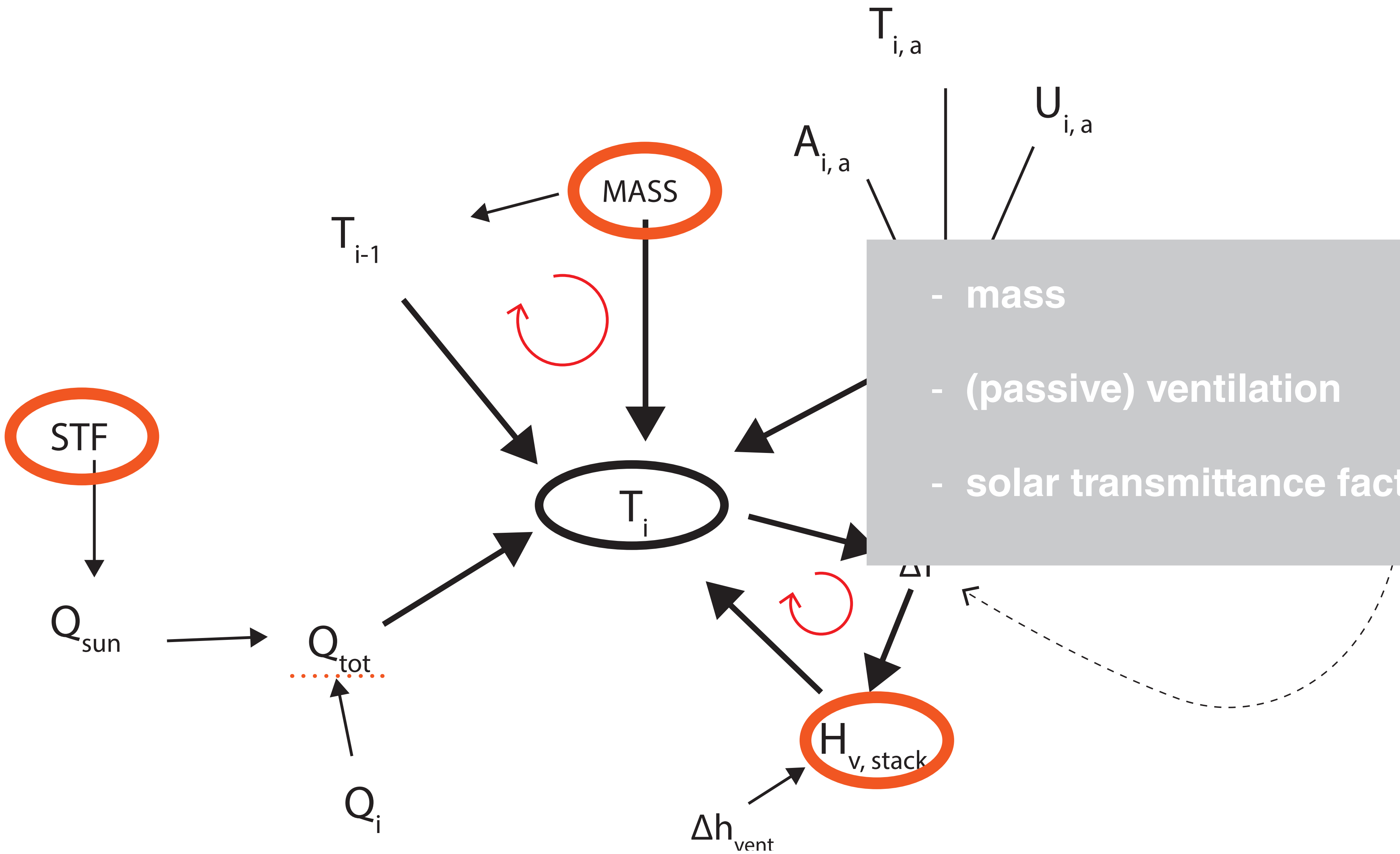
(ISO 1379:2008) DYNAMIC CALCULATION FORMULA

T_i	INSIDE TEMPERATURE	(K)	T_{i-1}	TEMPERATURE PREVIOUS HOUR	(K)
Q_i	INTERNAL HEAT	(W)	T_e	OUTSIDE TEMPERATURE	(K)
H	HEAT TRANSMISSION	(W/K)	Q_{SUN}	SOLAR HEAT	(W)
M	THERMAL ACTIVE MASS	(KG)			

INSIDE TEMPERATURE CALCULATION - MAJOR PARAMETERS



INSIDE TEMPERATURE CALCULATION - MAJOR PARAMETERS



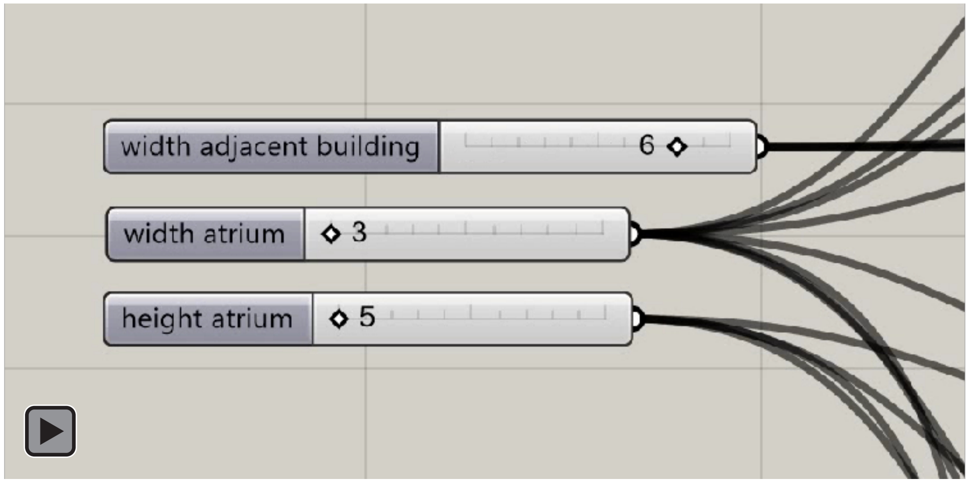
- mass
- (passive) ventilation
- solar transmittance factor

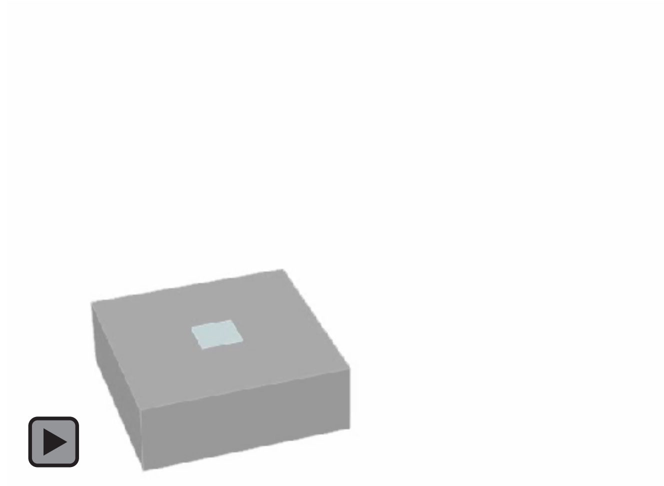
Parametric model:

Designer: what is the magnitude of parameter changes?

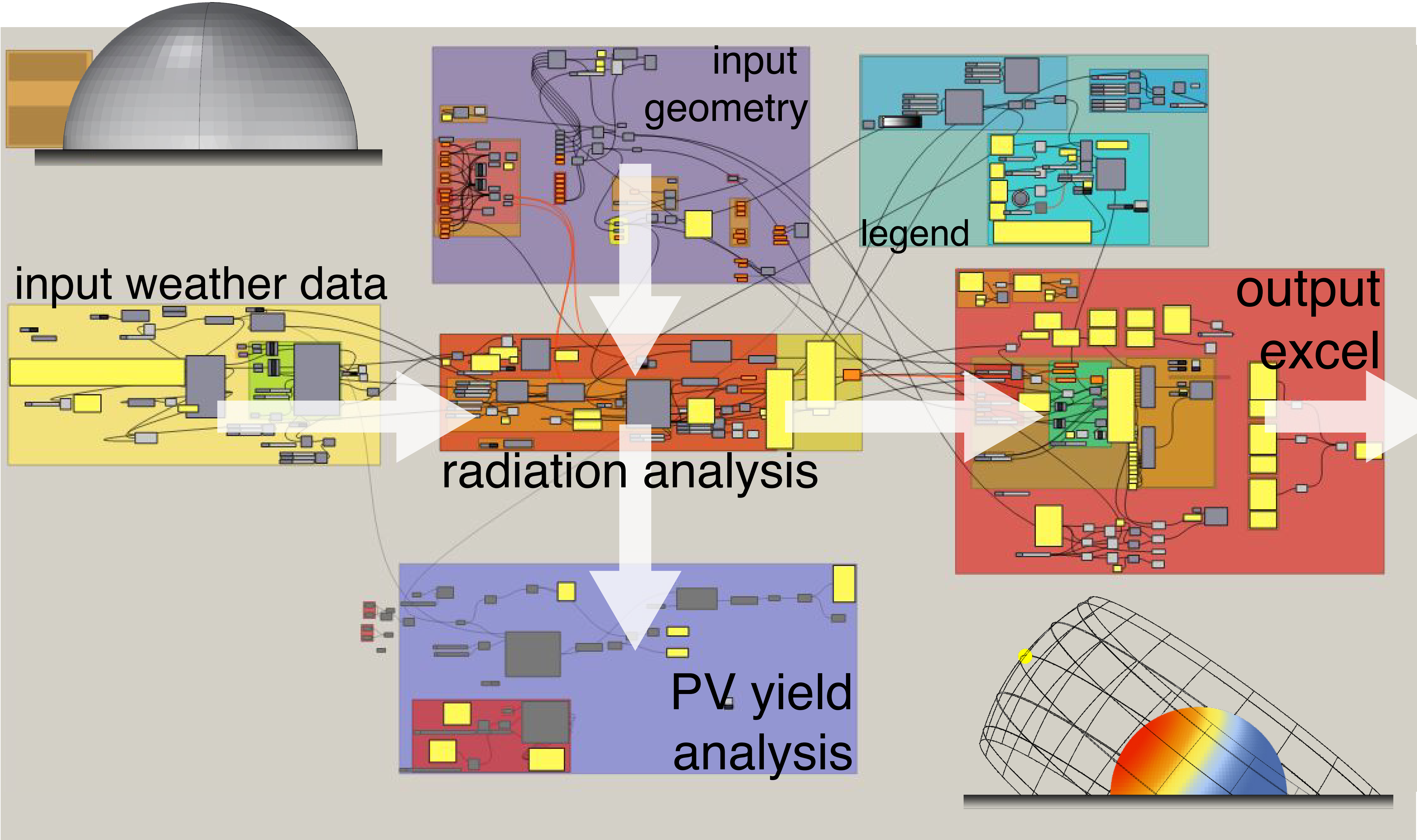
dimentions / properties

radiation analysis
temperature calculation
solar cells' yield

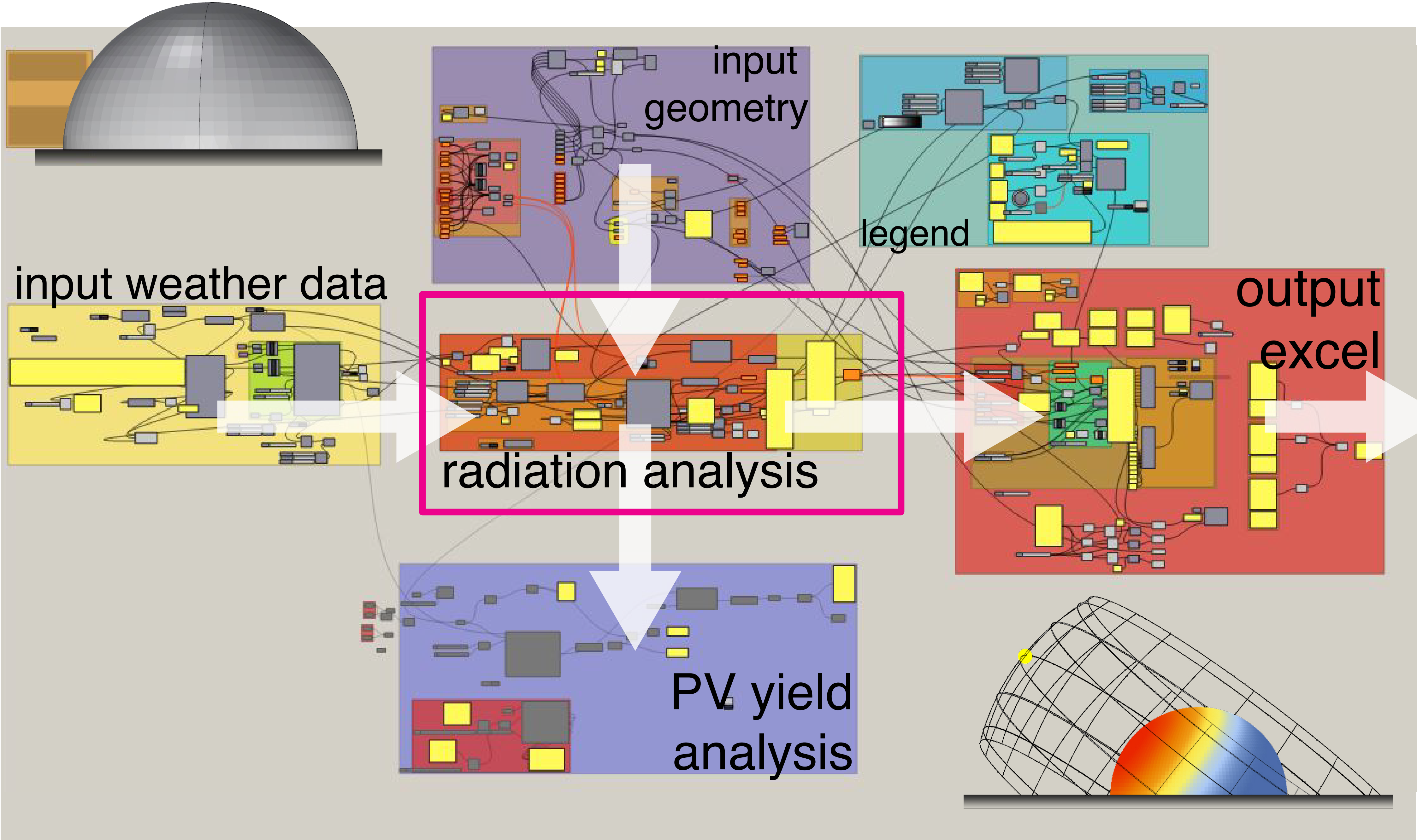




PARAMETRIC MODEL - GRASSHOPPER / LADYBUG

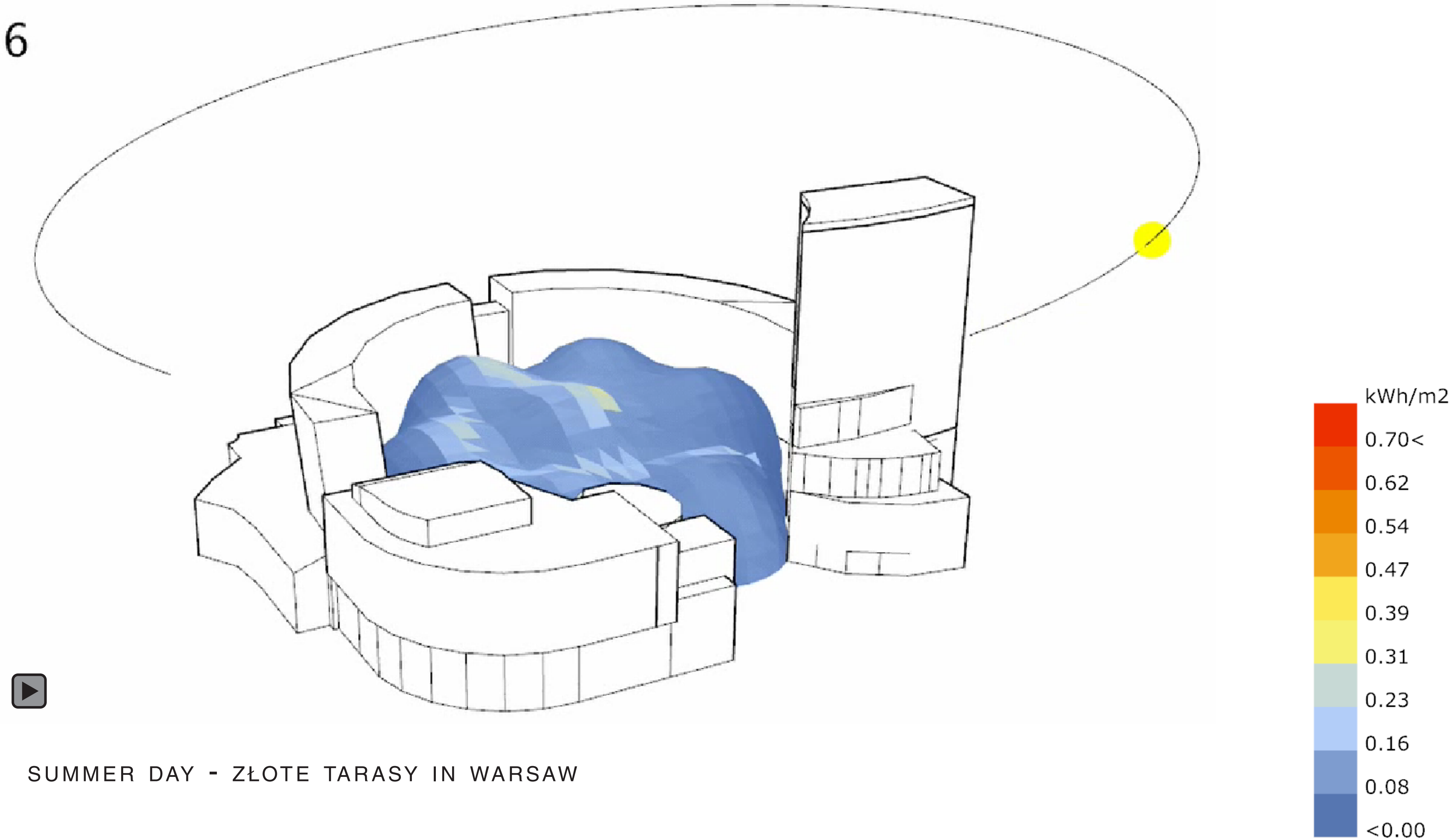


PARAMETRIC MODEL - GRASSHOPPER / LADYBUG



INSOLATION ANALYSIS

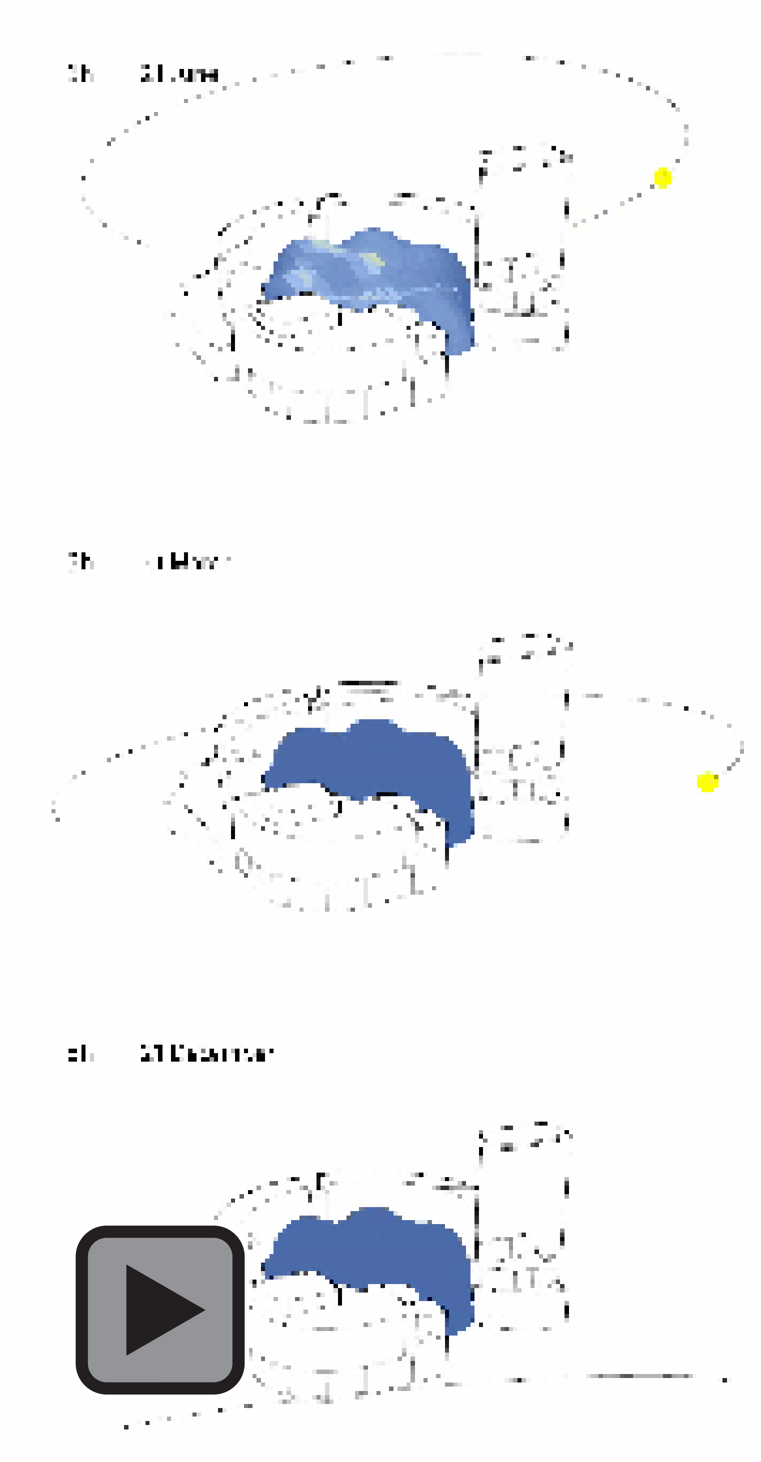
RADIANCE ANALYSIS COMPLEX SHAPE



SUMMER DAY - ZŁOTE TARASY IN WARSAW

INSOLATION ANALYSIS

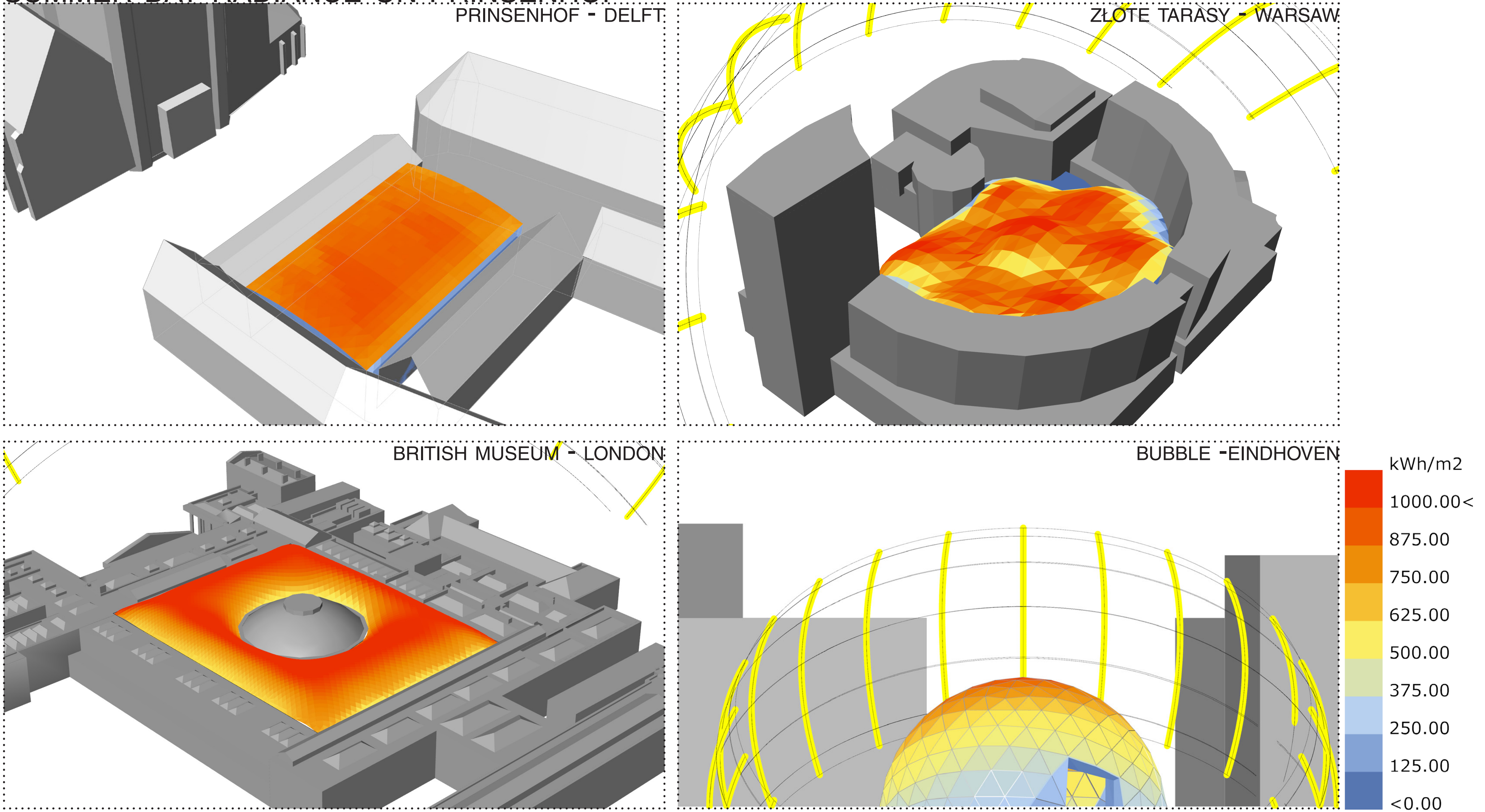
RADIANCE ANALYSIS COMPLEX SHAPE



SEASONS - ZŁOTE TARASY IN WARSAW

INSOLATION ANALYSIS

SUMMER DAY RADIANCE ON PRINSENHOF

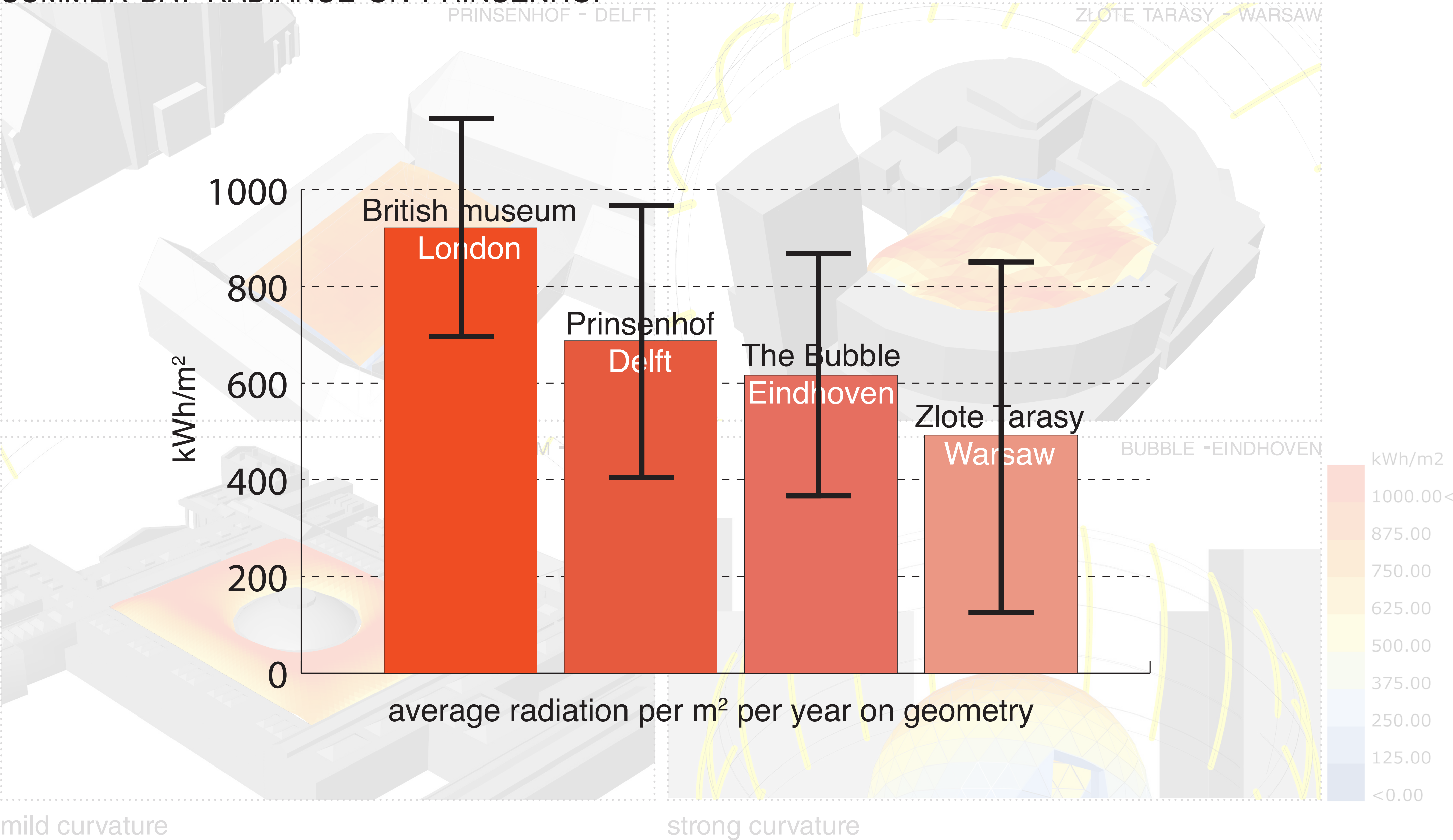


mild curvature

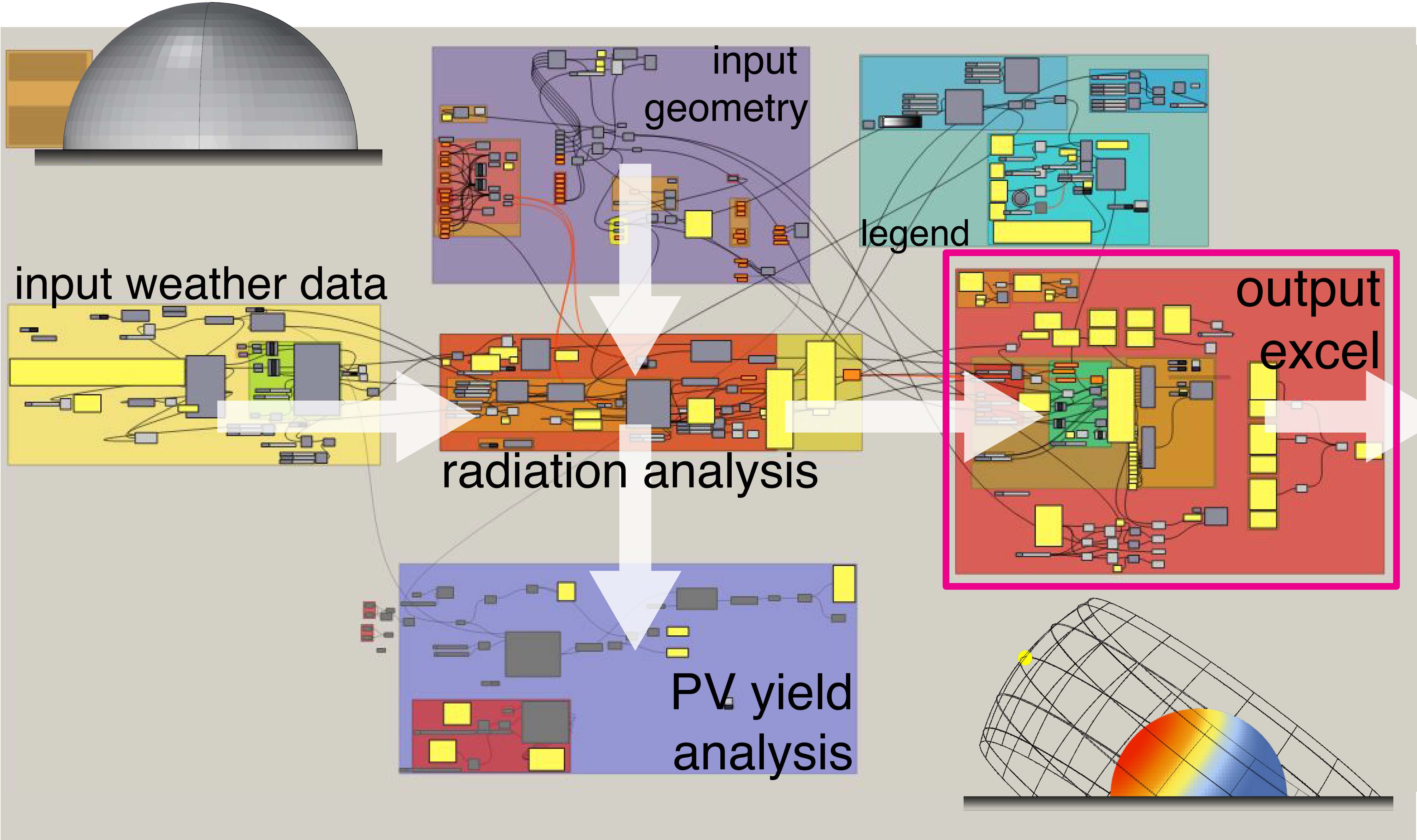
strong curvature

INSOLATION ANALYSIS

SUMMER DAY RADIANCE ON PRINSENHOF



PARAMETRIC MODEL - GRASSHOPPER / LADYBUG



INSIDE TEMPERATURE CALCULATION - SUMMER DAY

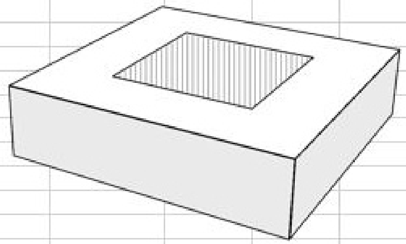
Input grasshopper (only change in grasshopper)
calculation grasshopper
Edit yellow fields only

make sure Iteration is activated

glas (facade and roof)	m2	1199,9	U-value	1,00	W/m2K	
non-transparent 1	m2	3278,3	U-value	0,33	W/m2K	
Tempertature inside	K	21,0				
G =	314720	kg	C=	840	alph.	1,4E-05
Air inlet	30,00	m2	Cd	0,7		
Air outlet	30,00	m2				
height difference	12,50	m				
Ae	21,2132034	m2				
STF	0,30					

Ht ex (W/K)	1200
Ht in (W/K)	1082

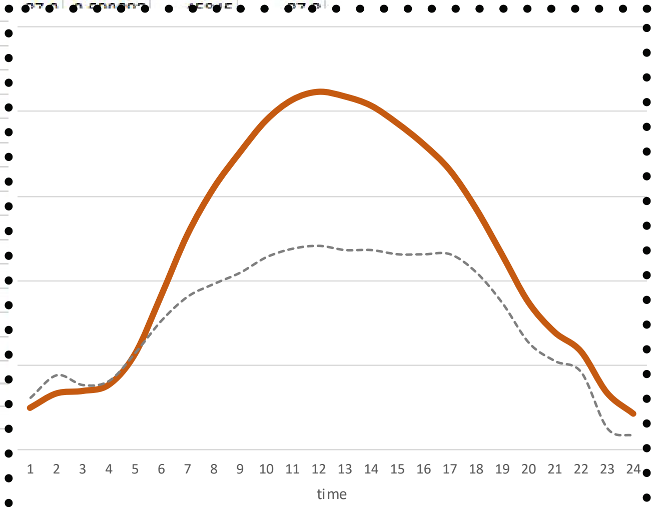
G=thermal active mass in kg
Hv=Q*rho*c
Ht=som (U*A)



FALSE
click here, repair

T(i) = (H*Ta+M/3600*T(i-1)+Q)/(H+M/3600)
new num method CEN 13790

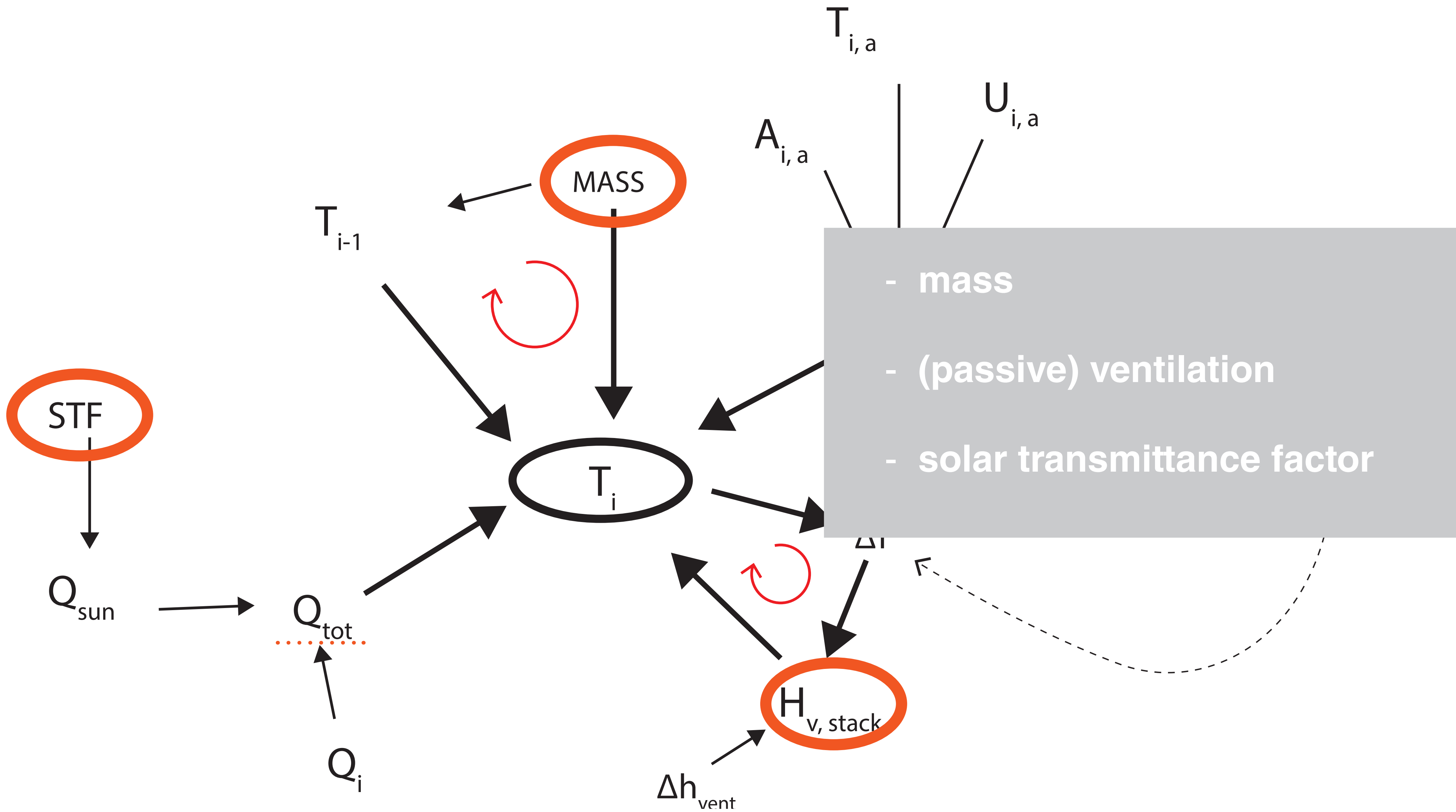
Tijd	Ta	Qz [W]	Qz in (W)	Qi [W]	Qtrans ex [W]	Qtrans in	Hv (W/K)	Qvent (W	dTex	dTin	Qres	T(i)	Ti (analytic	exp	Hv stack	Ti steady state
1	11,9	0	0,0	0,00	-1628	8431	17098	-43727	-1,4	7,8	3692	12,9	13,3	0,779441	17098	11,9
2	12,7	0	0,0	0,00	-328	8738	8079	-10961	-0,3	8,1	2552	12,9	13,3	0,89983	8079	12,7
3	12,3	0	0,0	0,00	-708	8774	11622	-3178	-0,6	8,1	-4889	12,8	13,1	0,861883	11622	12,3
4	12,5	26399	7919,6	0,00	-415	8876	10273	-6057	-0,3	8,2	5516	12,8	13,1	0,874377	10273	13,1
5	13,5	168798	50639,3	0,00	735	8831	4379	-1514	0,6	8,2	42588	13,5	13,8	0,932725	4379	15,6
6	14,6	453355	136006,5	0,00	1295	8092	13135	8047	1,1	7,5	118573	15,2	15,6	0,8216	13135	18,7
7	15,5	830624	249187,3	8000,00	254	6233	25308	27318	0,2	5,8	223383	17,8	18,5	0,70604	25308	21,8
8	15,9	1196100	358830,0	8000,00	-2330	3416	34949	7389	-1,9	3,2	358355	20,5	21,6	0,641351	34949	23,9
9	16,3	1508000	452400,0	8000,00	-5044	537	41548	-80692	-4,2	0,5	545598	22,9	24,5	0,608293	41548	25,6
10	16,9	1760500	528150,0	8000,00	-7210	-2011	45845	-192713	-6,0	-1,9	738083	24,9				
11	17,2	1930800	579240,0	8000,00	-9288	-4209	49076	-294878	-7,7	-3,9	895614	26,4				
12	17,3	1854300	556290,0	8000,00	-10992	-5853	50444	-390449	-9,2	-5,4	971584	27,1				
13	17,1	1665300	499590,0	8000,00	-11945	-6550	50482	-462436	-10,0	-6,1	988522	26,9				
14	17,1	1390100	417030,0	8000,00	-11777	-6399	48909	-486883	-9,8	-5,9	930089	26,3				
15	17,0	1033600	310080,0	8000,00	-11212	-5727	46352	-454942	-9,3	-5,3	789961	25,2				
16	17,0	631224	189367,1	8000,00	-9872	-4519	42229	-394579	-8,2	-4,2	606337	23,7				
17	17,0	305848	91754,3	8000,00	-8154	-2970	37370	-307440	-6,8	-2,7	418319	22,2				
18	16,3	91347	27404,1	8000,00	-7133	-1347	33807	-229737	-5,9	-1,2	273621	20,6				
19	15,2	9599	2879,6	0,00	-6491	423	31544	-187526	-5,4	0,4	196474	18,9				
20	13,8	0	0,0	0,00	-6156	2239	30800	-166605	-5,1	2,1	170522	17,3				
21	13,2	0	0,0	0,00	-5024	3963	28227	-144809	-4,2	3,7	145870	16,1				
22	12,8	0	0,0	0,00	-4029	5292	25640	-107352	-3,4	4,9	106089	15,2				
23	10,8	0	0,0	0,00	-5319	6293	29044	-97529	-4,4	5,8	96559	13,9				
24	11,3	0	0,0	0,00	-3069	7727	22777	-100968	-2,6	7,1	96310	13,2				
MAX	17,3	12380,6	Wh/m2								MAX	27,1				
AVG	14,8										AVG	19,1				



search for **required settings** to achieve acceptable max temp.

INSIDE TEMPERATURE CALCULATION - SUMMER DAY

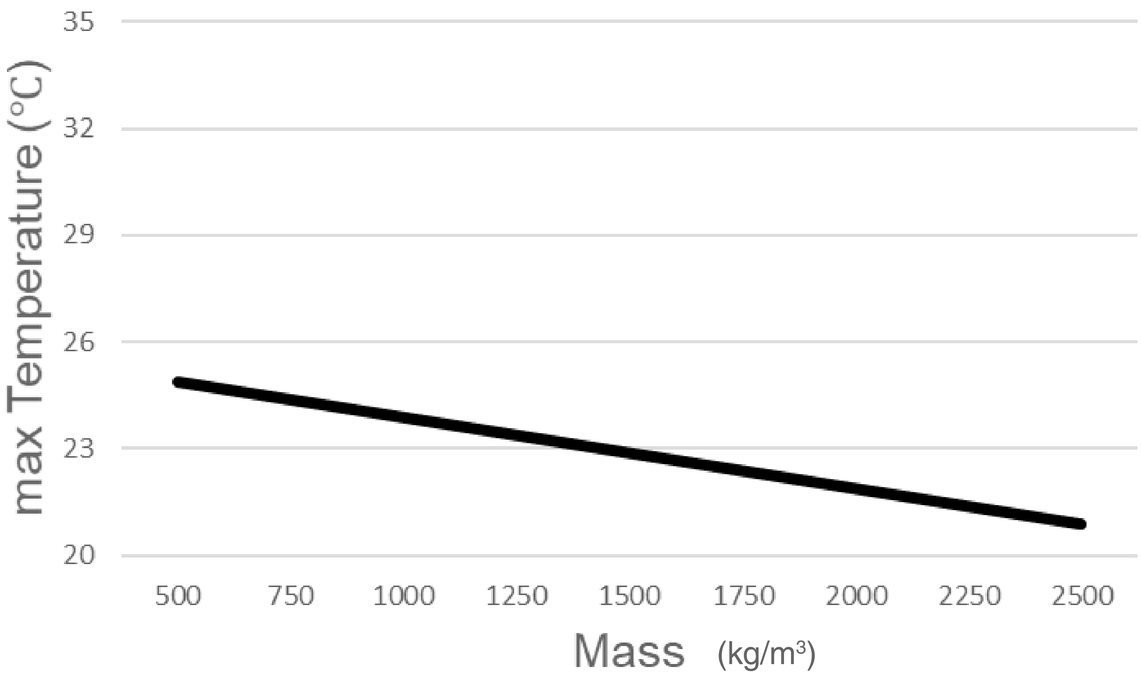
RESULTS

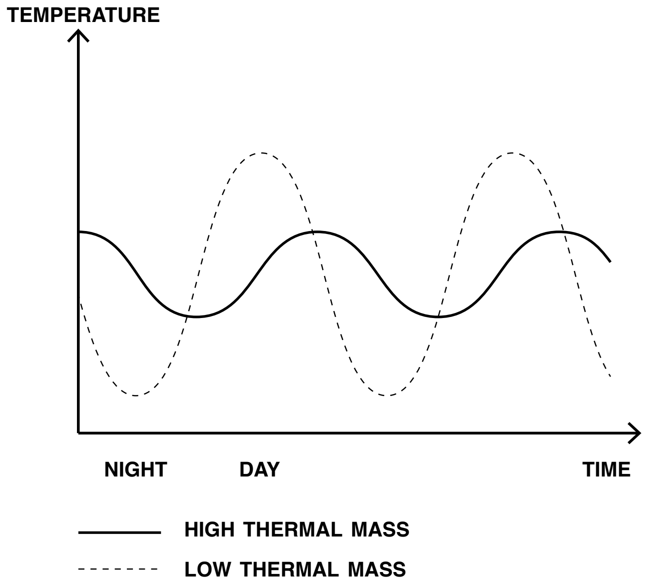


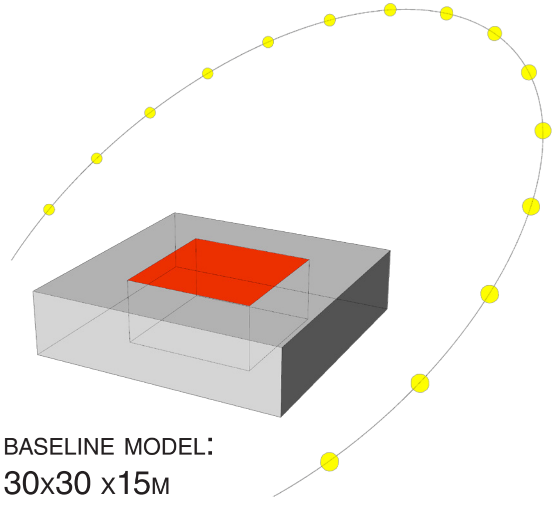
- mass
- (passive) ventilation
- solar transmittance factor

INSIDE TEMPERATURE CALCULATION - SUMMER DAY

RESULTS







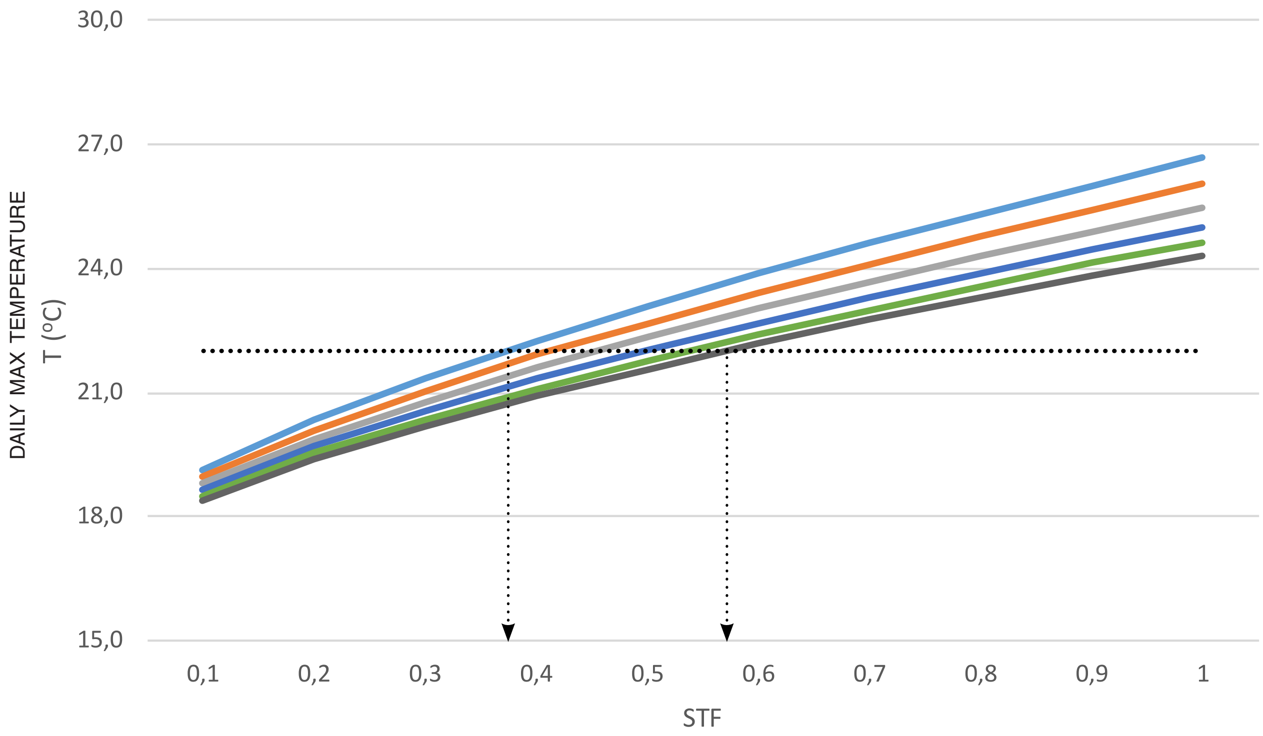
BASELINE MODEL:
30x30 x15M

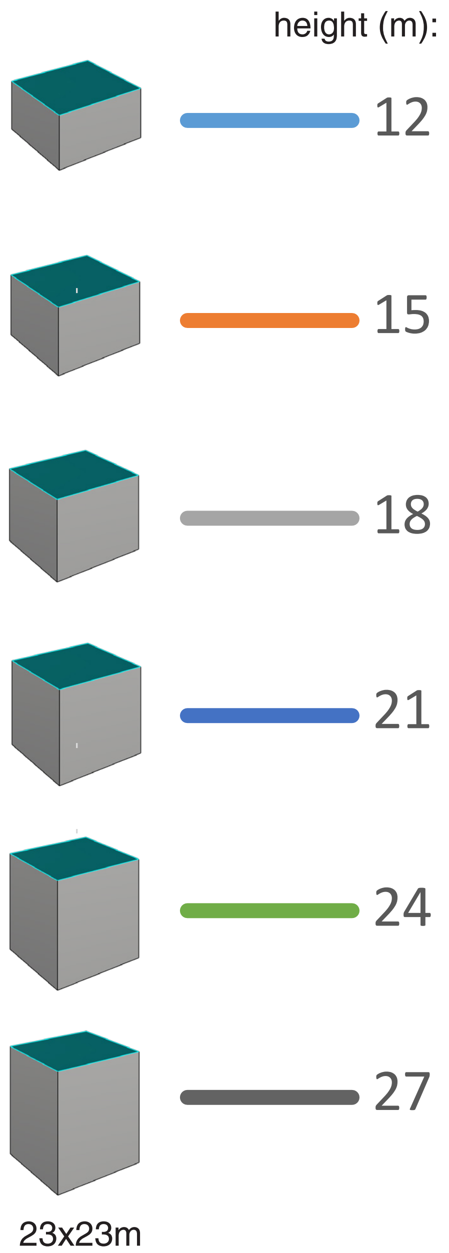
INSIDE TEMPERATURE CALCULATION - SUMMER DAY

RESULTS - MASS (HEAVY BUILDING)

variables:
mass
ventilation height
STF

constant:
area roof (insolation)
ventilation area
U-value
outside temp





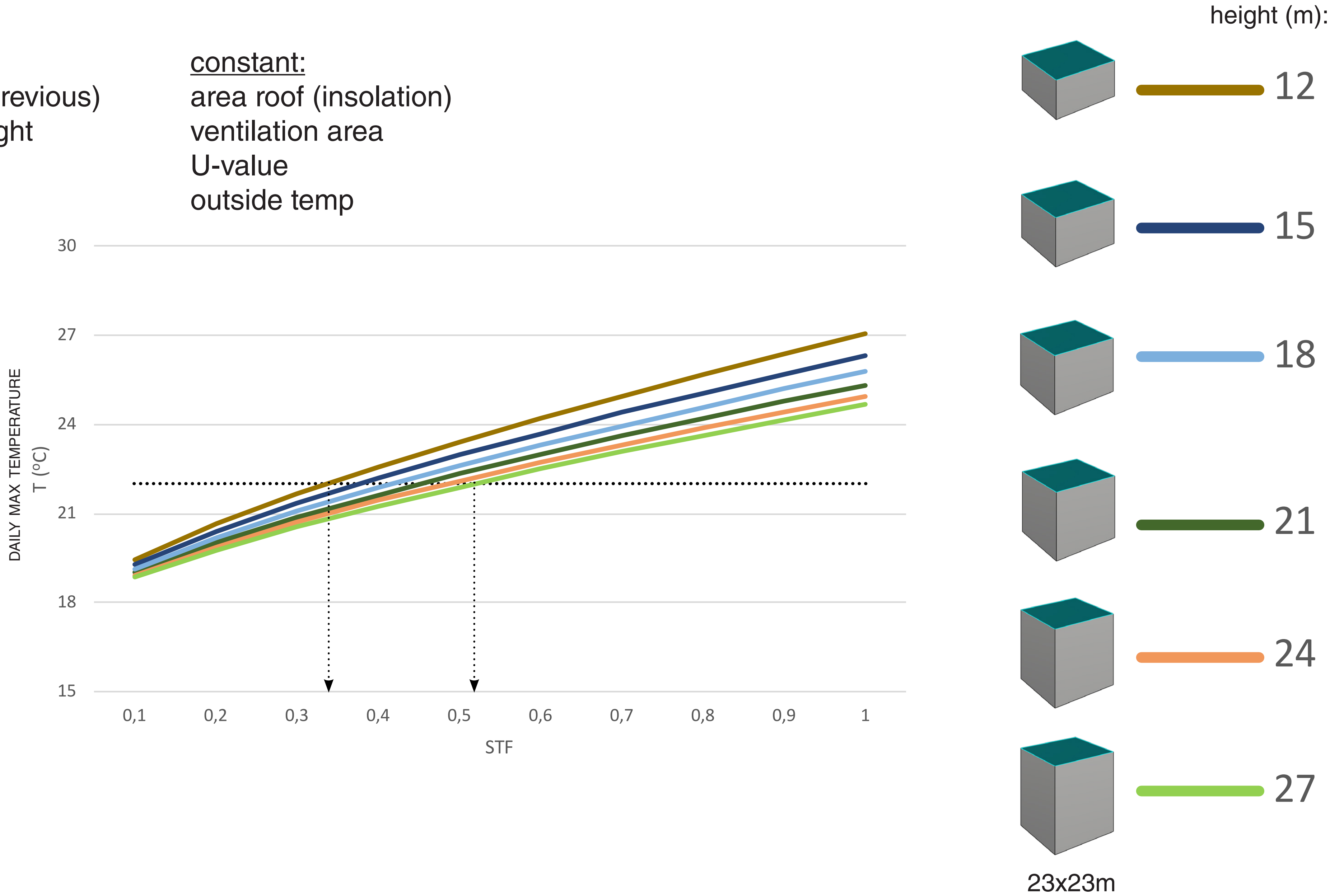
conclusion: smallest, least mass -> highest temperature

INSIDE TEMPERATURE CALCULATION - SUMMER DAY

RESULTS - MASS (LIGHT BUILDING 1/3 OF MASS)

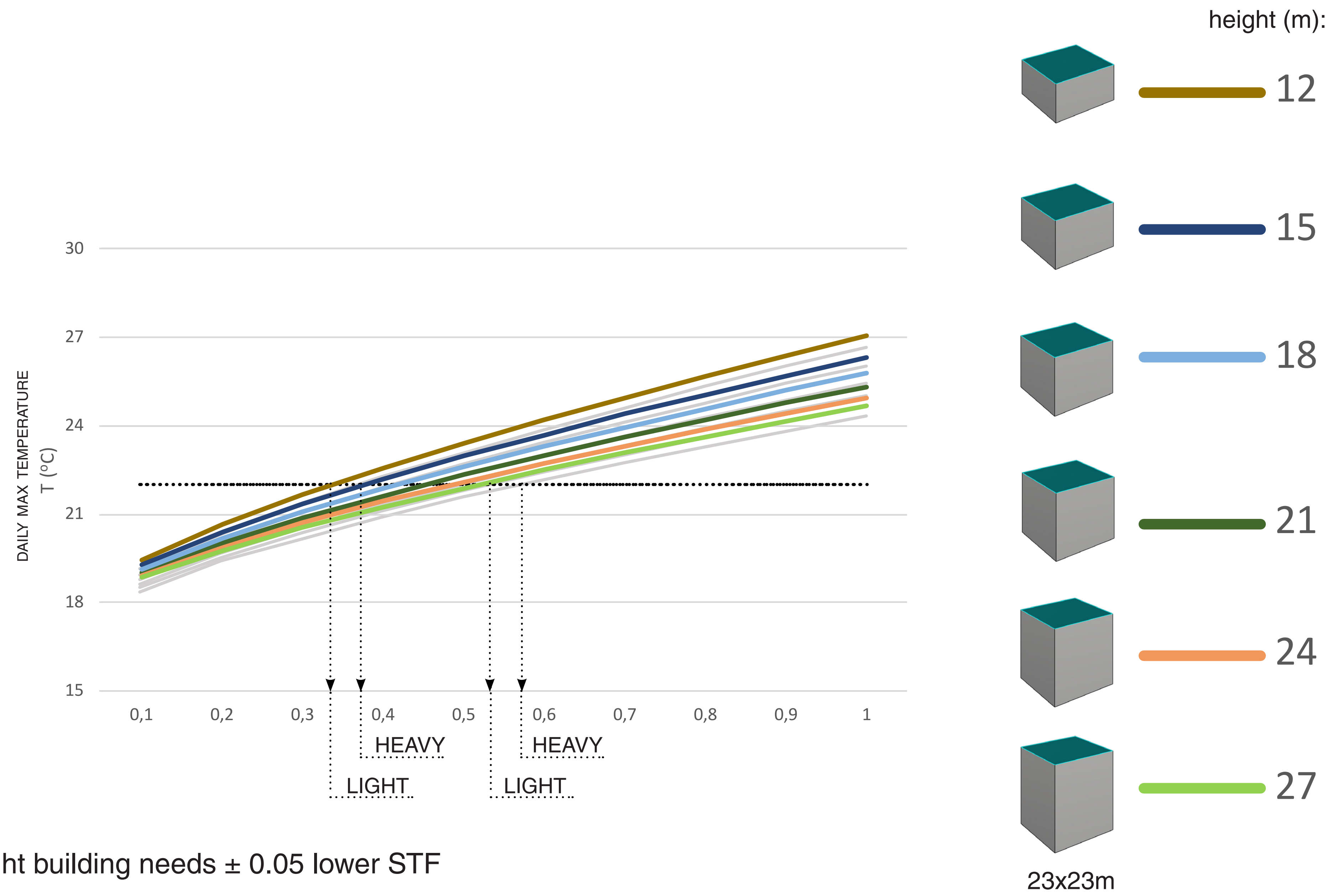
<u>variables:</u>
mass (1/3 of previous)
ventilation height
STF

<u>constant:</u>
area roof (insolation)
ventilation area
U-value
outside temp



INSIDE TEMPERATURE CALCULATION - SUMMER DAY

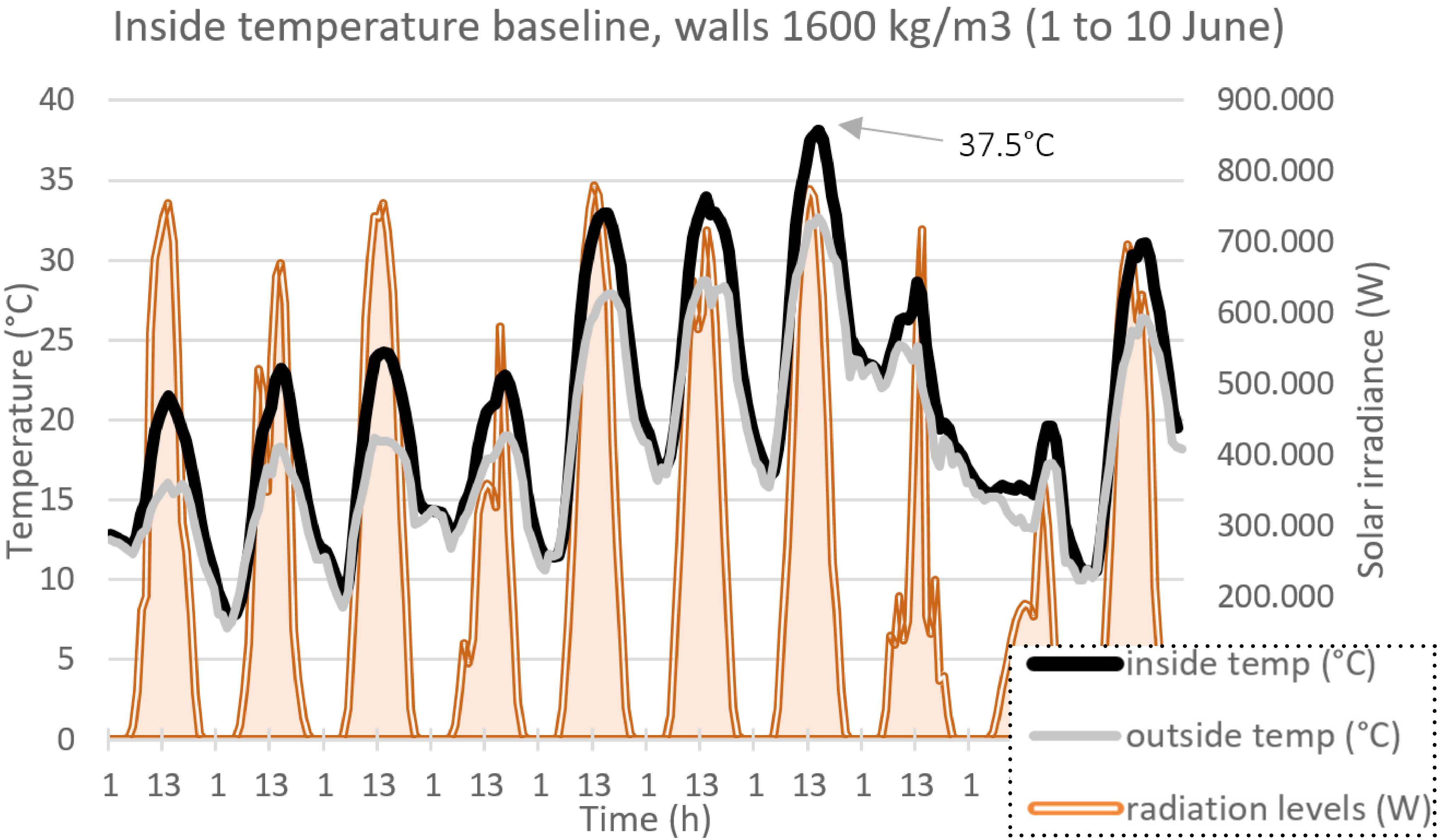
RESULTS - MASS VS. 1/3 MASS



<u>conclusion:</u> light building needs ± 0.05 lower STF

INSIDE TEMPERATURE CALCULATION - YEAR ANALYSIS

RESULTS - CUMMULATIVE HEAT EFFECT?



VENTILATION - (PASSIVE) STACK EFFECT

$$H_{v,stack} = C_d \cdot A_{eff} \sqrt{2gh \frac{\Delta T}{T_i}} \cdot \rho c$$

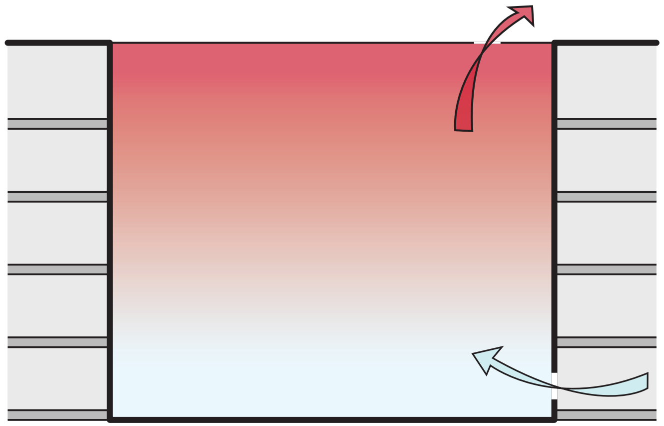
$$\frac{1}{A_{eff}^{\;2}} = \frac{1}{A_{bottom}^{\;2}} + \frac{1}{A_{top}^{\;2}}$$

ventilation height
(pressure difference)

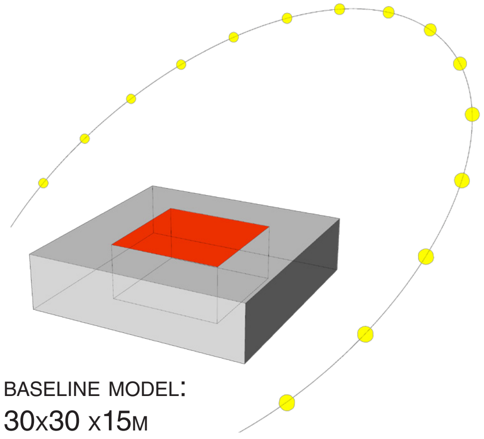
effective open area

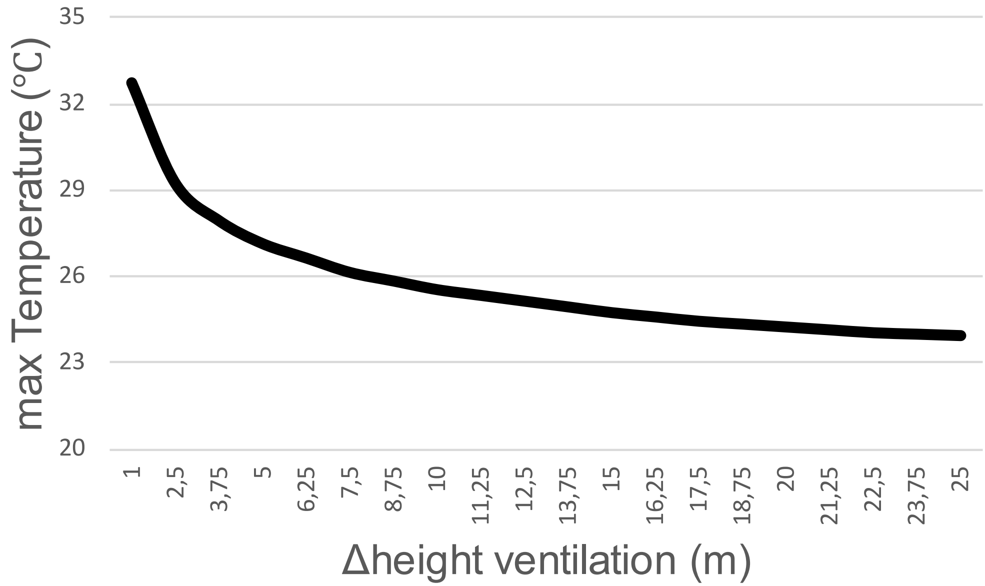
$$Q_{v,stack} = H_{v,stack} \cdot \Delta T_{i-1}$$

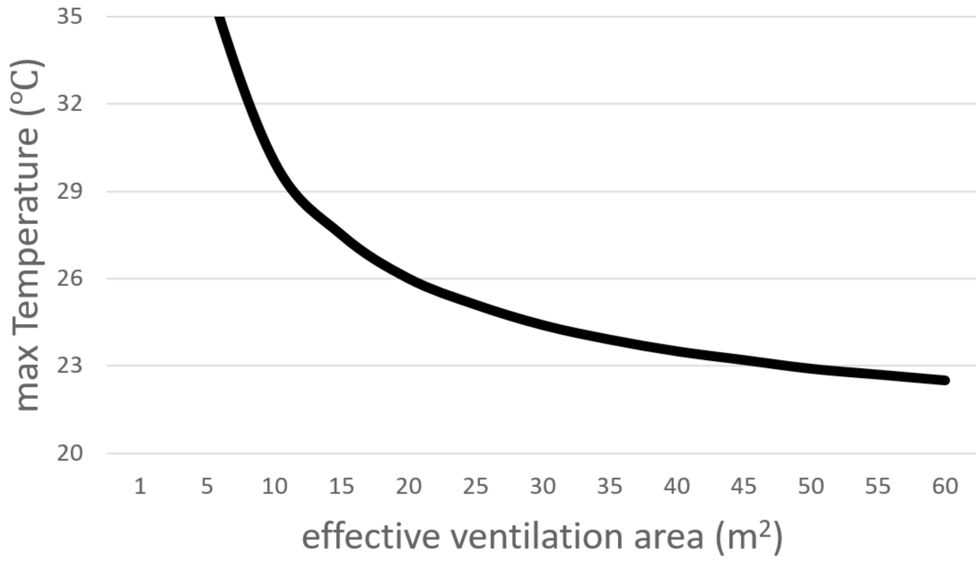
heat by ventilation



VENTILATION - (PASSIVE) STACK EFFECT



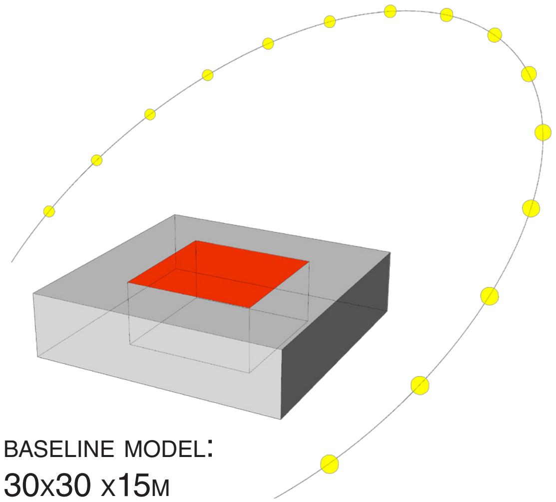




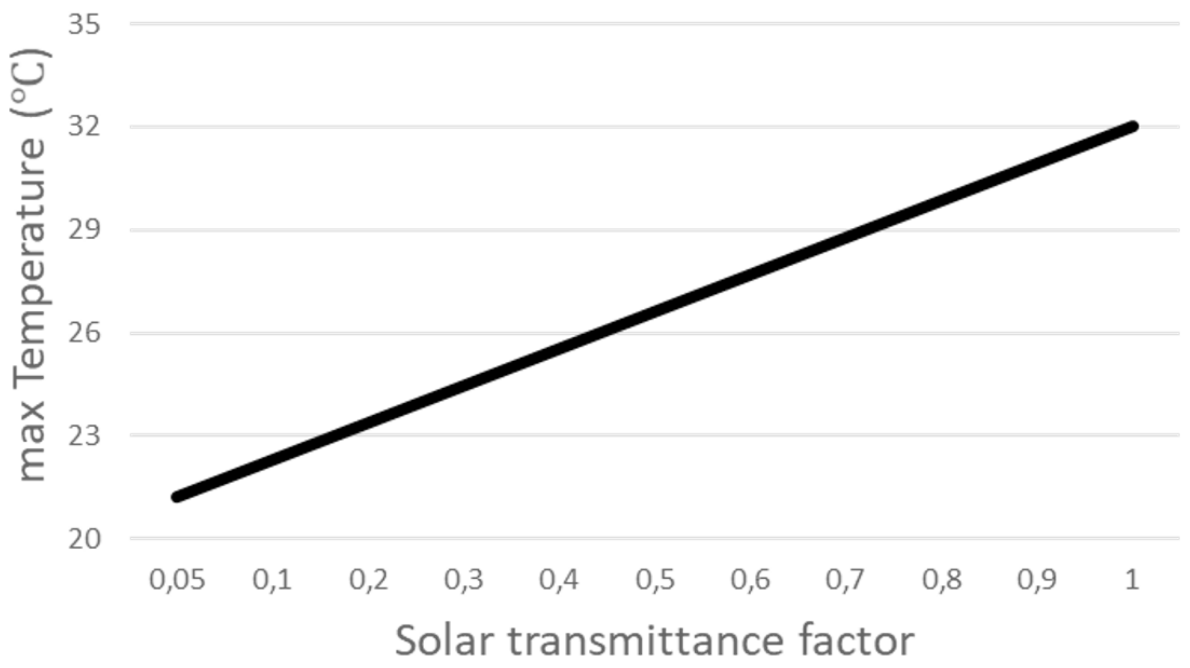
$$H_{v,stack} = C_d \cdot A_{eff} \sqrt{2gh\frac{\Delta T}{T_i}} \cdot \rho c$$

$$\frac{1}{A_{eff}^{\ 2}} = \frac{1}{A_{bottom}^{\ 2}} + \frac{1}{A_{top}^{\ 2}}$$

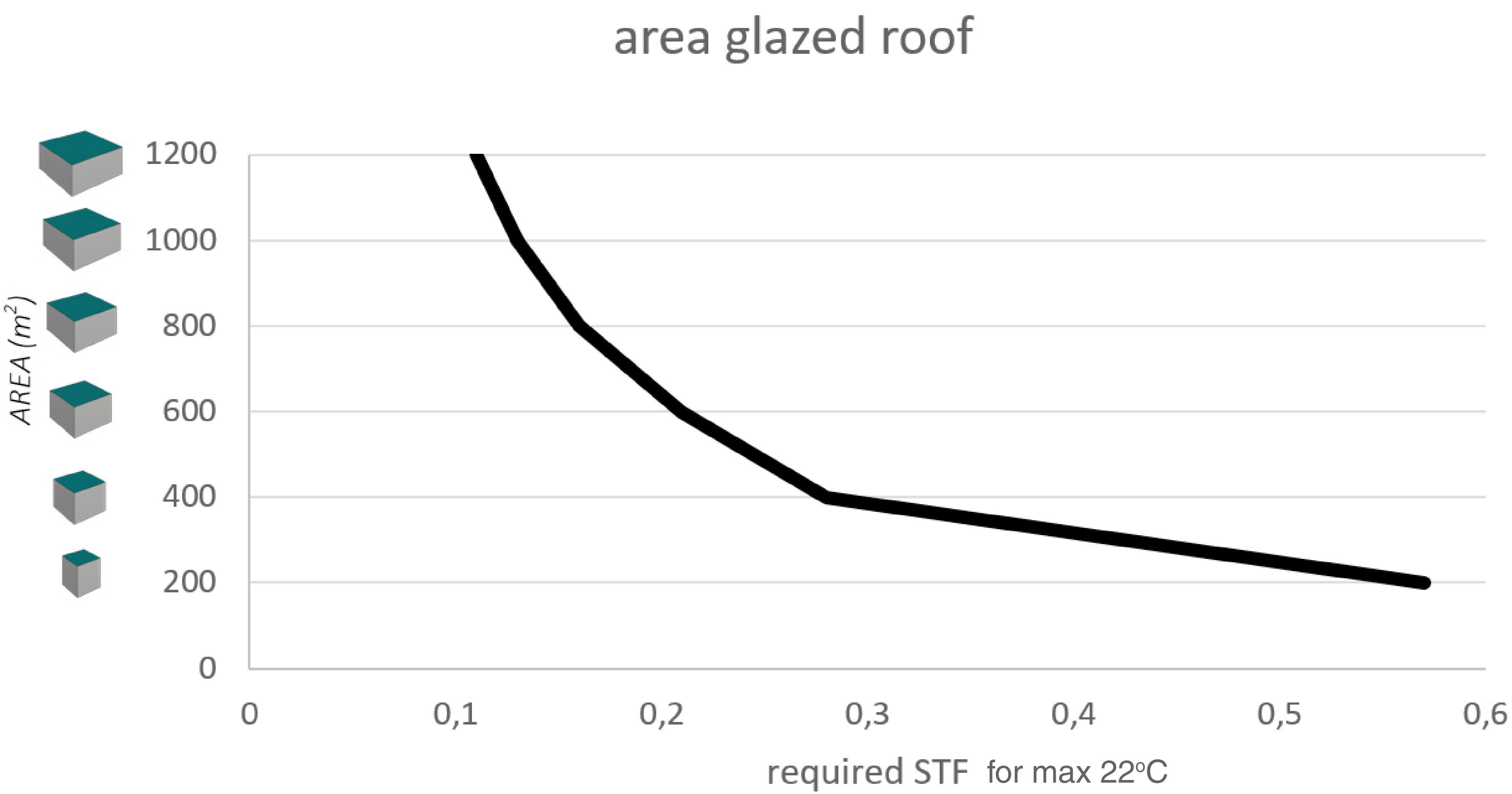
SOLAR TRANSMITTANCE FACTOR (STF)



BASELINE MODEL:
30x30 x15M



SOLAR TRANSMITTANCE FACTOR (STF)



CALCULATION RESULTS - THE VALUE OF THE RESULTS

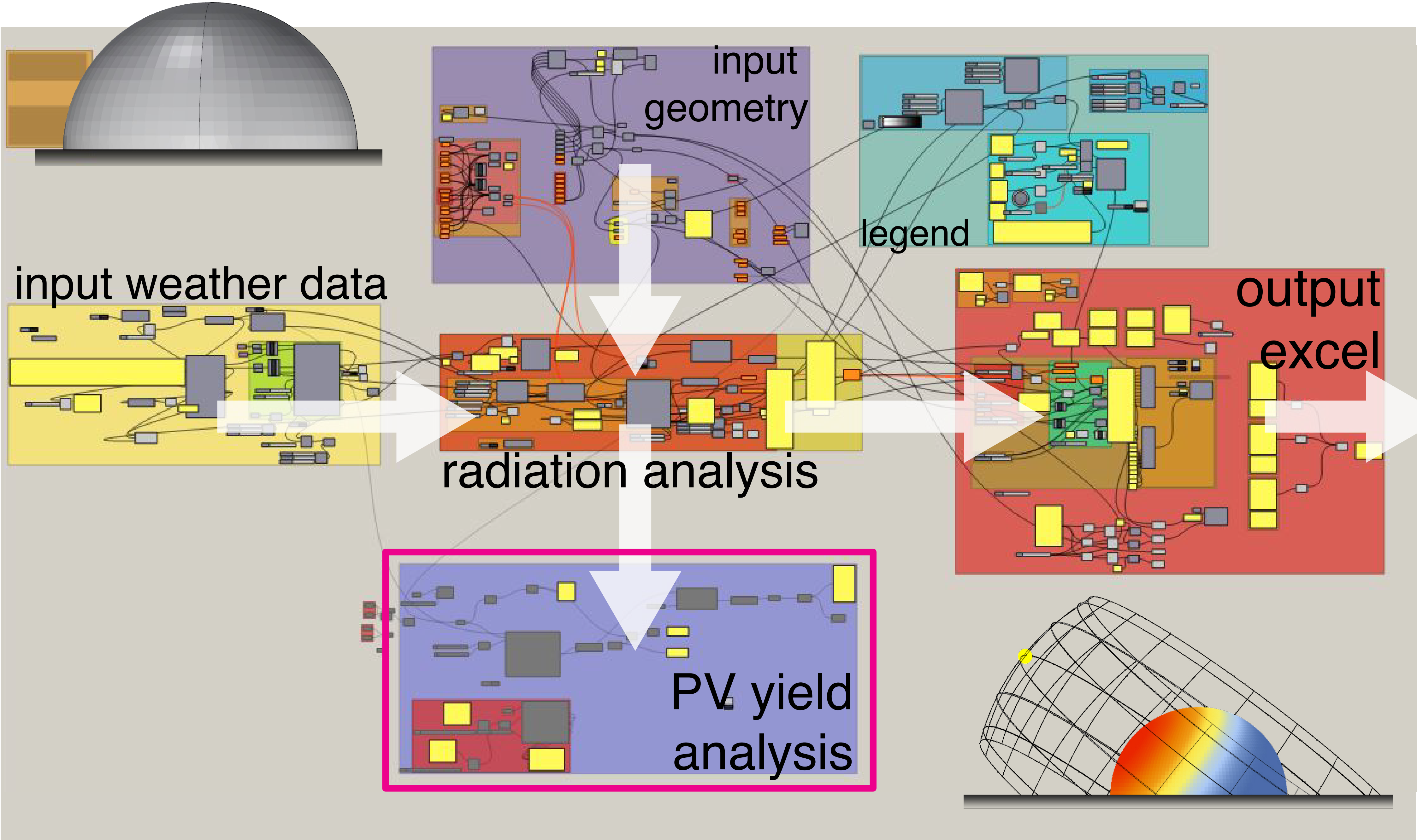
- temperature distribution in space is equal
- selected day (21 July), is it representative?
- should be validated by verified calculation software

calculation temp distribution

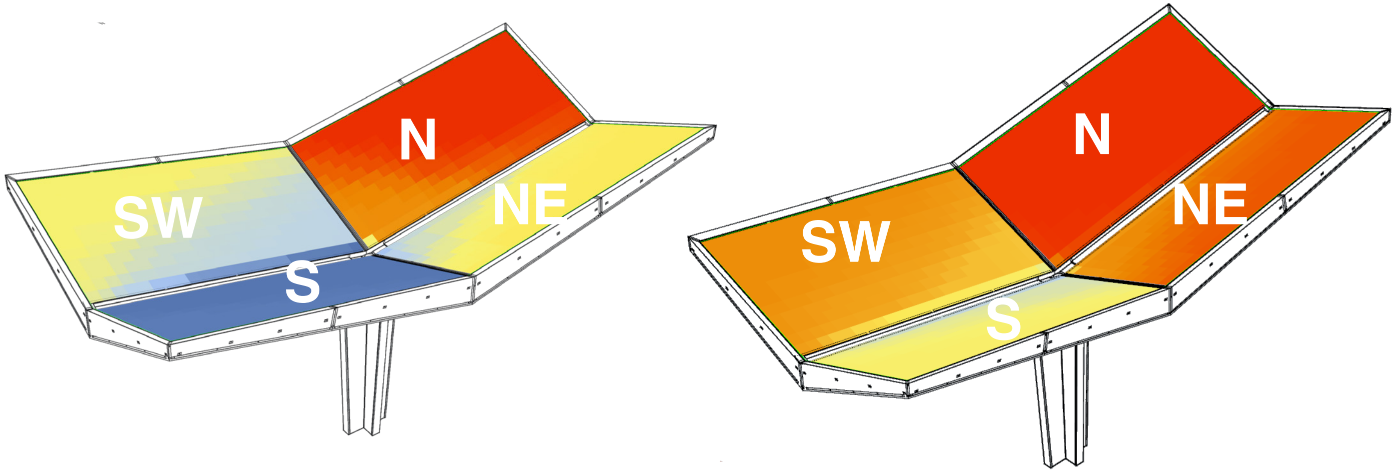
realistic temp distribution

TEMPERATURE RESULTS NOT ABSOLUTE - USE FOR RELATIVE COMPARISON

ELECTRICAL YIELD VERIFICATION



ELECTRICAL YIELD VERIFICATION



measured yield (december to february):

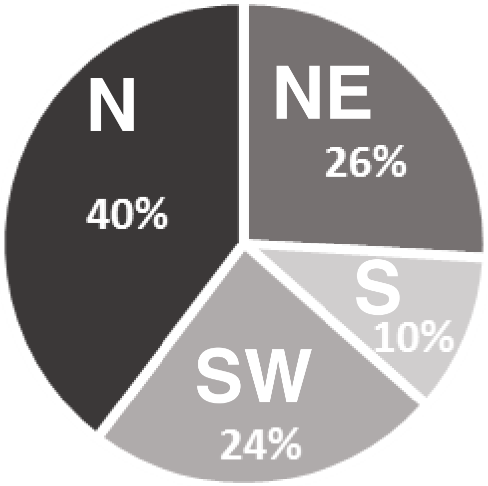
214 kWh

calculated yield (december to february):

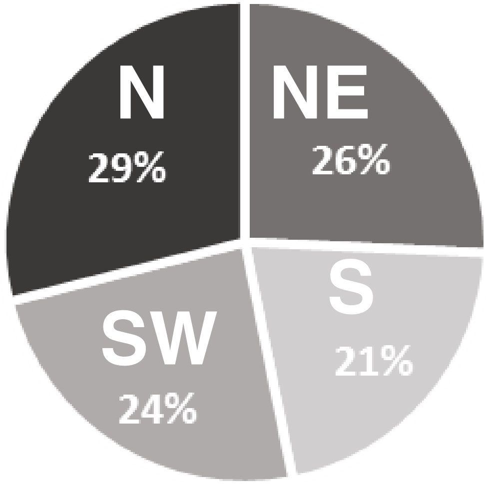
237 kWh

calculated yield (year):

3350 kWh



yield winter



annual yield

ELECTRICAL YIELD VERIFICATION

measured yield (december to february):

214 kWh

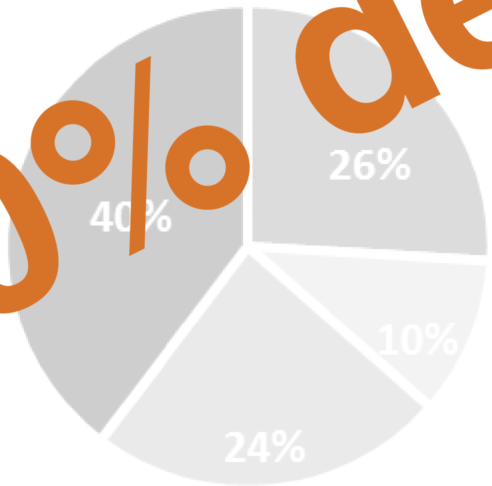
calculated yield (december to february):

237 kWh

calculated yield (year):

3350 kWh

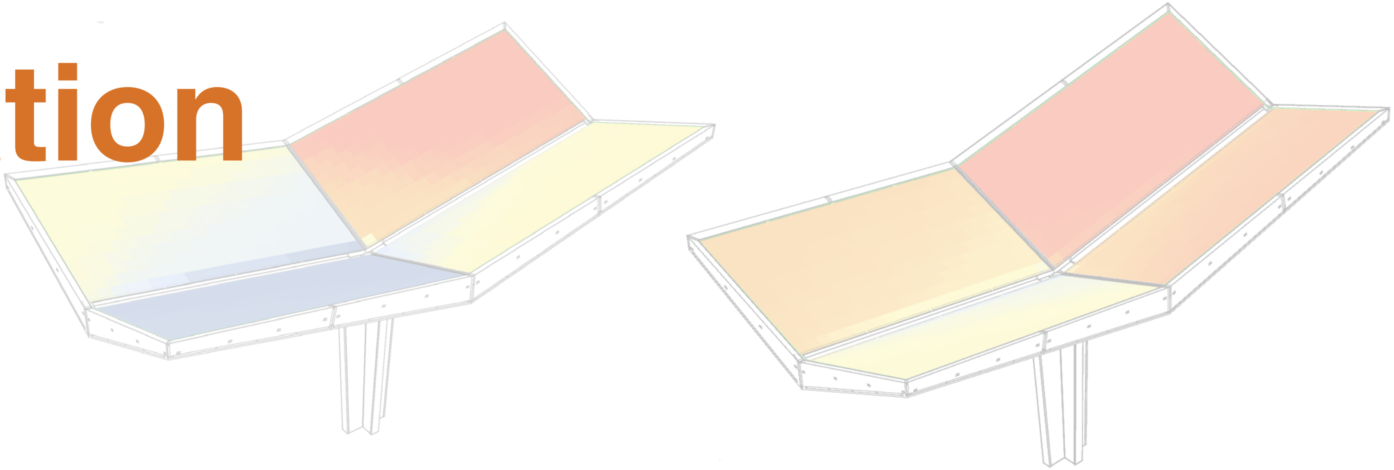
±10% deviation



yield winter

annual yield

ELECTRICAL YIELD VERIFICATION



±10% deviation

- verification OK

- PV layout calculation only possible for PV types that are on the market
- not possible for curved geometries
- calculation based on 'perfect working' system

measured yield (december to february):

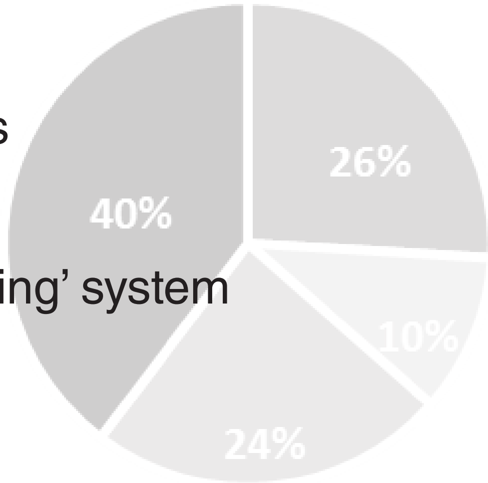
214 kWh

calculated yield (december to february):

237 kWh

calculated yield (year):

3350 kWh



yield winter

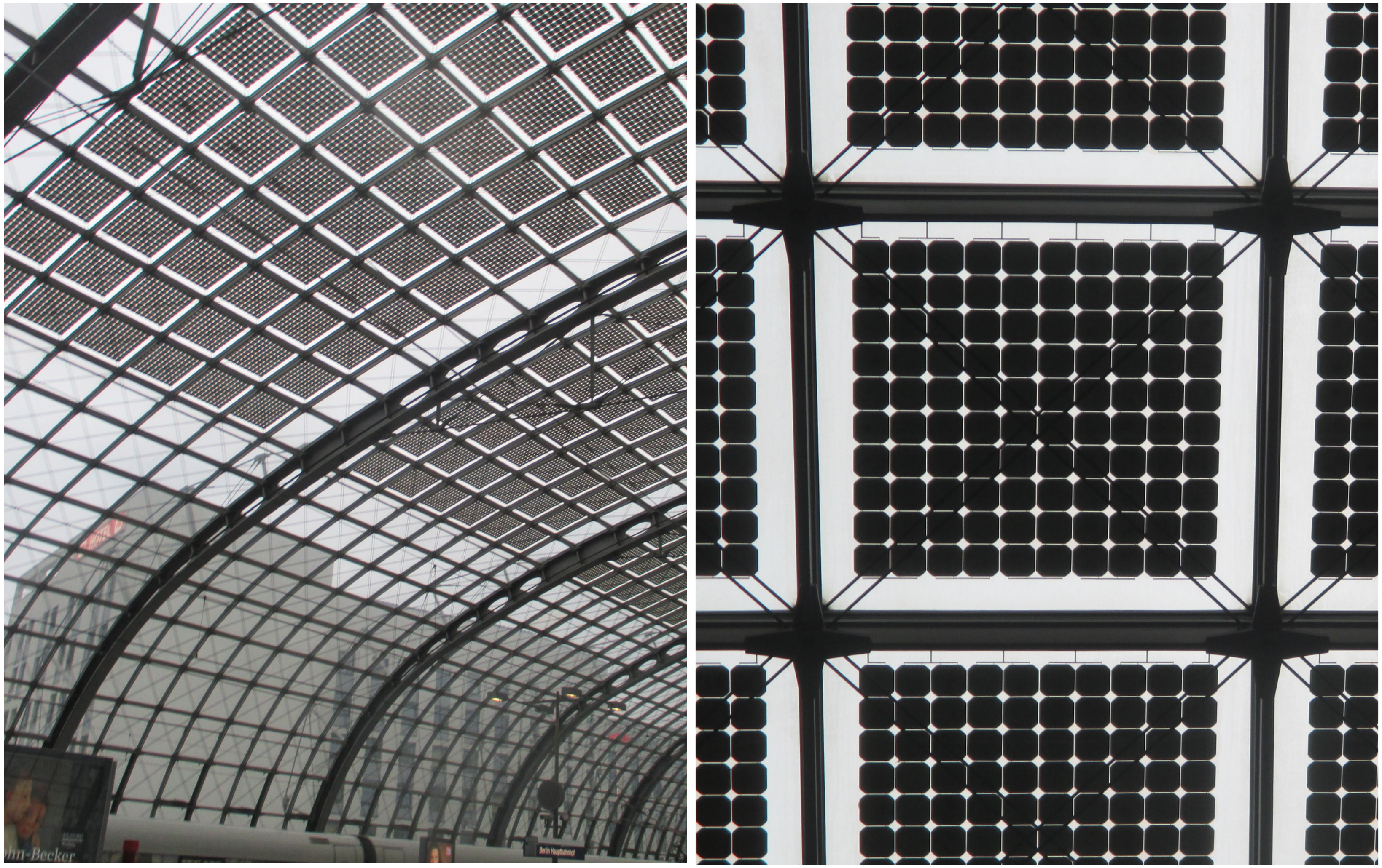
annual yield

Energy production:

Which types of PV can a designer choose from?

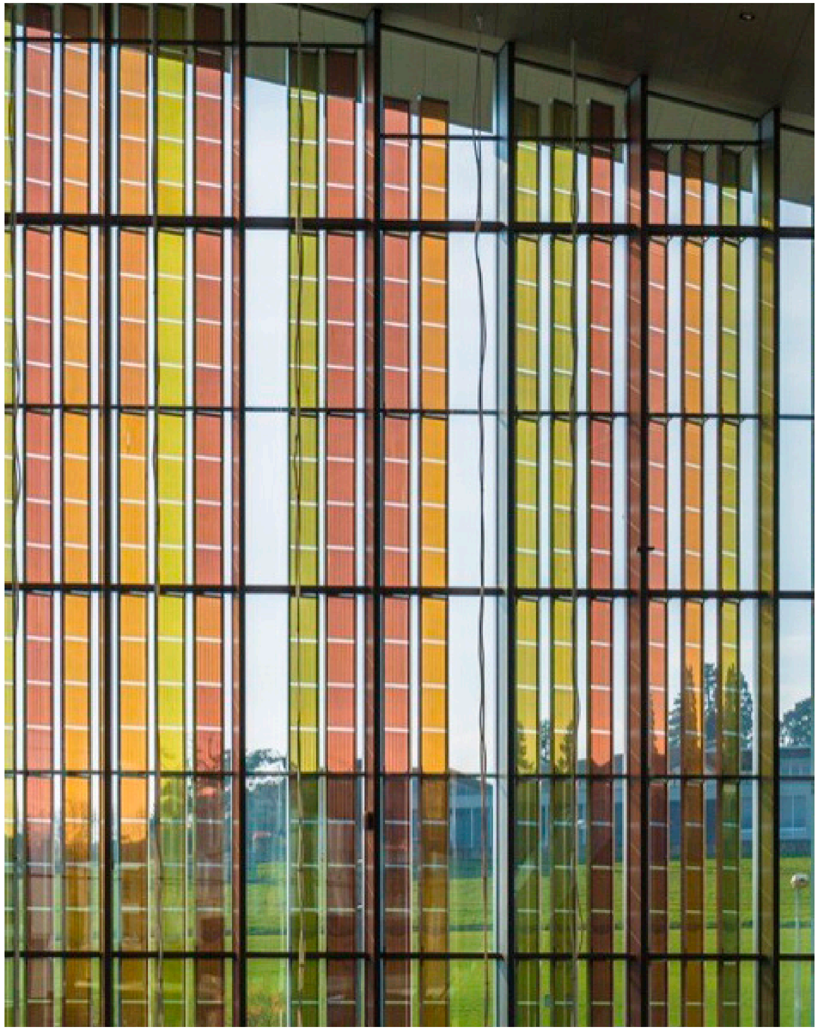
What is the yield?

What are the pro’s and con’s?

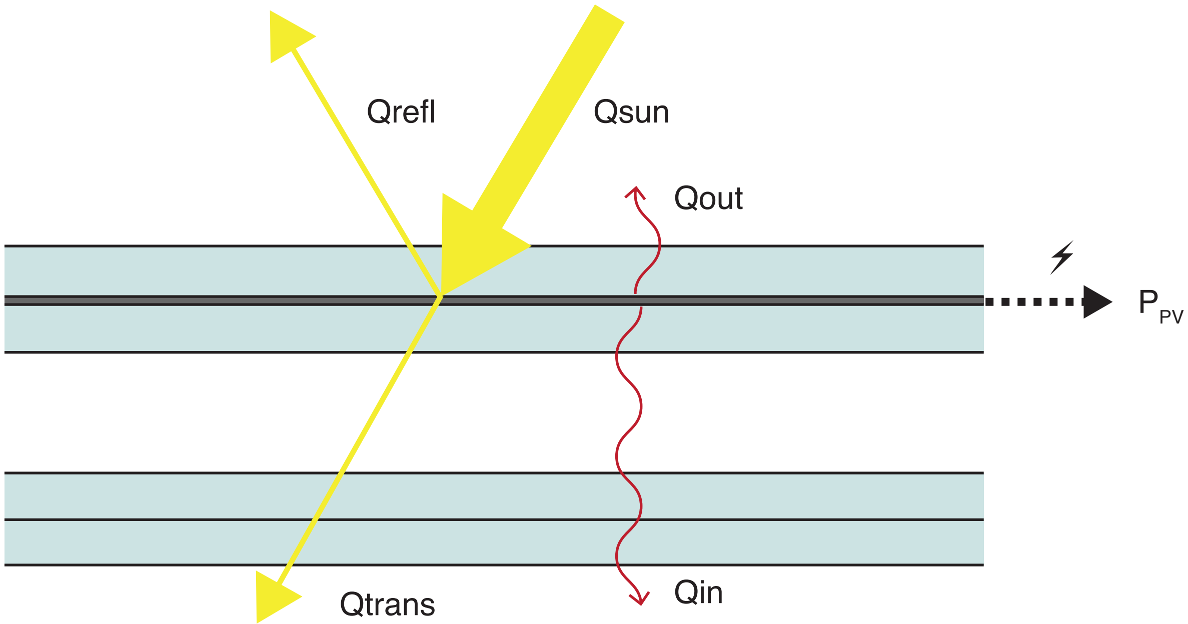


HAUPTBAHNHOF - BERLIN

BELGIUM PAVILION - MILAN




BELGIUM PAVILION - MILAN


Qrefl
Qsun
Qout
P_{PV}
Qtrans
Qin

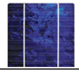
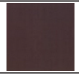
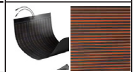
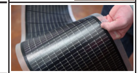
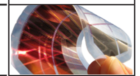
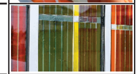
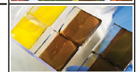
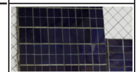
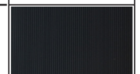
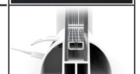
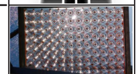
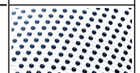
PV CELL TYPES

various pv cell types

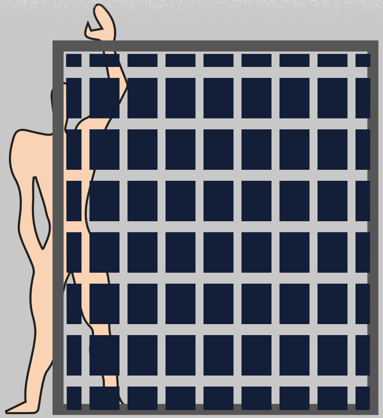
↓

selection building sector/ integration glass

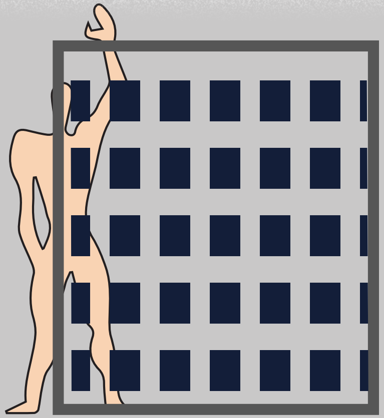
LAYOUT SCHEMES PV

group	type	efficiency module (lab)	visual transparency	W_{peak}/m^{2*}	technique	low light performamnce/ angle sensitivity	thickness / flexibility	state of commercialisation	notably	appearance
CRYSTALLINE SILICON	monocrystalline silicon (mono C-Si)	15 - 24% (25.6%)	0% 50% (spacing)* 70% (spacing)*	200 100 60	glass-glass module	low / high	160 - 240 μm / brittle	mature, large scale production		
CRYSTALLINE SILICON	polycrystalline silicon (poly C-Si)	13 -18% (21.3%)	0% 50% (spacing)* 70% (spacing)*	160 80 48	glass-glass module	low / high	160 - 240 μm / brittle	mature, large scale production	different colours possible	
THIN FILM	amorphous silicon (a-Si)	5 - 10% (14.0%)	10% 20%	50 40	on flexible substrate (eg. PET), or glass	medium / low	0.01 - 2 μm / flexible**	mature, large scale production	non-toxic	
THIN FILM	copper indium gallium selenide (CI(G)S)	7-12% (22.6%)	0% 50% (spacing) 70% (spacing)	95 48 29	on flexible substrate (eg. PET), or glass	medium / medium	0.01 - 2 μm / flexible	early, medium scale production	toxic	
THIN FILM	cadmium telluride (CdTe)	8 - 11% (21.1%)	0% 50% (spacing) 70% (spacing)	95 48 29	on flexible substrate (eg. PET), or glass	medium / medium	0.01 - 2 μm / flexible	early, medium scale production		
THIN FILM	Copper, zinc, tin, sulfide (CZTS)	10% (12.6%)	0% 50% (spacing) 70% (spacing)	100 50 30	on flexible substrate (eg. PET), or glass	medium / medium	0.01 - 2 μm / flexible	fundamental research phase	abundant materials / non-toxic	
NANO	Organic solar cell (OPV)	1 - 10% 4.5% (11.5%)	0% 70%	55 45	on flexible substrate (eg. PET), or glass	medium / medium		research and development phase	vulnerable to degradation, organic, IR	
NANO	dye-sensitized solar cells (DSSC)	1 - 10% (14.1%)		50	organic dye, based on photosinthesis			early, first applications	(in)organic vulnerable to frost, increase eff. by temp increase,	
NANO	perovskite solar cells (PSC)	10 - 15% (22.1%)					0.1 - 0.6 μm / flexible	fundamental research phase	vulnerable to degradation,range of colours	
NANO	gallium arsenide (GaAs)	33%			on flexible substrate (eg. PET)		μm / flexible	mainly space applications		
NANO	quantum dots solar cells (QDSC)	(9.9%)			on flexible substrate (eg. PET)			fundamental research phase		
NANO	micro-crystalline silicon (μ C-Si)	(6.5%)			on flexible substrate (eg. PET)			research and development phase	option: 10% transp. visible spectrum, 5%ef	
APPLIED	powerwindow	~0.05% ~0.1% (30W/m2)	~90% ~70%	0.5 1	reflection in-plane by coating + CIGS	no		product development, first applications		
APPLIED	lumiduct		diffuse		concentrator / GaAs cels	no (tracks the sun)		product development, first applications		
APPLIED	glass prisms									
APPLIED	sphelar	15 - 24% (25.3%)	50% 70% 80%	100 60 40	micro-spheres of mono C-Si, between glass	no		product development phase	effective in all directions	
APPLIED	luminescent concentrators (LSC)	0.1 - 2% (5.8%)			reflection in-plane	no	not flexible		first results in IR part spectrum	
	Belectric leaves				integrated in glass, OPV			early, first applications		

PV CELL TYPES - CRYSTALLINE SILICON (MONO/POLY)

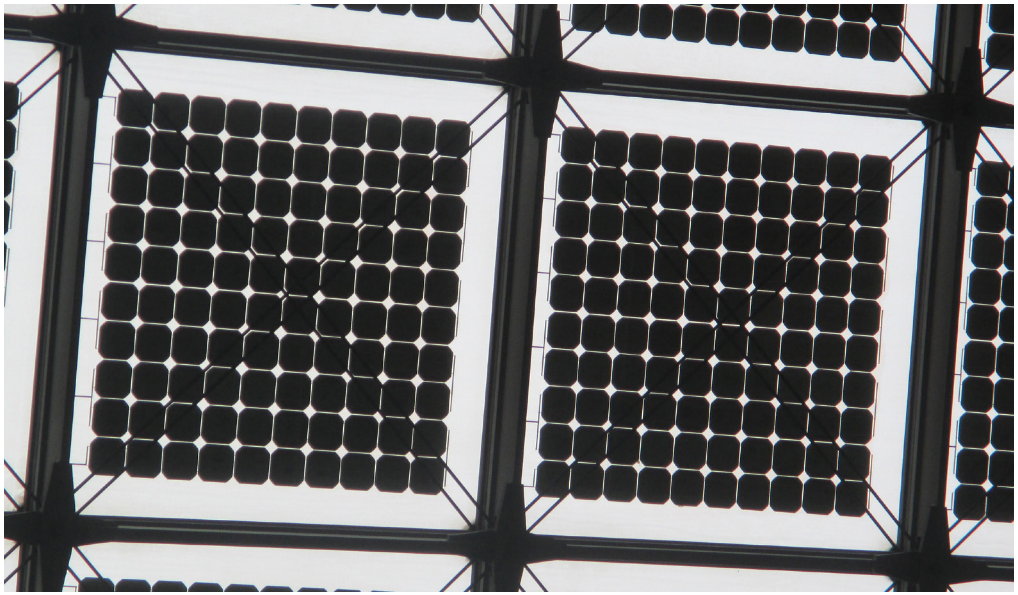


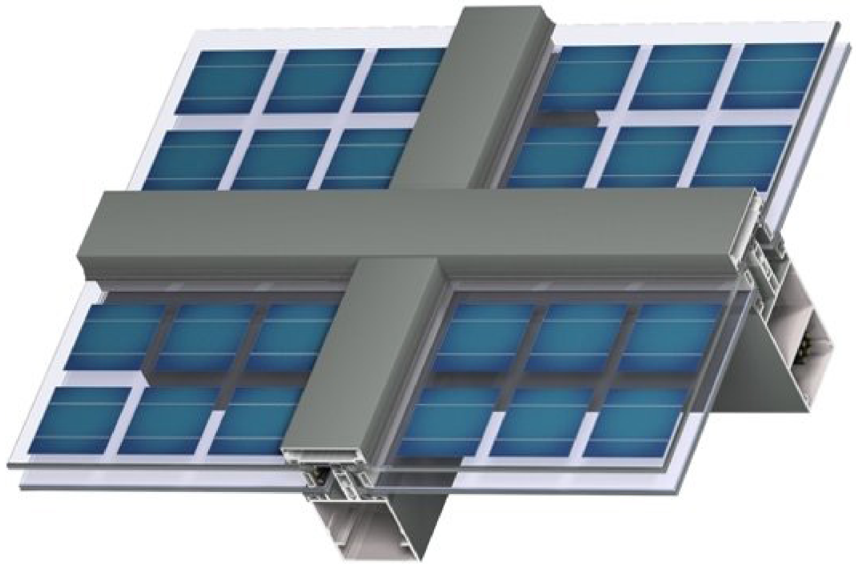
C-SI IN GLASS - 75%



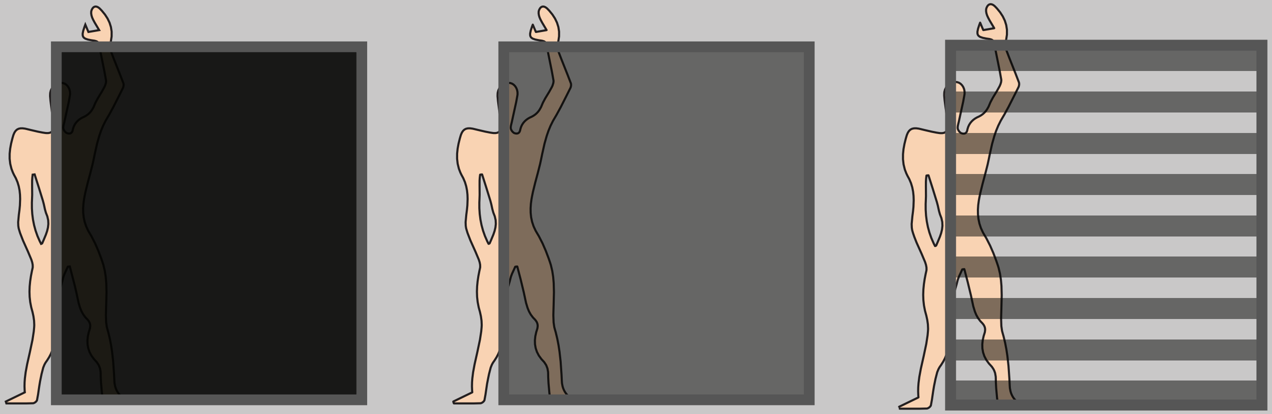
C-SI IN GLASS - 35%

- 20% efficiency ✓
- performance sub-optimal orientation ✗
- embodied energy ✗
- design freedom ✗
- (potential) cost ✗





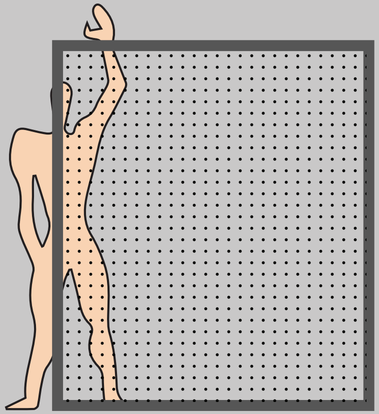
PV CELL TYPES - THIN FILM (a-Si, CIGS, CdTe, CZTS, ...)

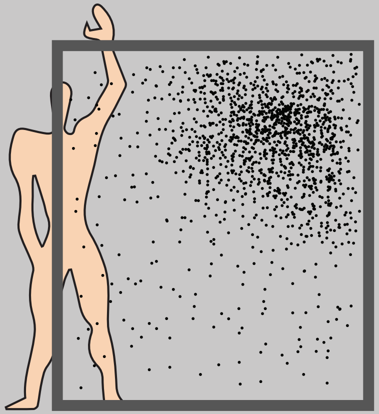


THIN FILM - 90% THIN FILM - 50% THIN FILM ZEBRA PATTERN

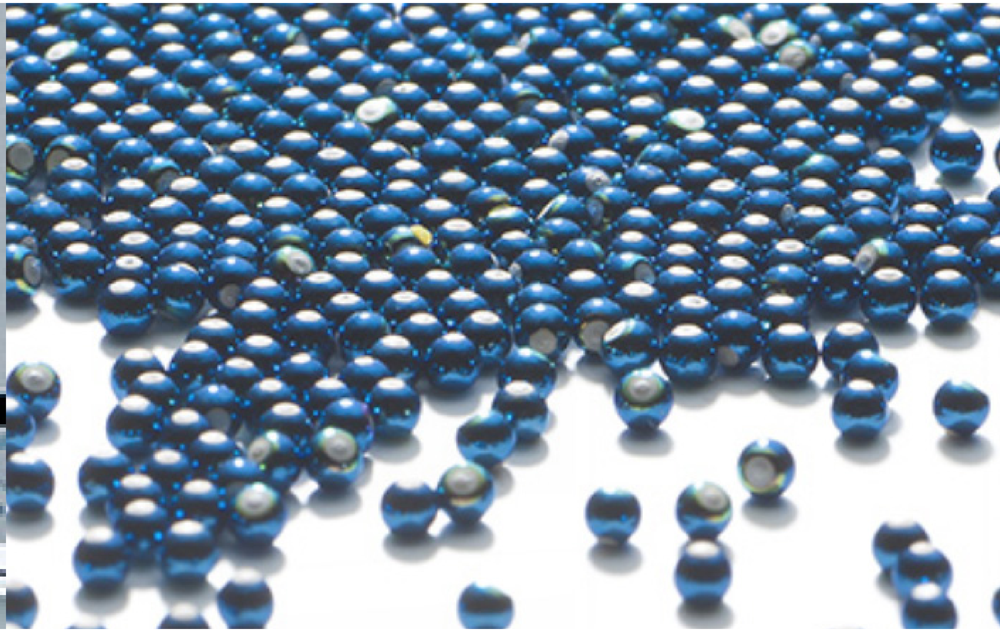
- 10 - 14% efficiency ✓/✗
- performance sub-optimal orientation ✓
- embodied energy ✓/✗
- design freedom ✓/✗
- (potential) cost ✓/✗

PV CELL TYPES - 'SPHELAR' (MONO CRYSTALLINE SILICON)

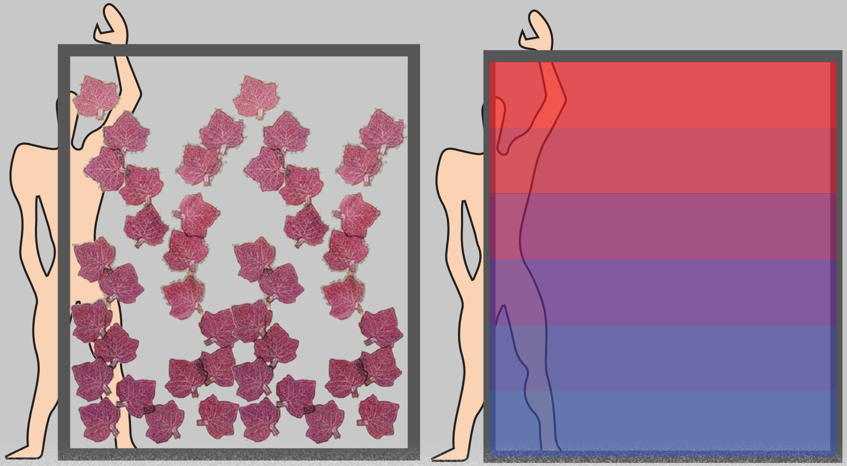




20% efficiency	✓
performance sub-optimal orientation	✓
embodied energy	✗
design freedom	✓
(potential) cost	✗

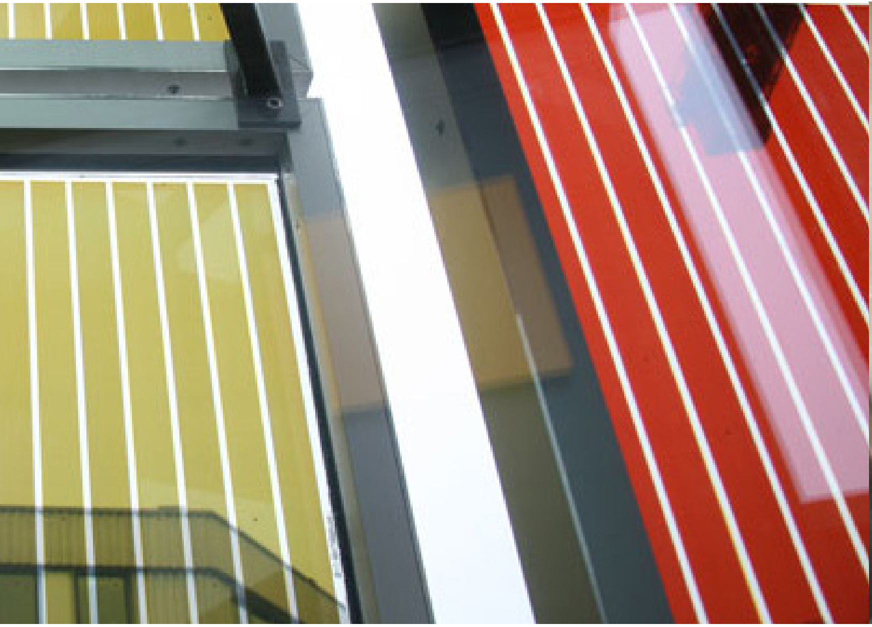


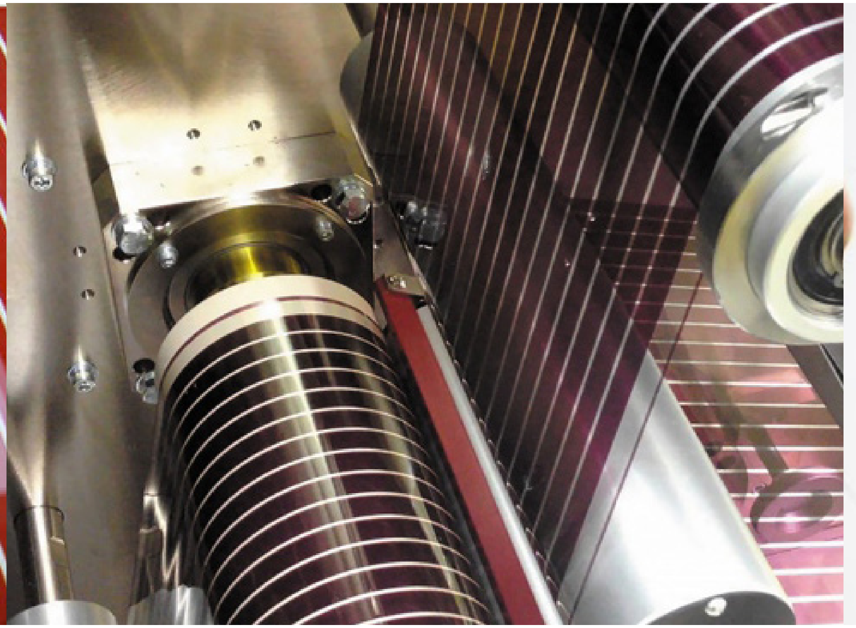
PV CELL TYPES - ORGANIC PV / DYE-SENSITIZED SOLAR CELLS



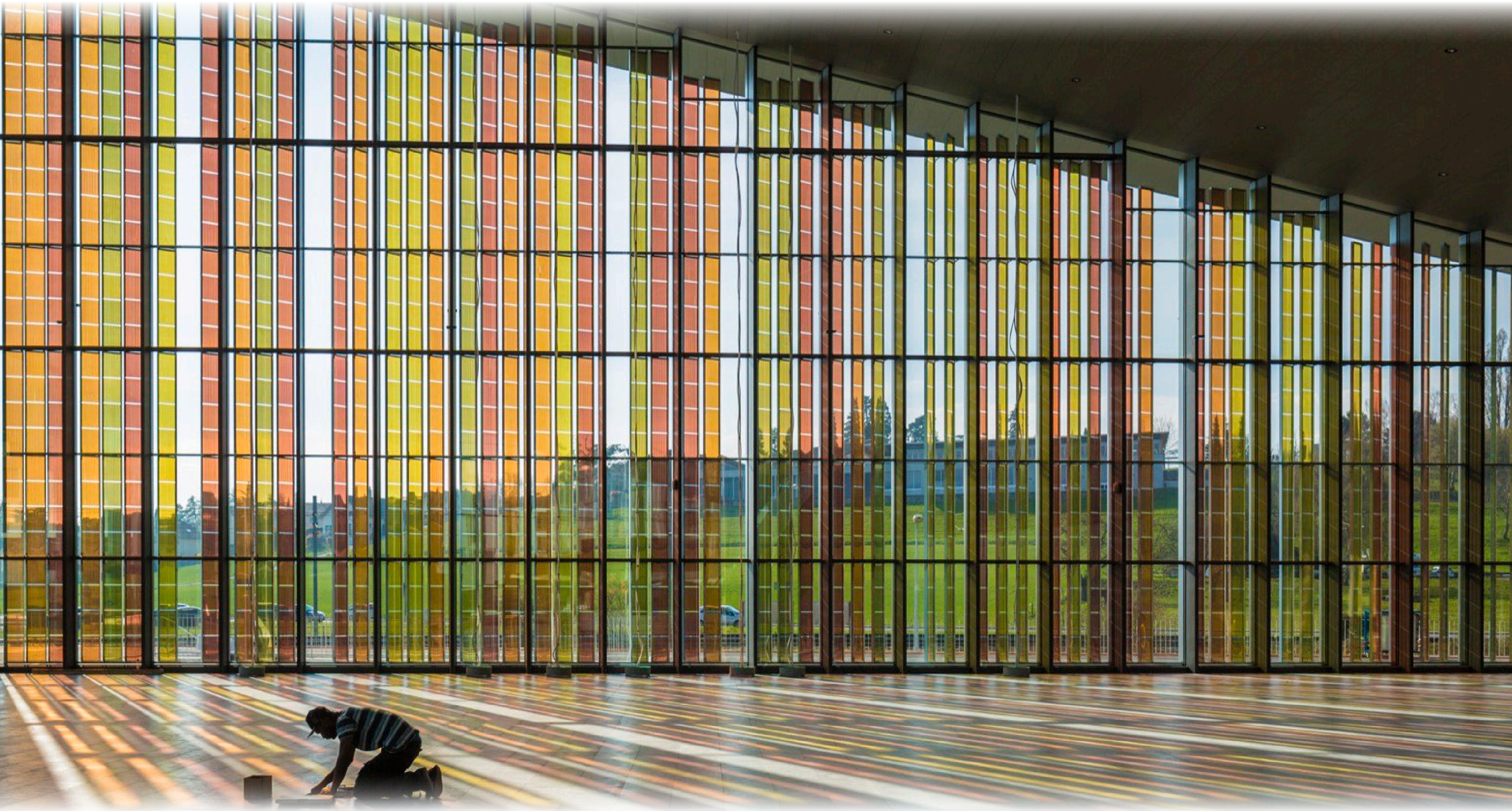
ORGANIC PV / DYE-SENSITIZED

5-15% efficiency	✓/✗
performance	
sub-optimal orientation	✓
embodied energy	✓
design freedom	✓
(potential) cost	✓





PV CELL TYPES - DYE-SENSITIZED SOLAR CELLS



SWISSTECH CONVENTION CENTER - LAUSANNE

FIRST BUILDING INTEGRATION - 2013

PV CELL TYPES - DYE-SENSITIZED SOLAR CELLS

POTENTIAL

AMSTERDAM CENTRAL STATION

PV CELL TYPES - DYE-SENSITIZED SOLAR CELLS

POTENTIAL

AMSTERDAM CENTRAL STATION

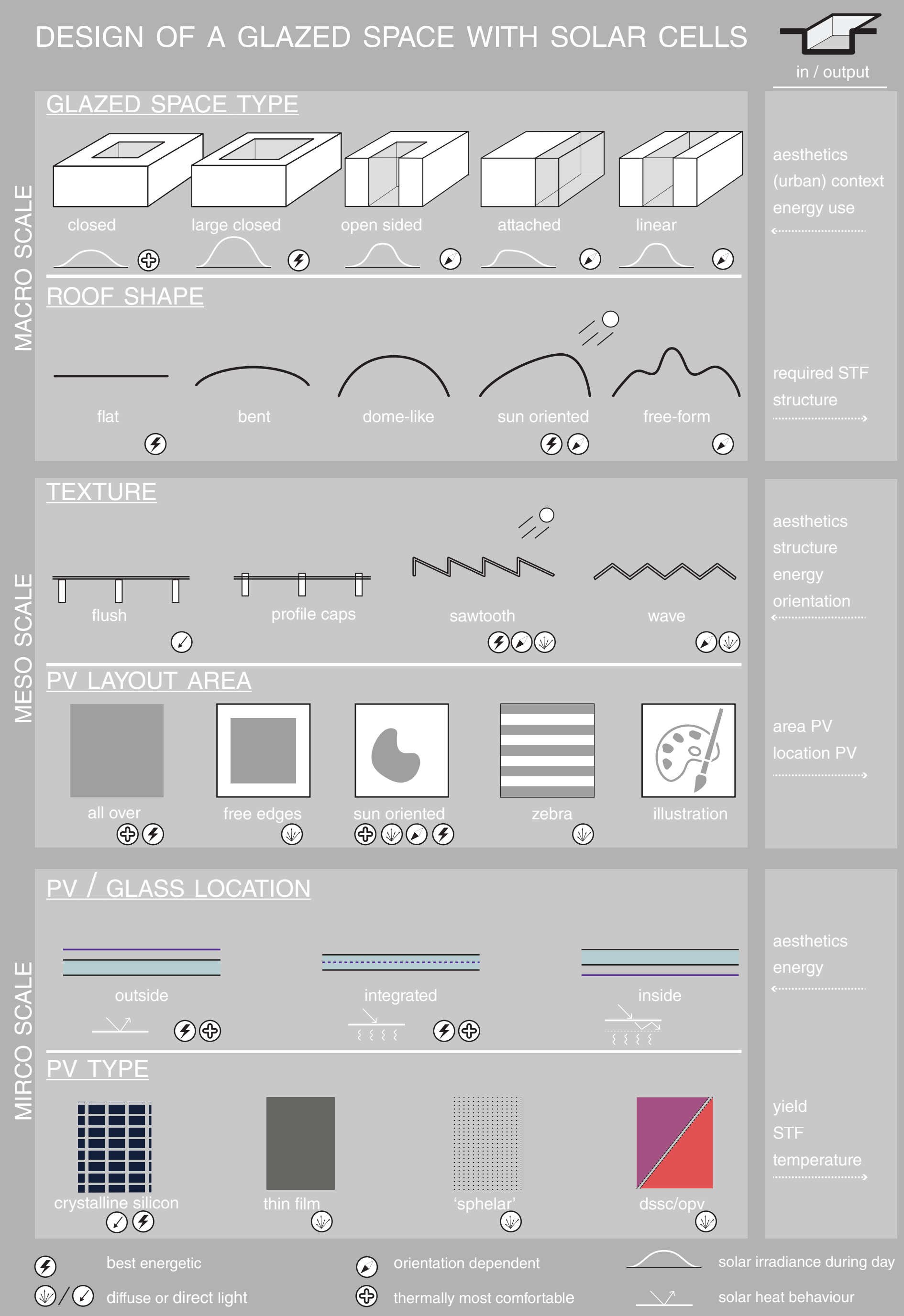
PV CELL TYPES - DYE-SENSITIZED SOLAR CELLS

POTENTIAL

SAGRADA FAMILIA, BARCELONA

DESIGN:

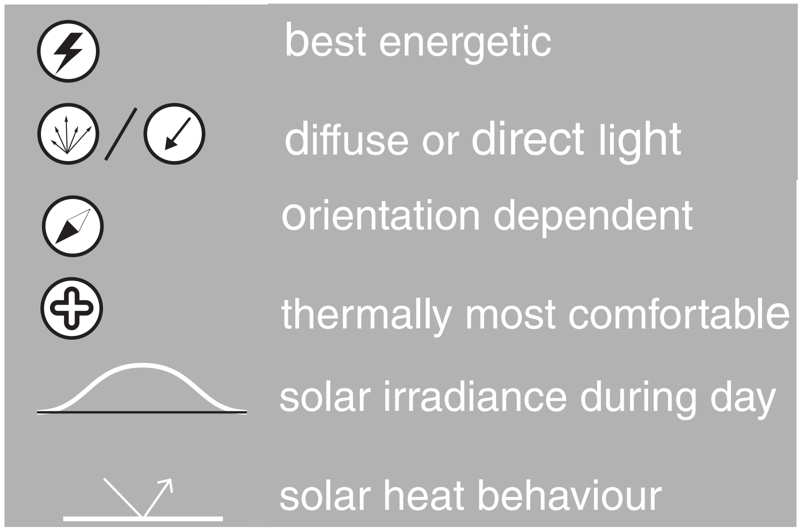
what can a designer do with this knowledge?



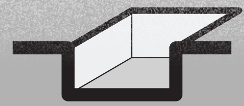
MORPHOLOGICAL DESIGN OVERVIEW

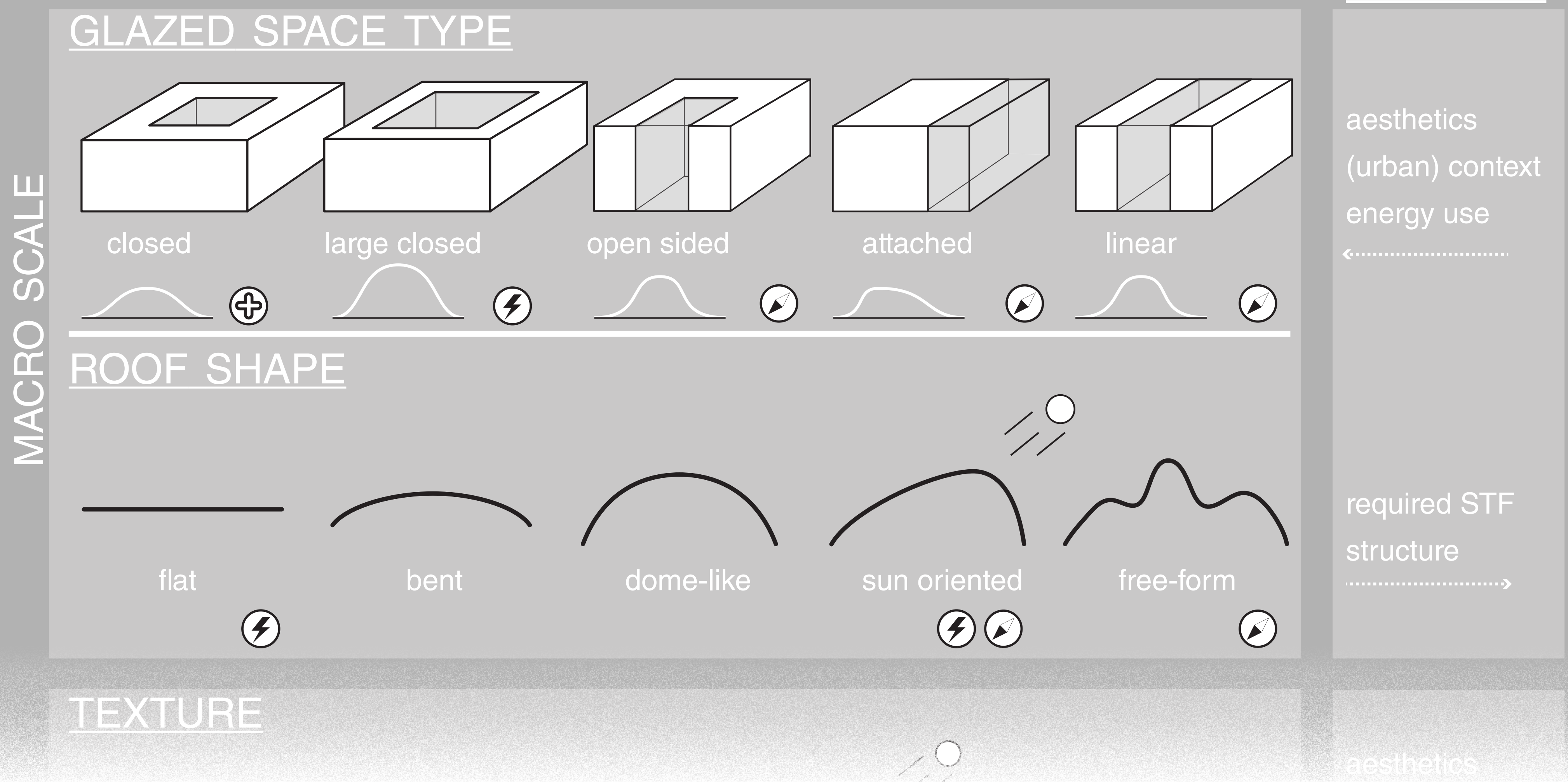
- before / together with parametric calc. model
- overview decision options
- consequences of choices

Labels



DESIGN OF A GLAZED SPACE WITH SOLAR CELLS





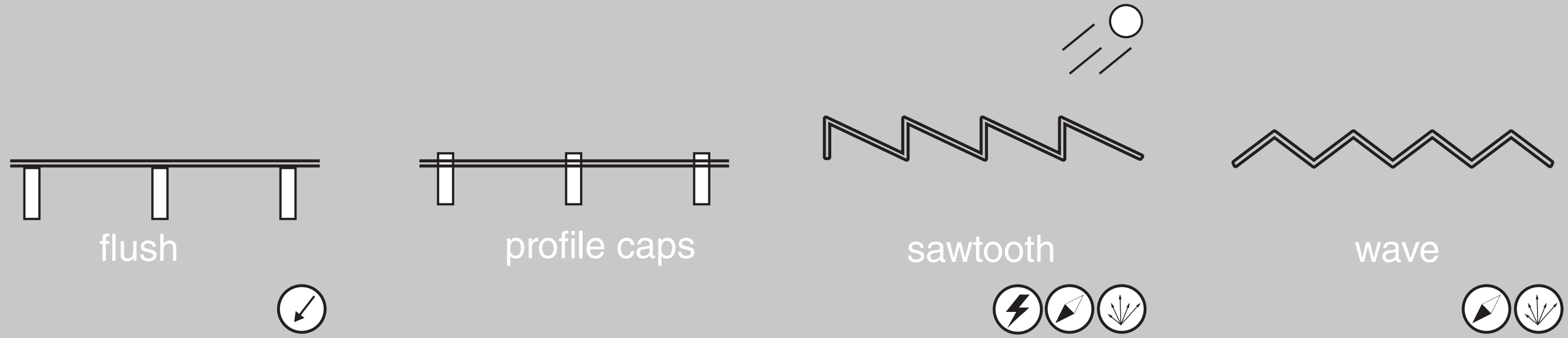
MORPHOLOGICAL DESIGN OVERVIEW

MESO SCALE

flat bent dome-like sun oriented free-form

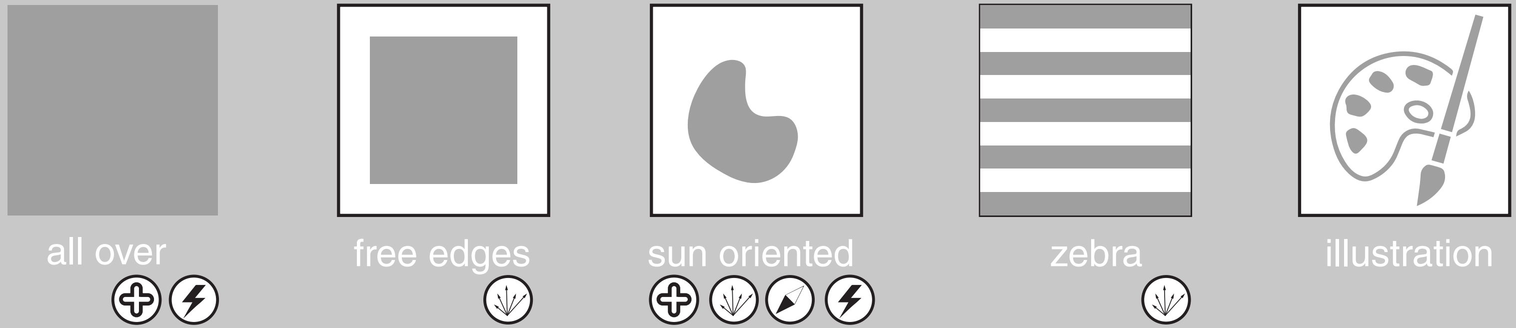
MESO SCALE

TEXTURE



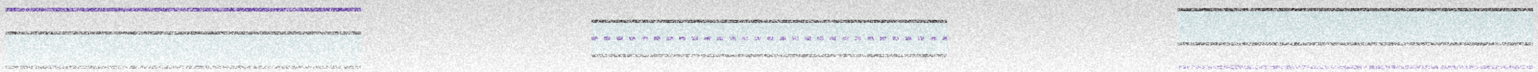
aesthetics
structure
energy
orientation

PV LAYOUT AREA



area PV
location PV

PV / GLASS LOCATION



aesthetics
energy

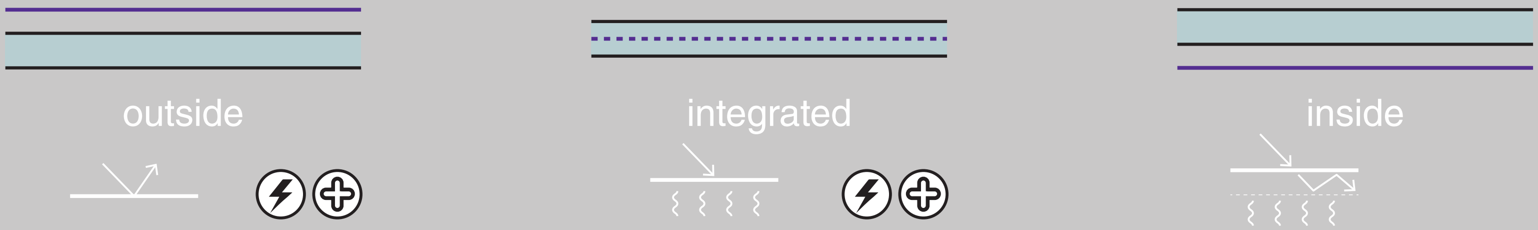
MORPHOLOGICAL DESIGN OVERVIEW

MICRO SCALE

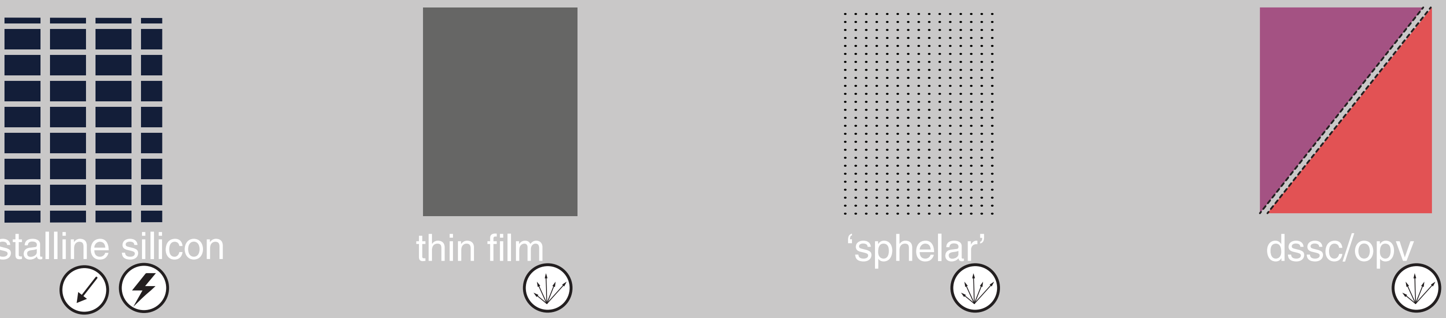
all over | free edges | sun oriented | zebra | illustration

MIRCO SCALE

PV / GLASS LOCATION



PV TYPE



aesthetics

energy

yield

STF

temperature

best energetic

diffuse or direct light

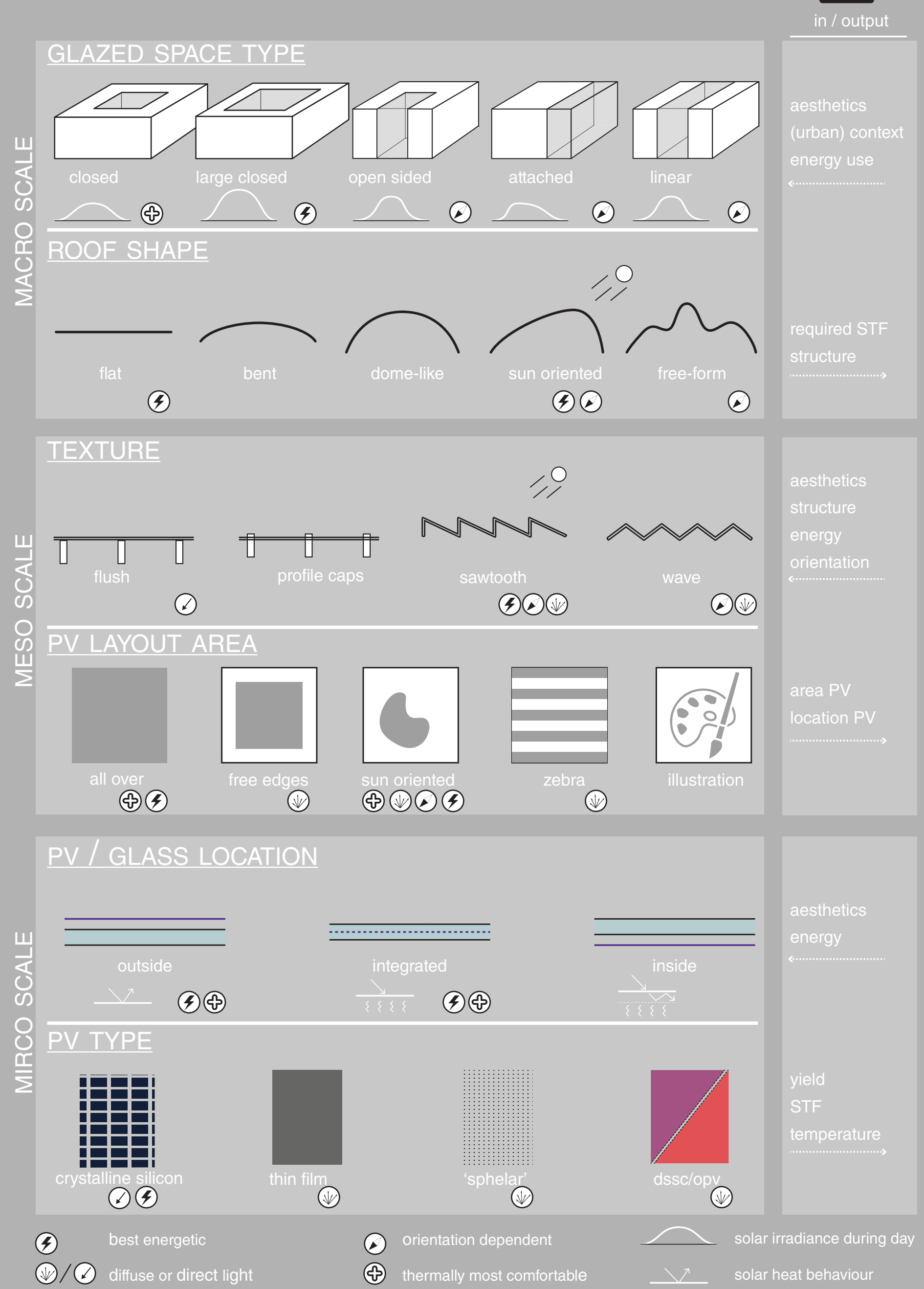
orientation dependent

thermally most comfortable

solar irradiance during day

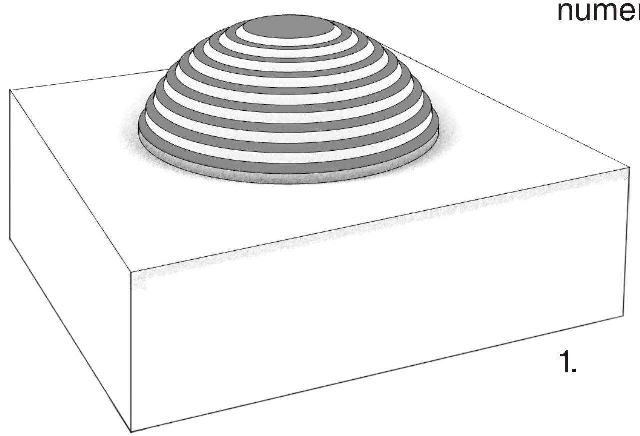
solar heat behaviour

DESIGN OF A GLAZED SPACE WITH SOLAR CELLS

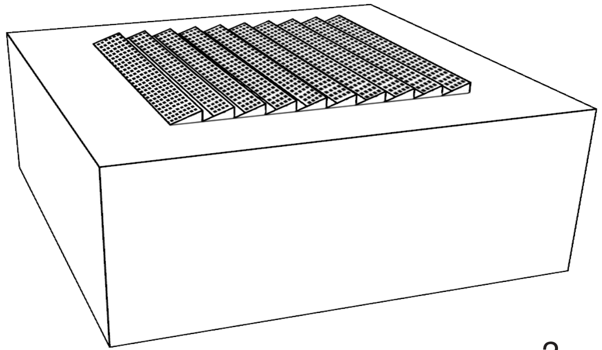


MORPHOLOGICAL DESIGN OVERVIEW

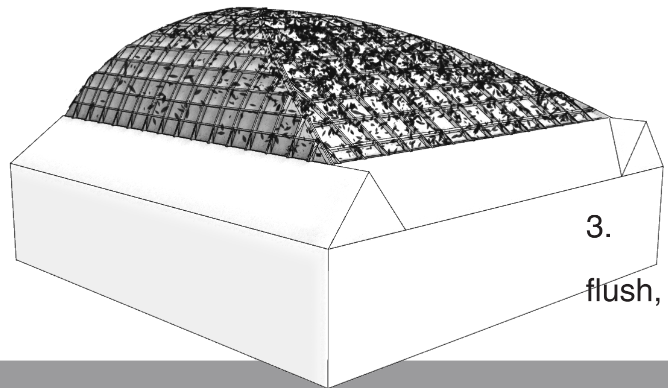
numerical and visual feedback:



1. dome, wave, thinfilm

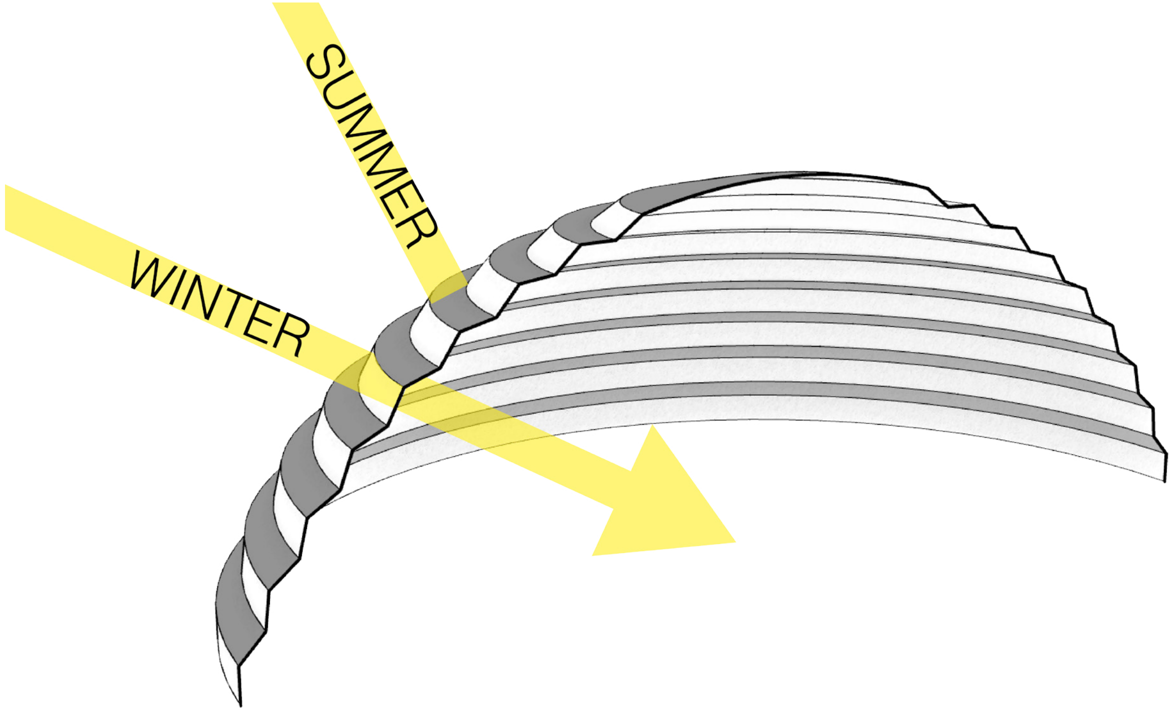


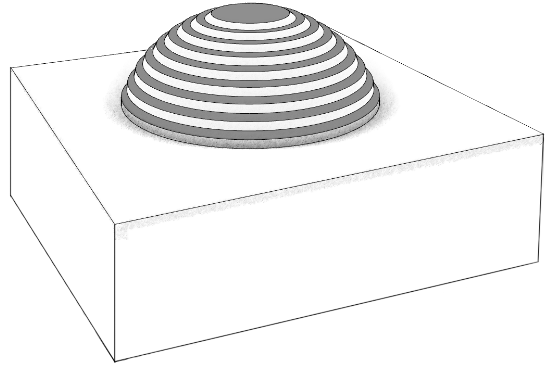
2. flat, sawtooth, c-Si

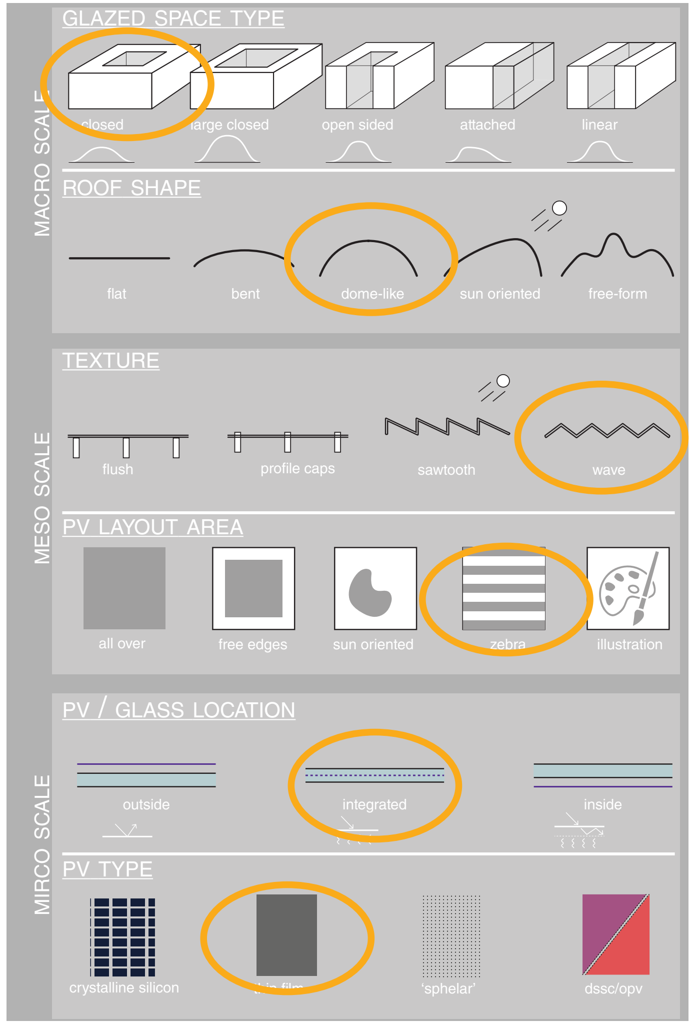


3. future vision: sun oriented, flush, dye sensitized

DESIGN CASE 1







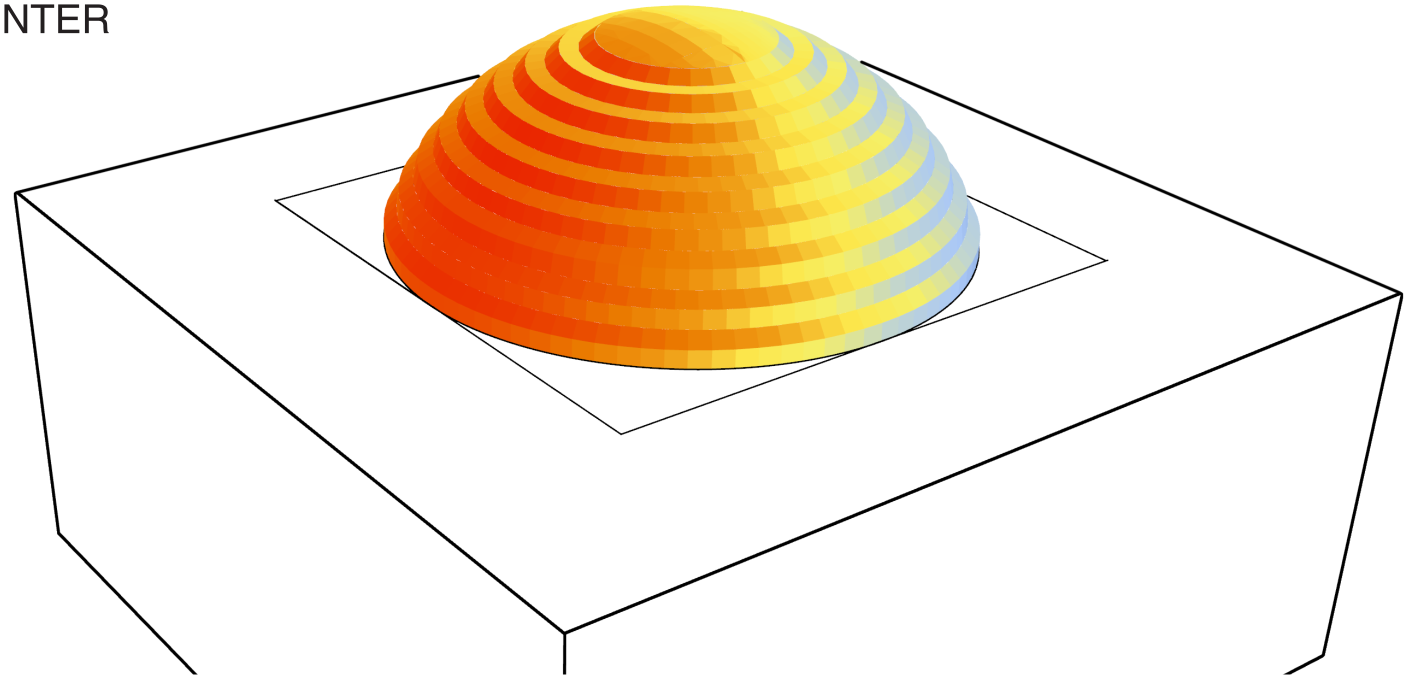
block summer sun - prevent overheating

allow winter sun - enhance heat gain

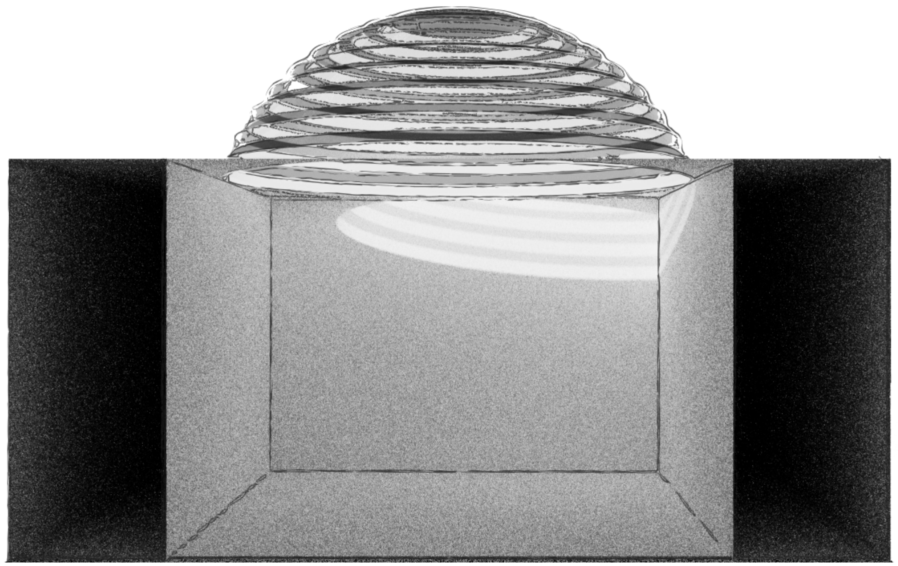
closed atrium, dome-like, wave texture, zebra layout,

integrated PV, thin film

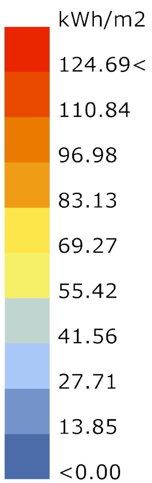
DESIGN CASE 1 - WINTER



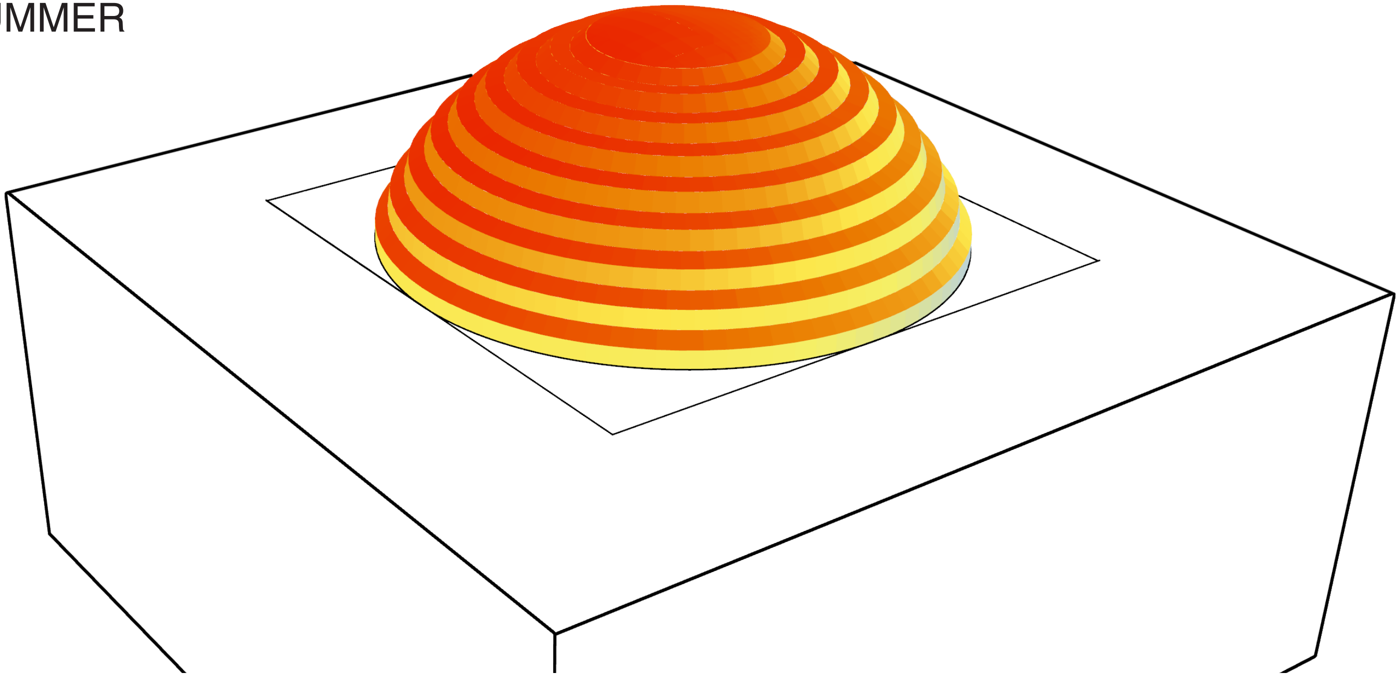
radiation analysis winter



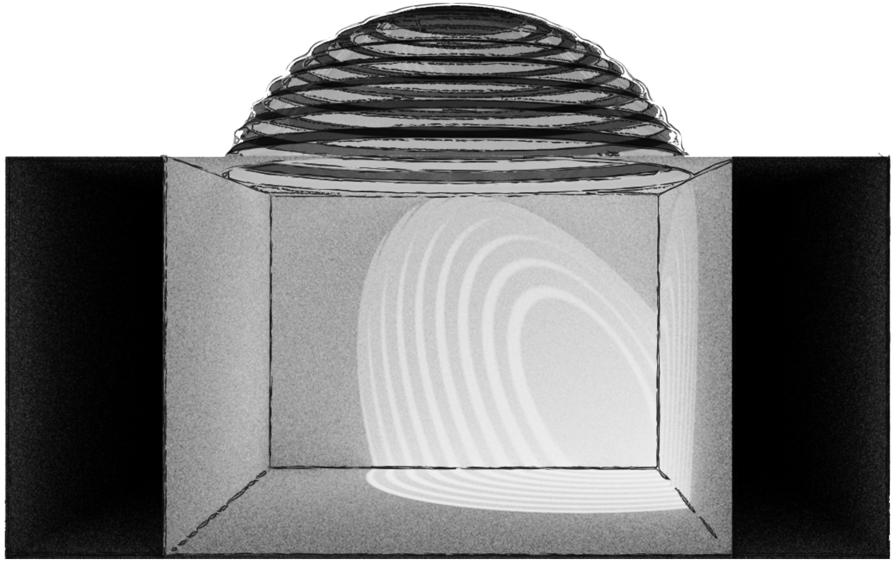
daylight assessment winter



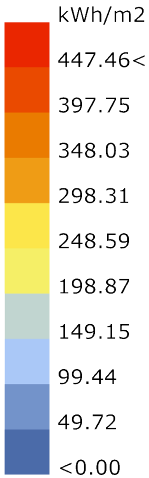
DESIGN CASE 1 - SUMMER

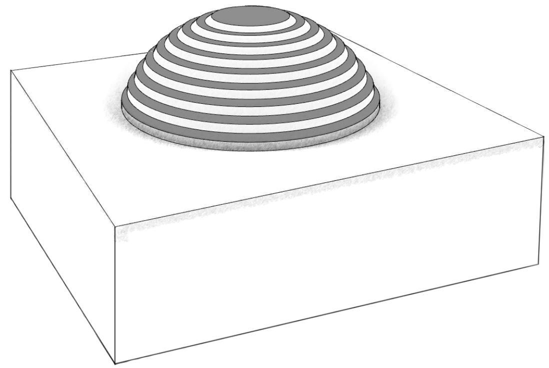


radiation analysis summer



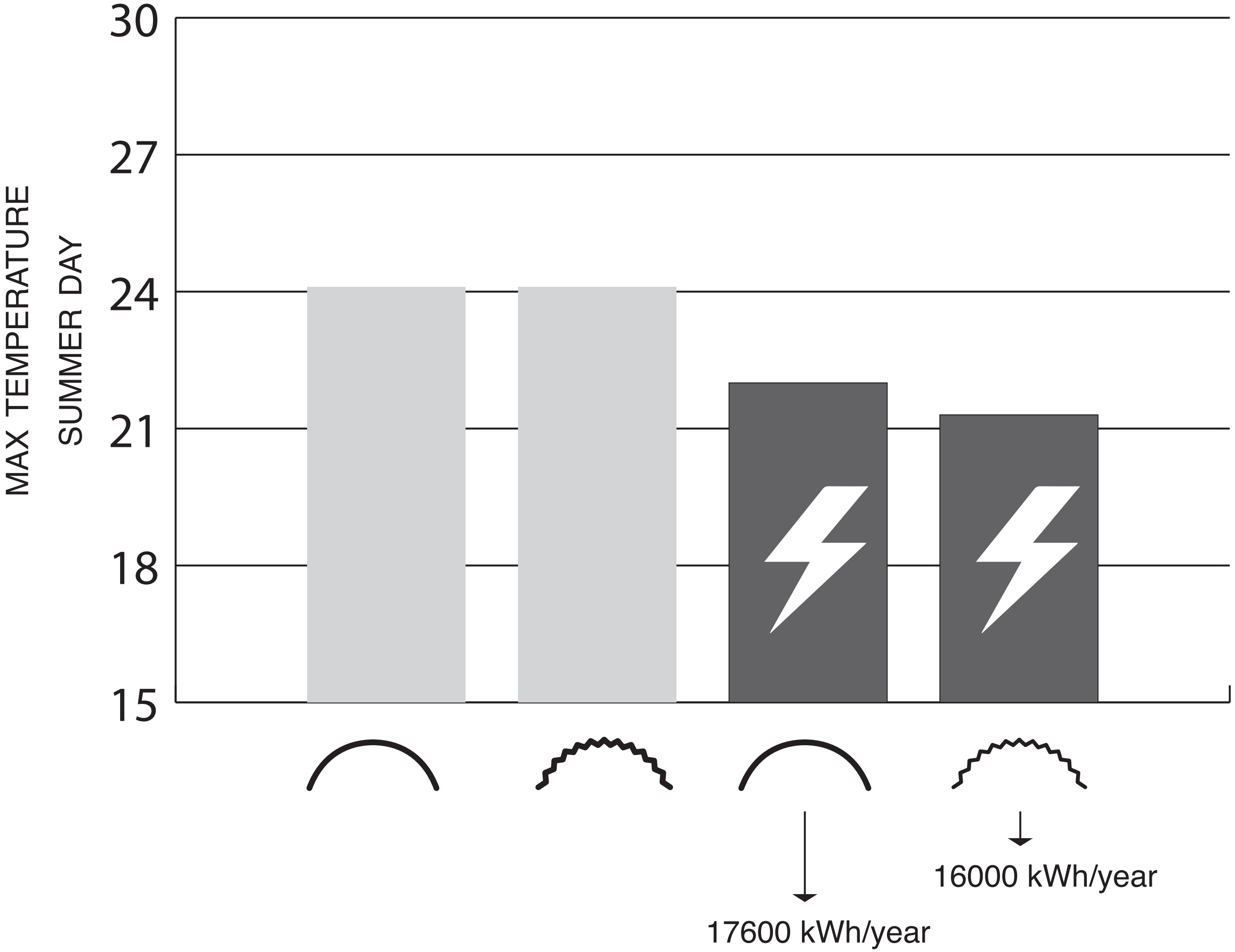
daylight assessment summer





MAX TEMPERATURE AND YEARLY YIELD

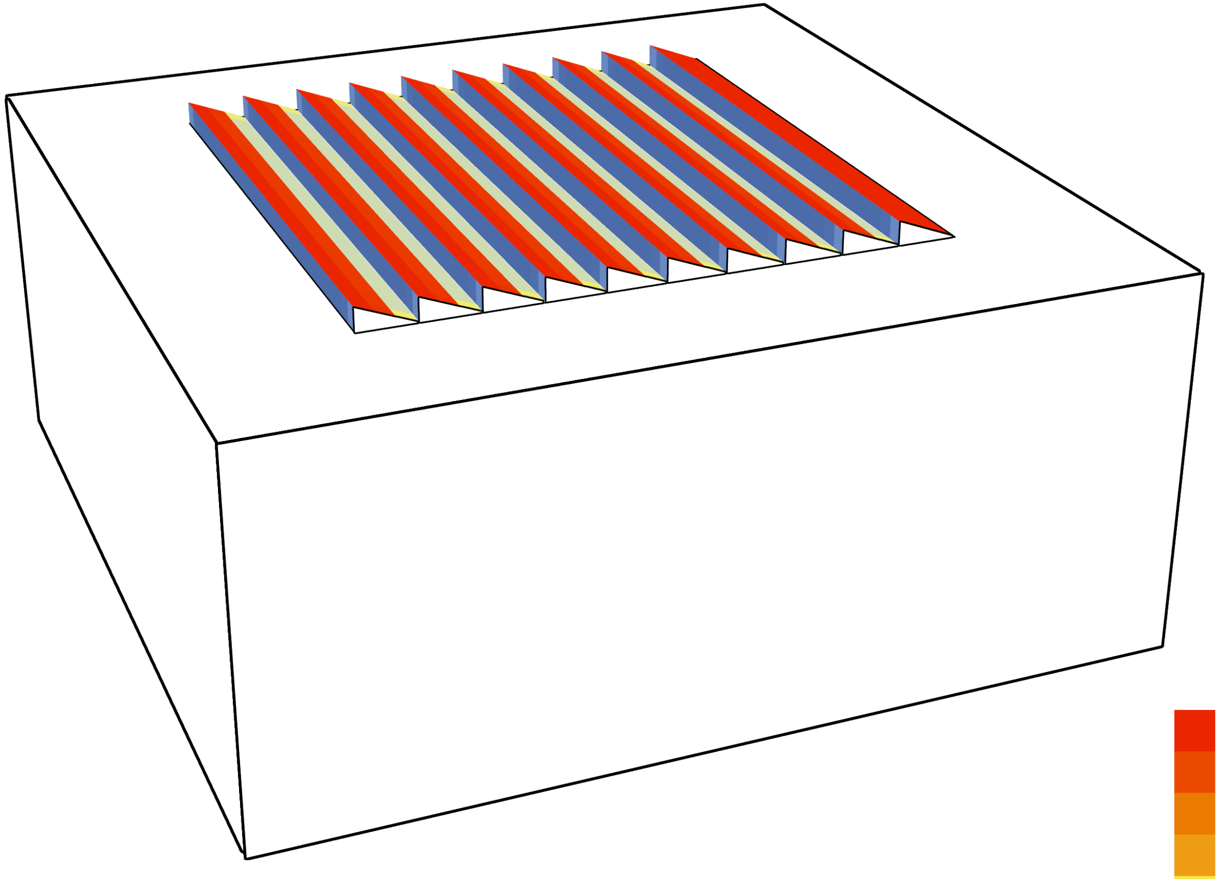
20% TRANSLUCENT THINFILM (CDTE)

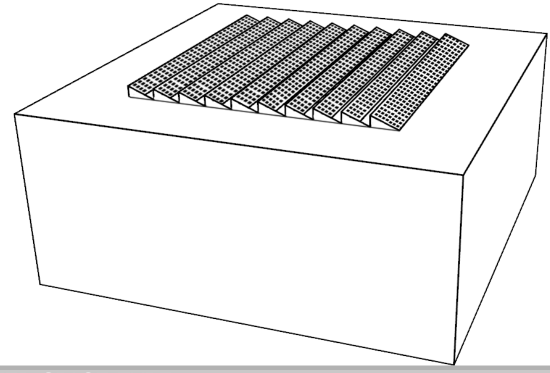


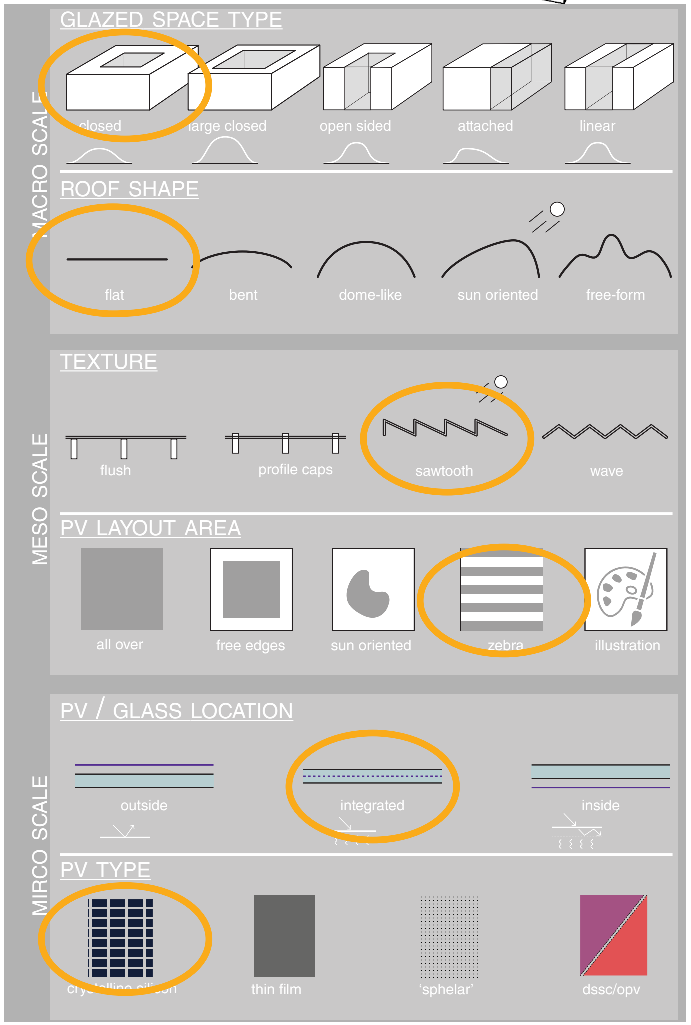
conclusion:

- yield low;
- effective shading (-3 ^{o}C)

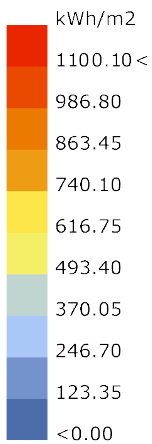
DESIGN CASE 2





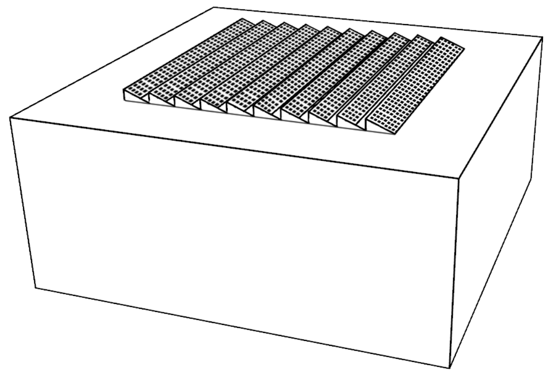


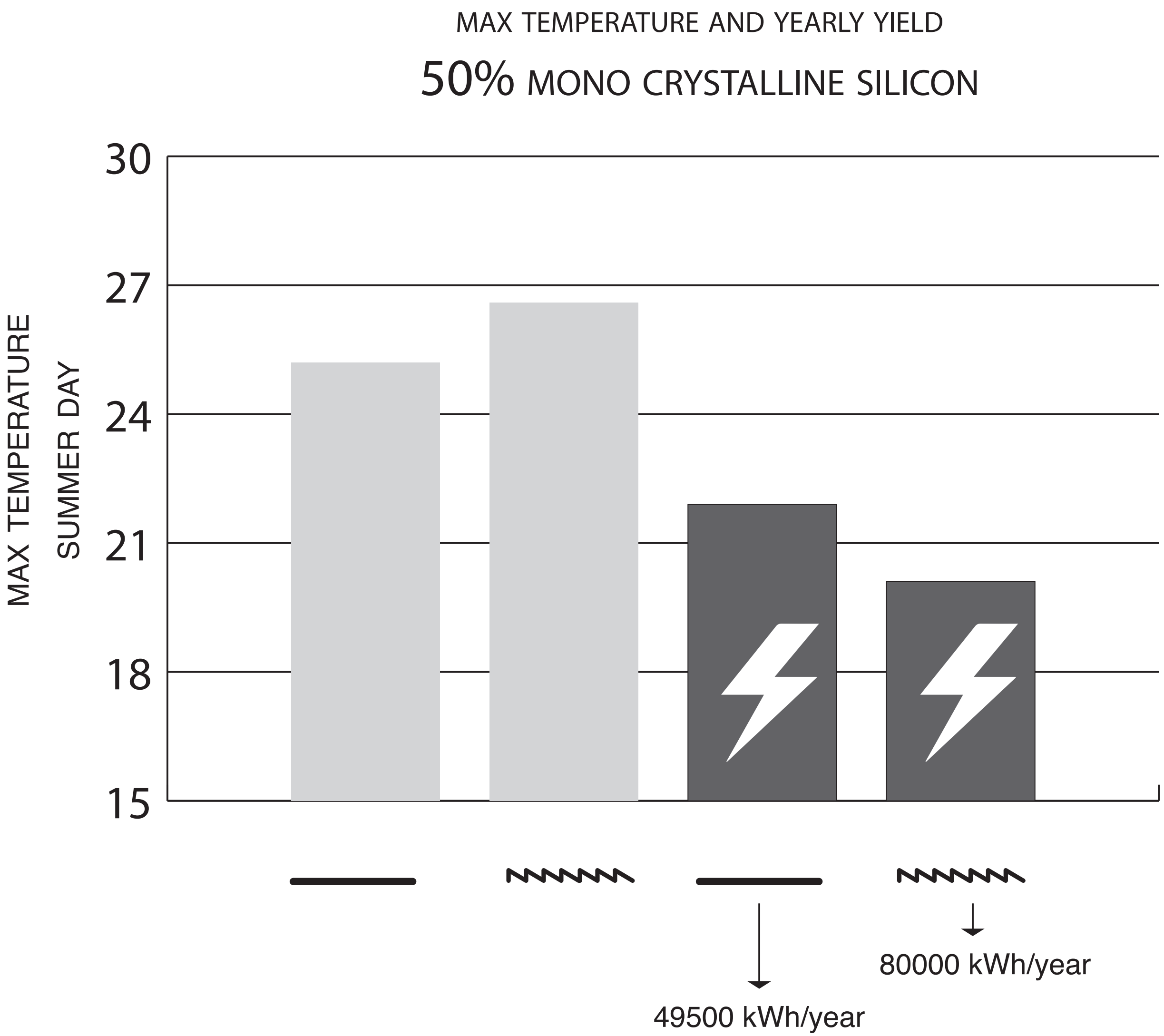
layout,



radiation analysis result

average: 635 kWh/m²





conclusion:

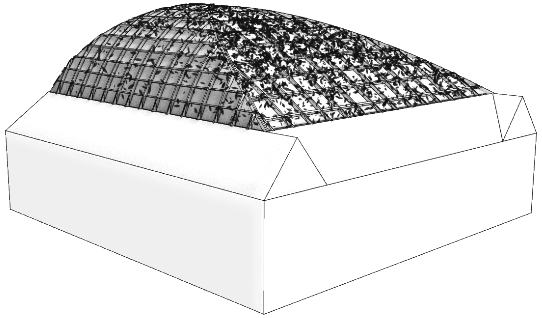
- high yield;
- effective shading (-5 °C)

DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN

Redesign

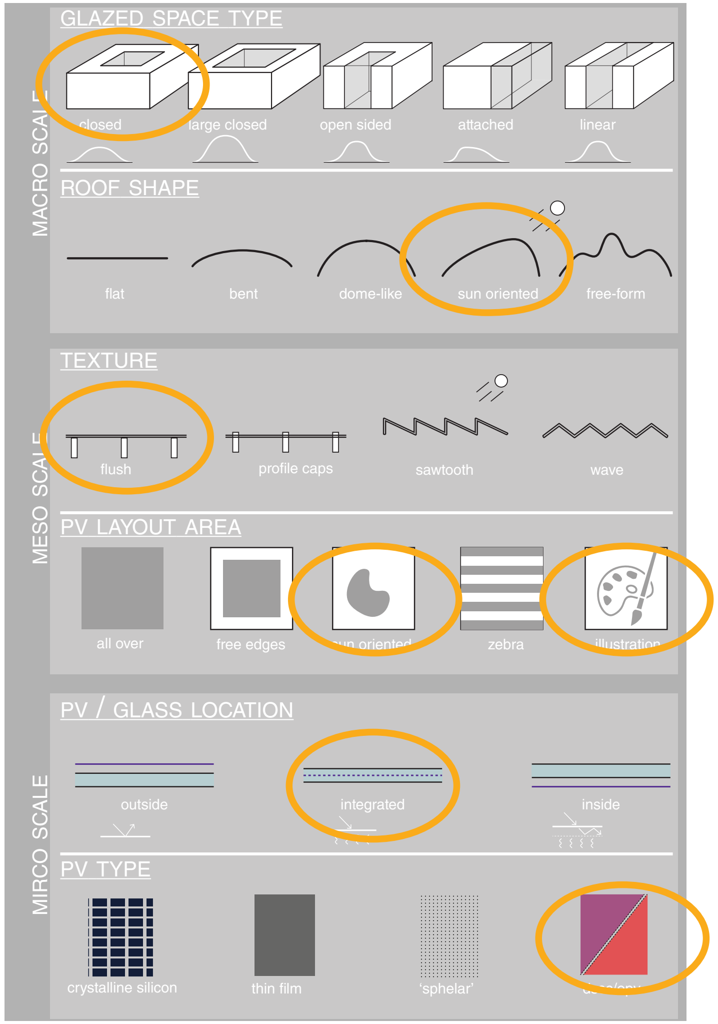
- nature museum
- educative function
- additional architectural value of DSSCs

DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN



REDESIGN

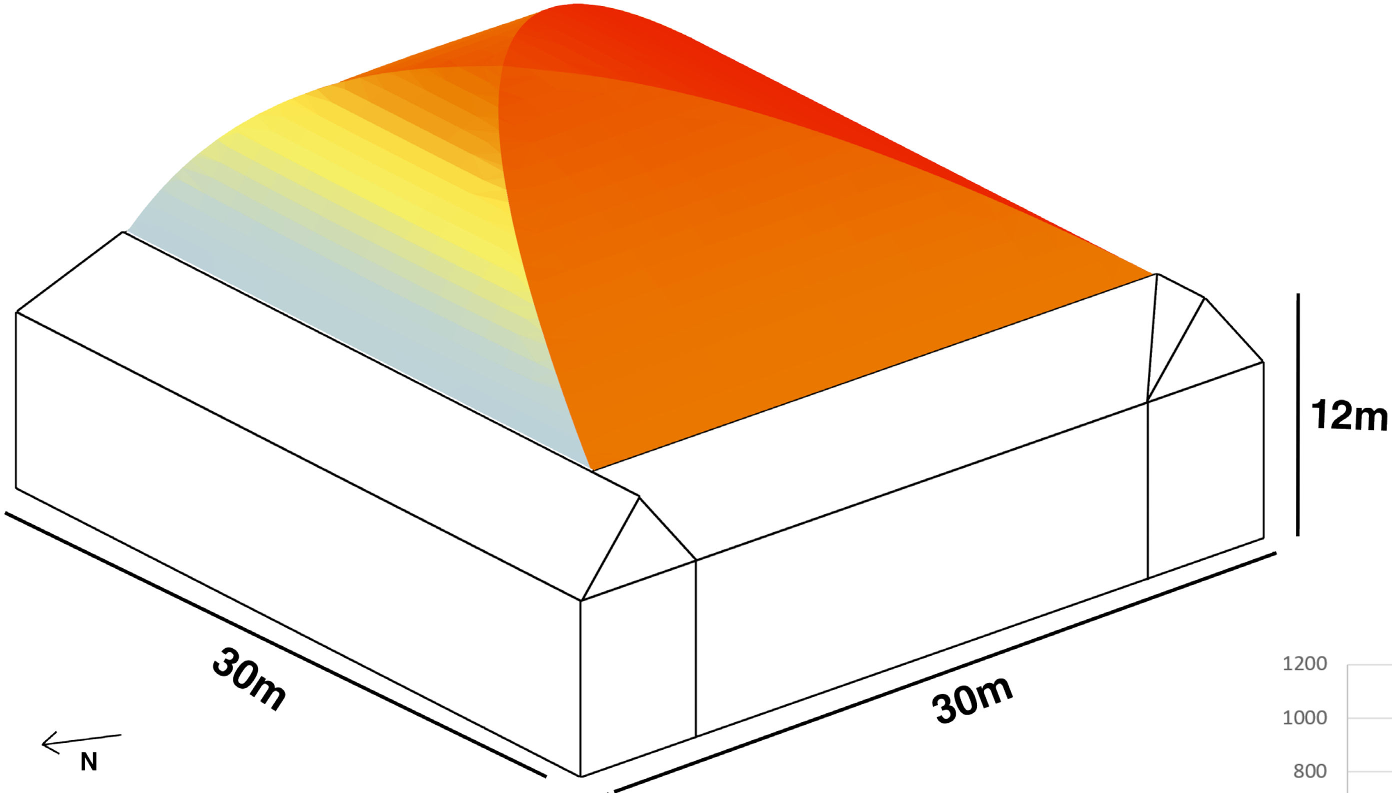
- SUN ORIENTED GEOMERTY
- SUN ORIENTED PV LAYOUT
- DYE-SENSITIZED SOLAR CELLS

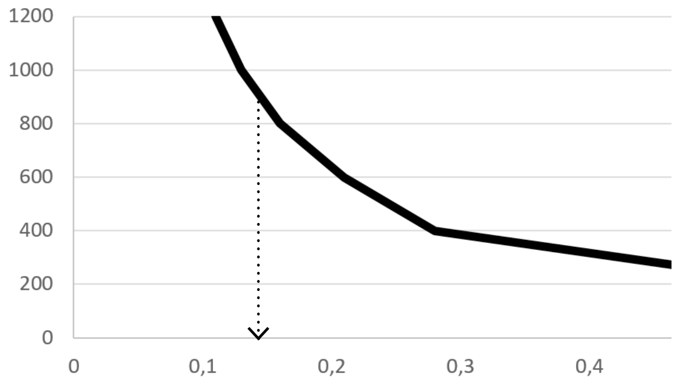


closed atrium, sun oriented roof, flush texture, sun oriented/
all over layout, integrated PV, dye-sensitized solar cells

dye-sensitized solar cells

DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN

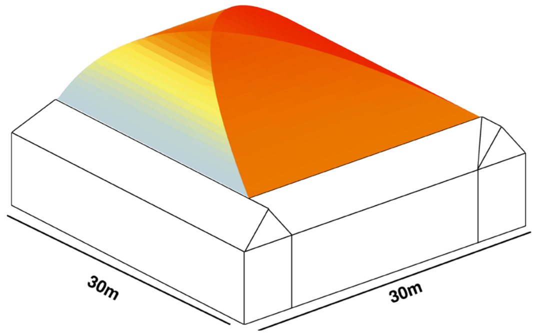


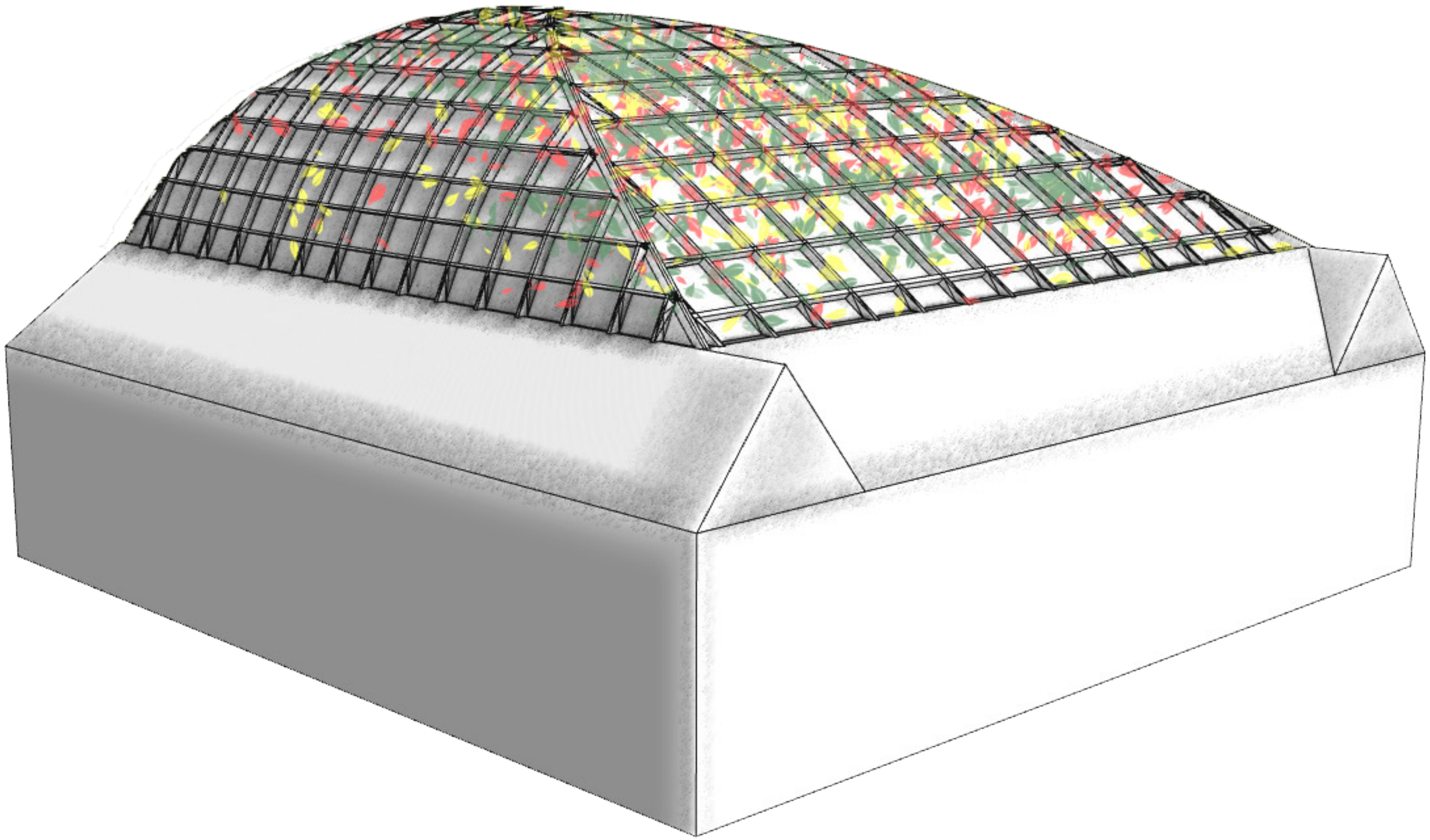


sun oriented roof shape

required STF: **0.14**

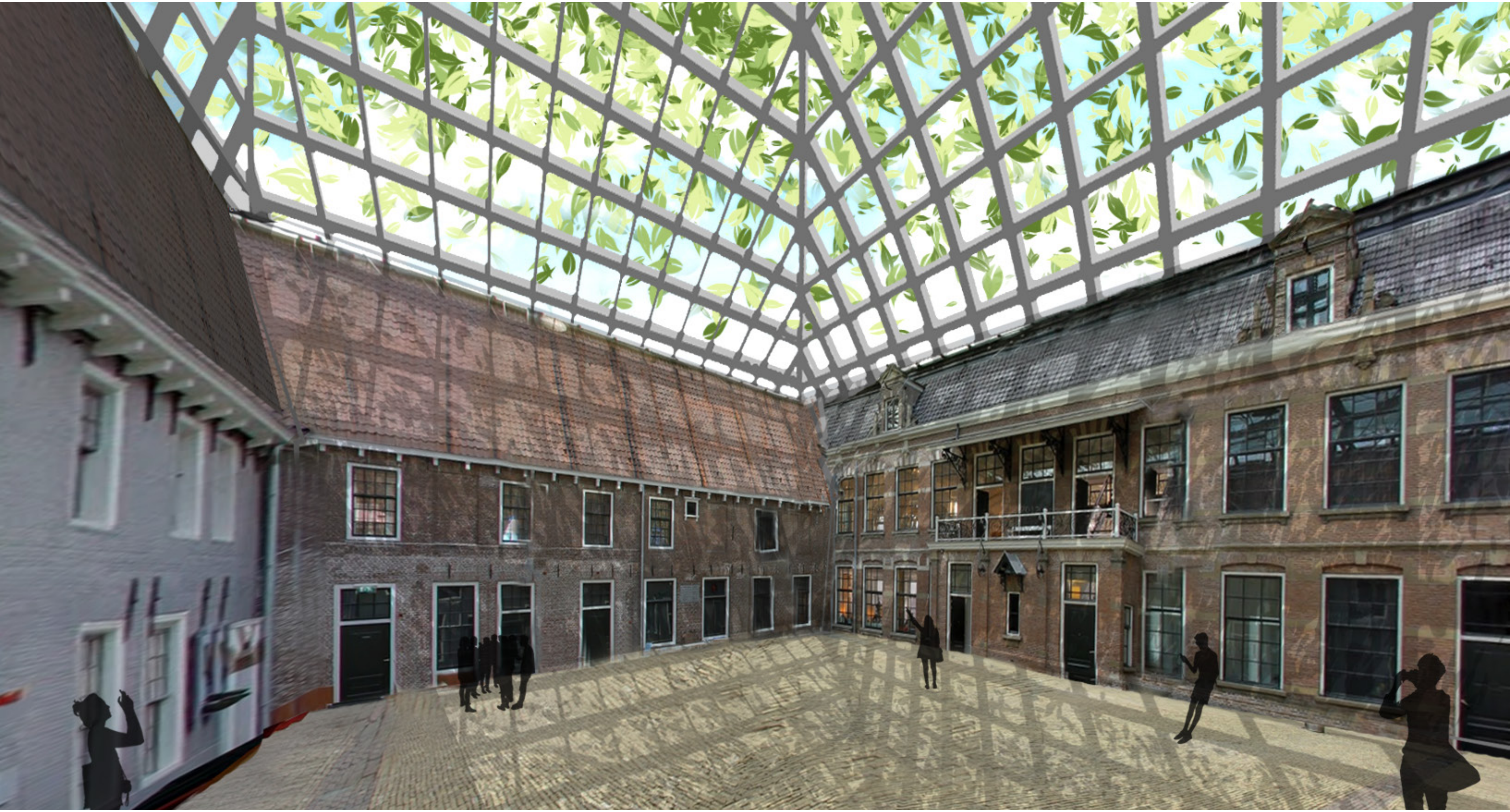
DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN





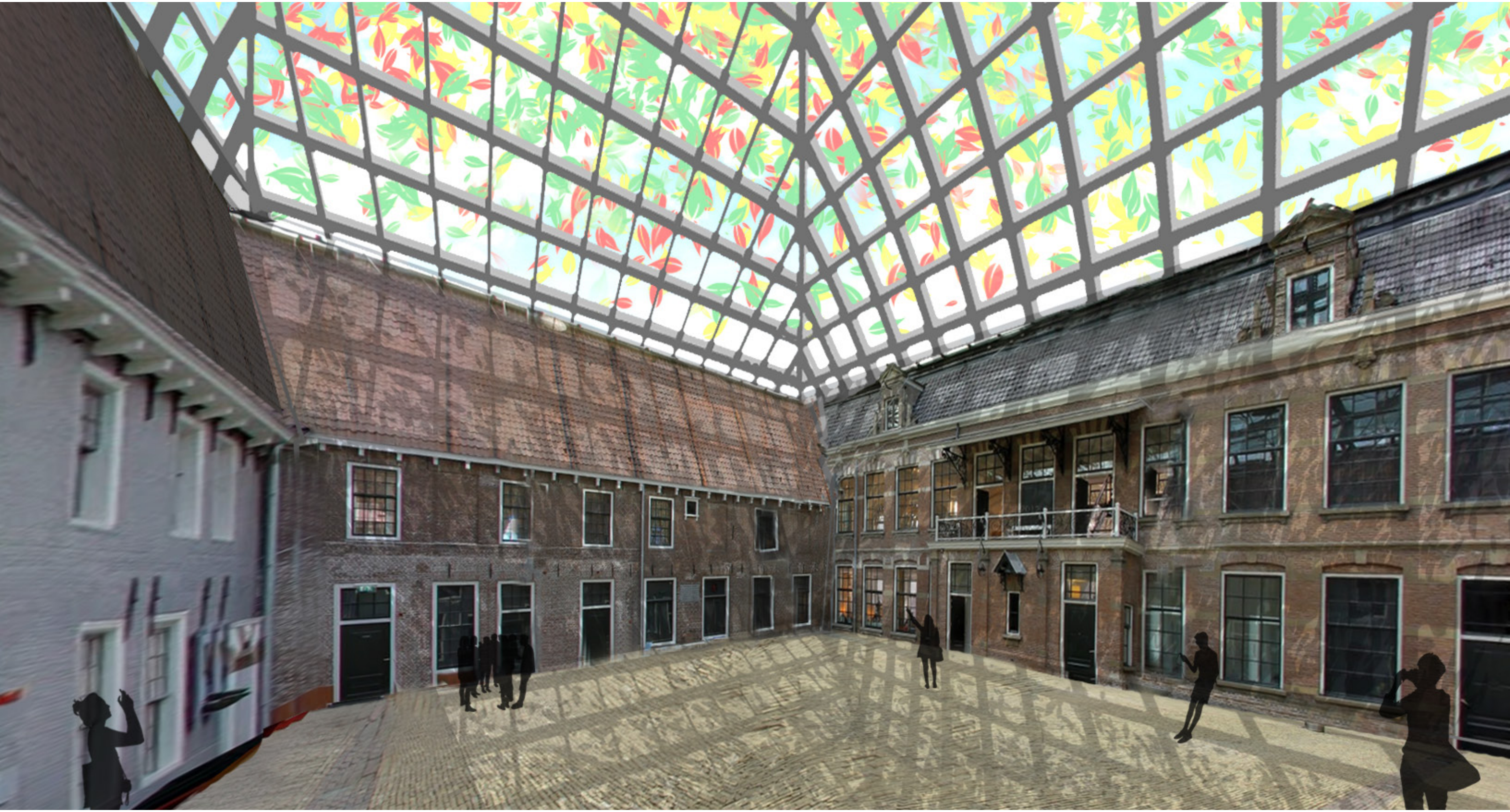
DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN

DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN



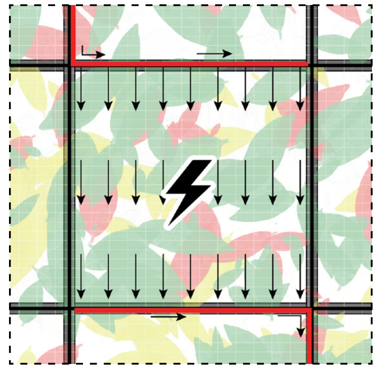
INTERNAL VIEW - ROOF PRINTED WITH DYE-SENSITIZED SOLAR CELLS

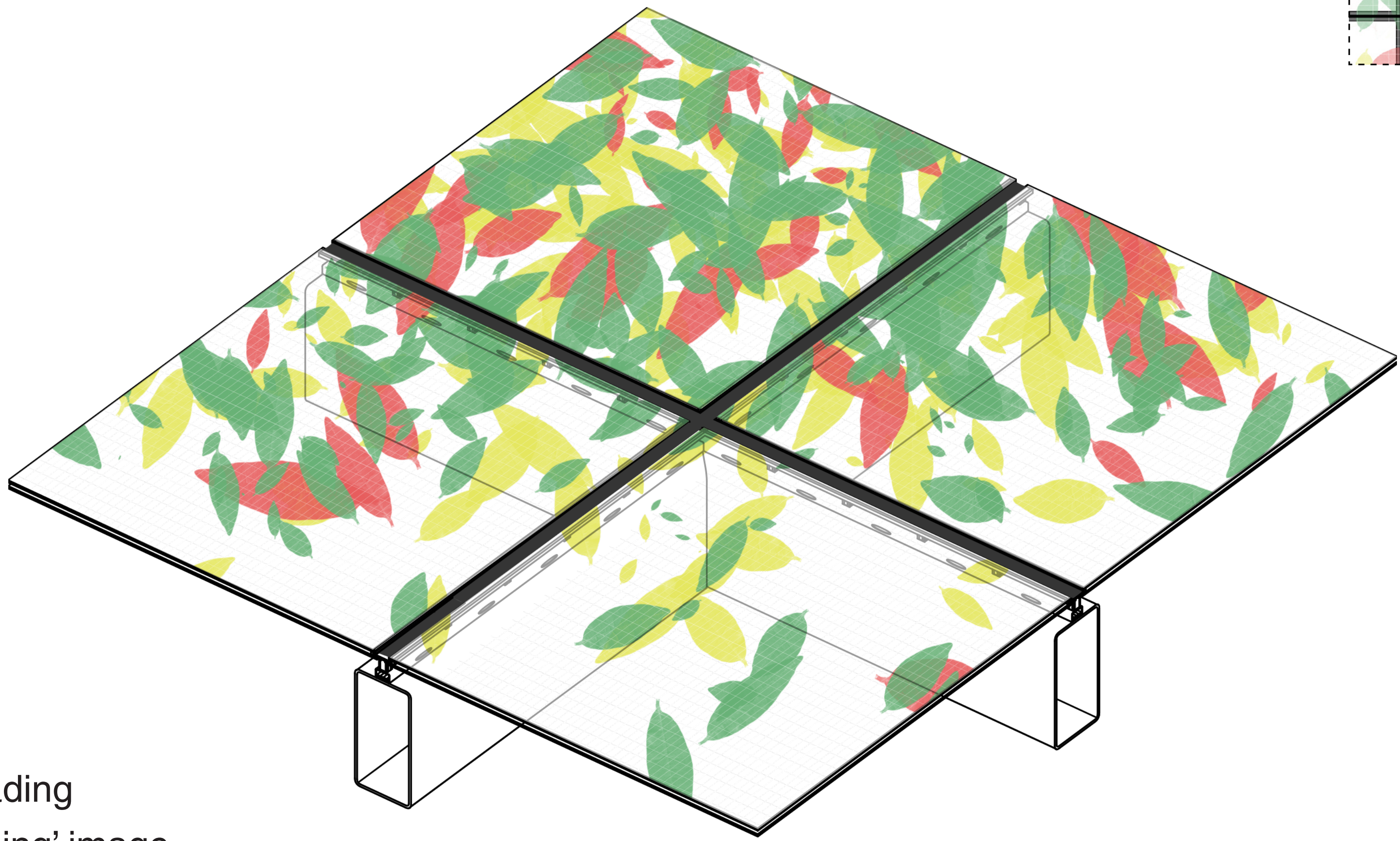
DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN



INTERNAL VIEW - ROOF PRINTED WITH DYE-SENSITIZED SOLAR CELLS

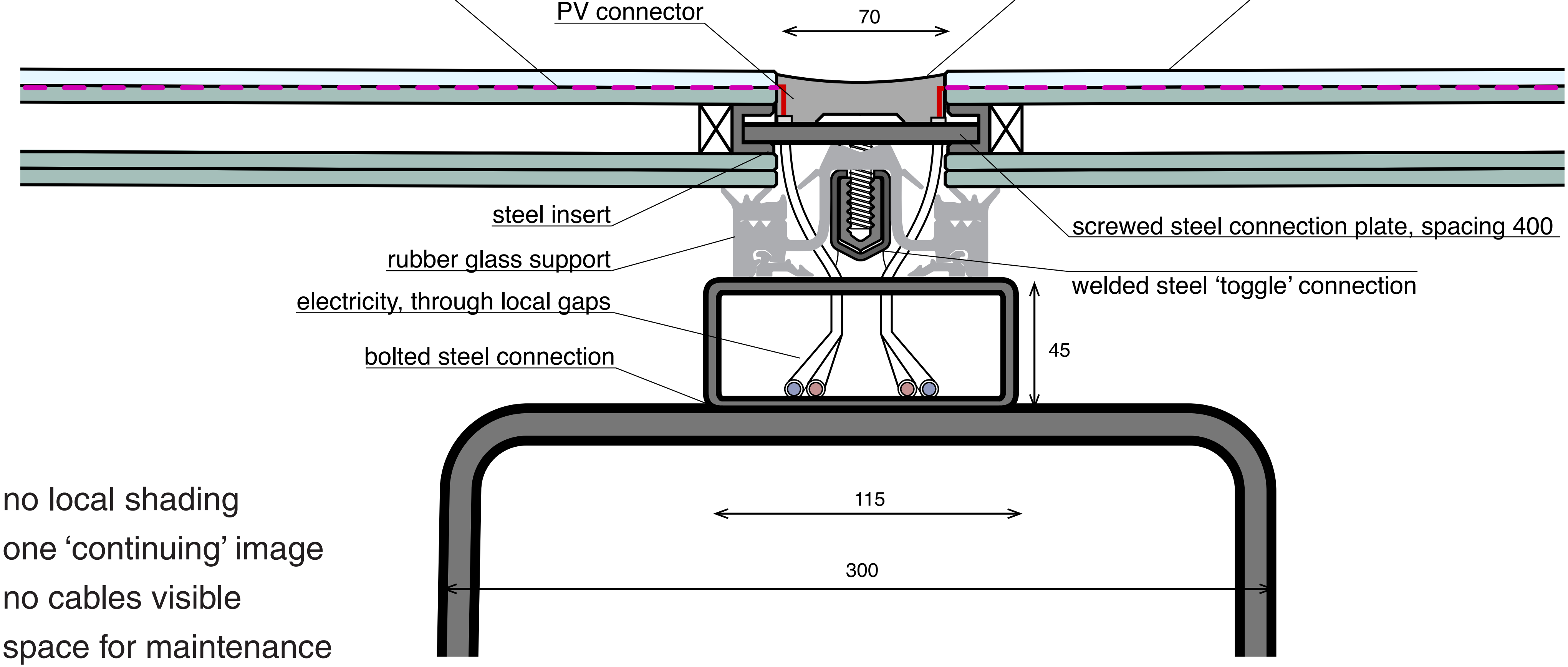
DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN



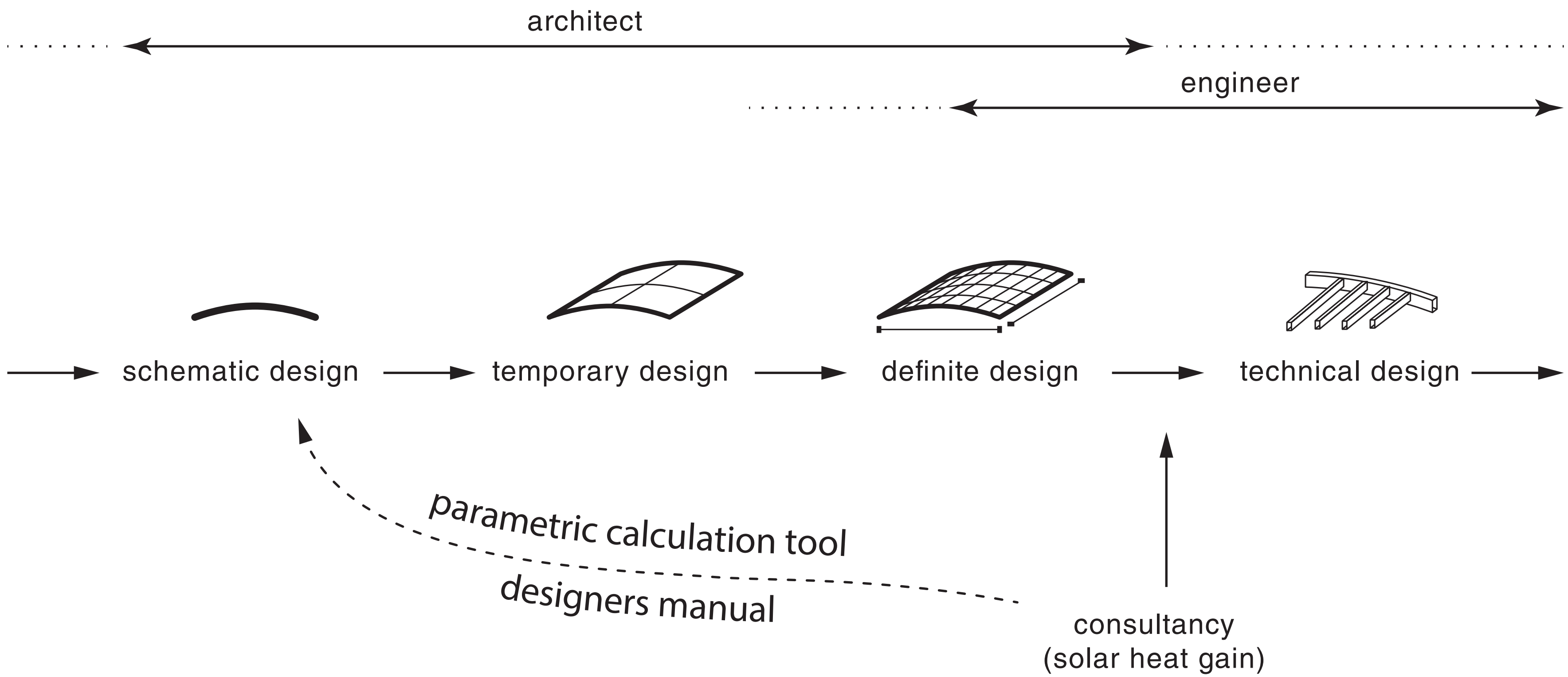


- no local shading
- one 'continuing' image
- no cables visible
- space for maintenance

DESIGN CASE 3 - NATURE MUSEUM LEEUWARDEN



- no local shading
- one 'continuing' image
- no cables visible
- space for maintenance


architect
engineer
schematic design
temporary design
definite design
technical design
parametric calculation tool
designers manual
consultancy
(solar heat gain)

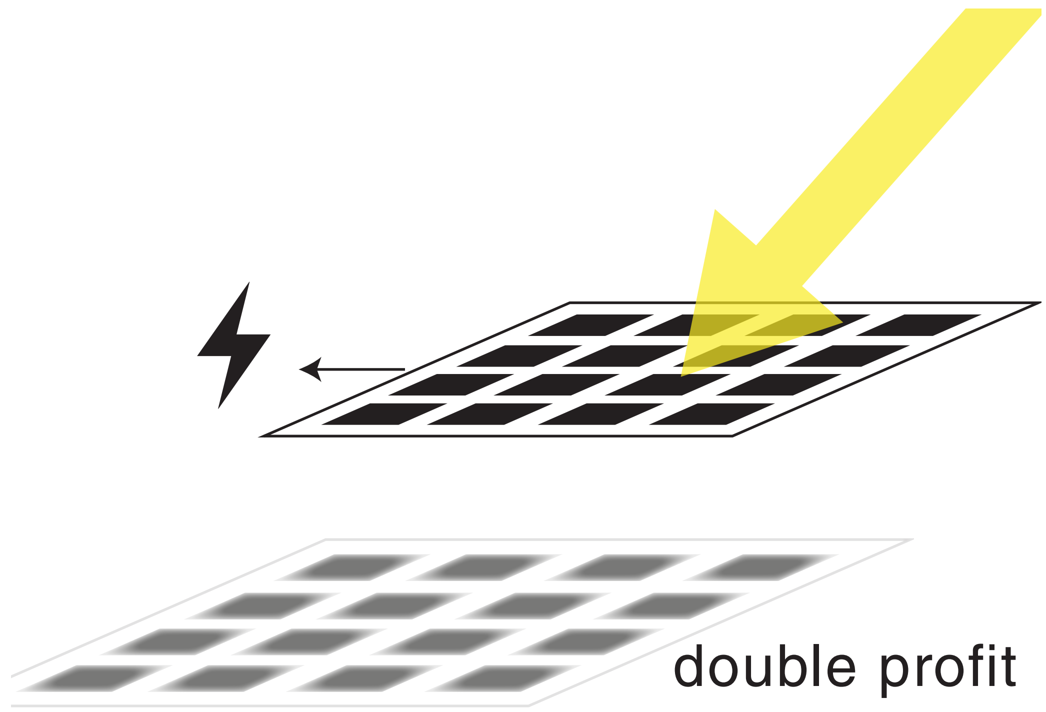
CONCLUSIONS

CONCLUSIONS

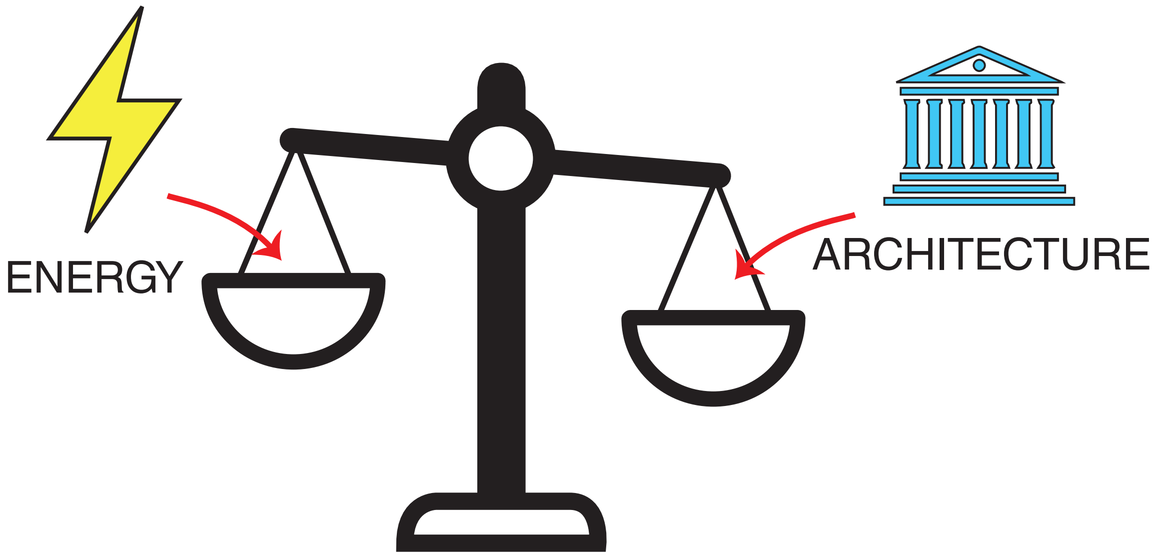
RESEARCH QUESTION

In what way, can the integration of solar cells in a transparent roof structure be applied effectively and contribute to the internal climate of a large glazed space?

- parametric model
- results
- PV technology
- design



CONCLUSIONS



BALANCE BETWEEN ENERGY EFFICIENCY AND ARCHITECTURE

THANK YOU FOR LISTENING!

...QUESTIONS?