the innovation and valorization formula

M2i Materials innovation institute

Sustainable E+ Steel-frame Industrial Halls :
advanced design support and assessment

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Duurzaam bouwen met staal :
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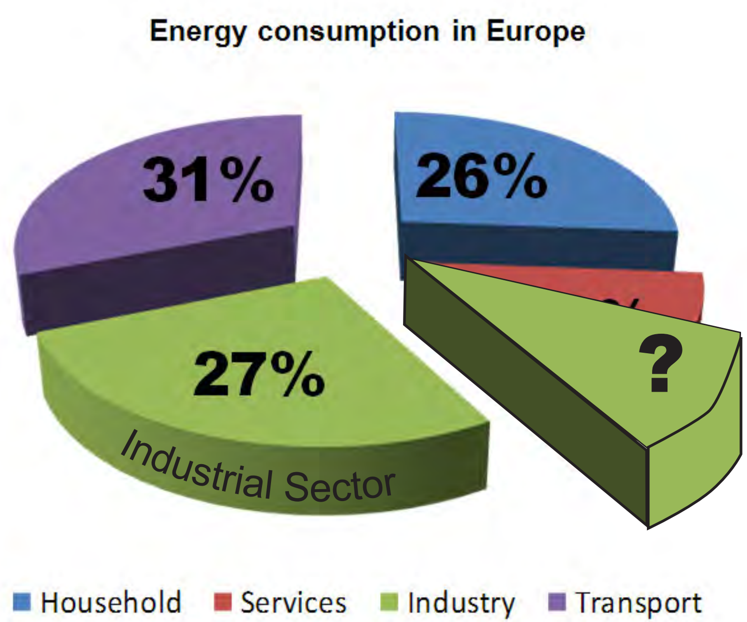
TATA STEEL
BEKAERT
bouwen met staal

Contents:

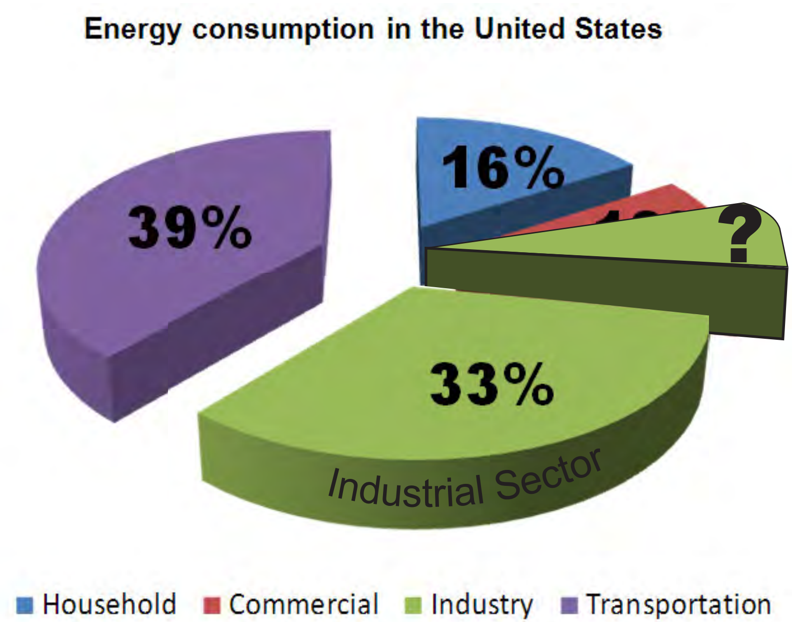
- Background
- Life-cycle Analysis
- Quick Screening Tool / Databases
- Design Trends

Tremendous amount of energy consumed by the industrial sector ...
and “Industrial Halls” are not limited to **FACTORIES**, but also :

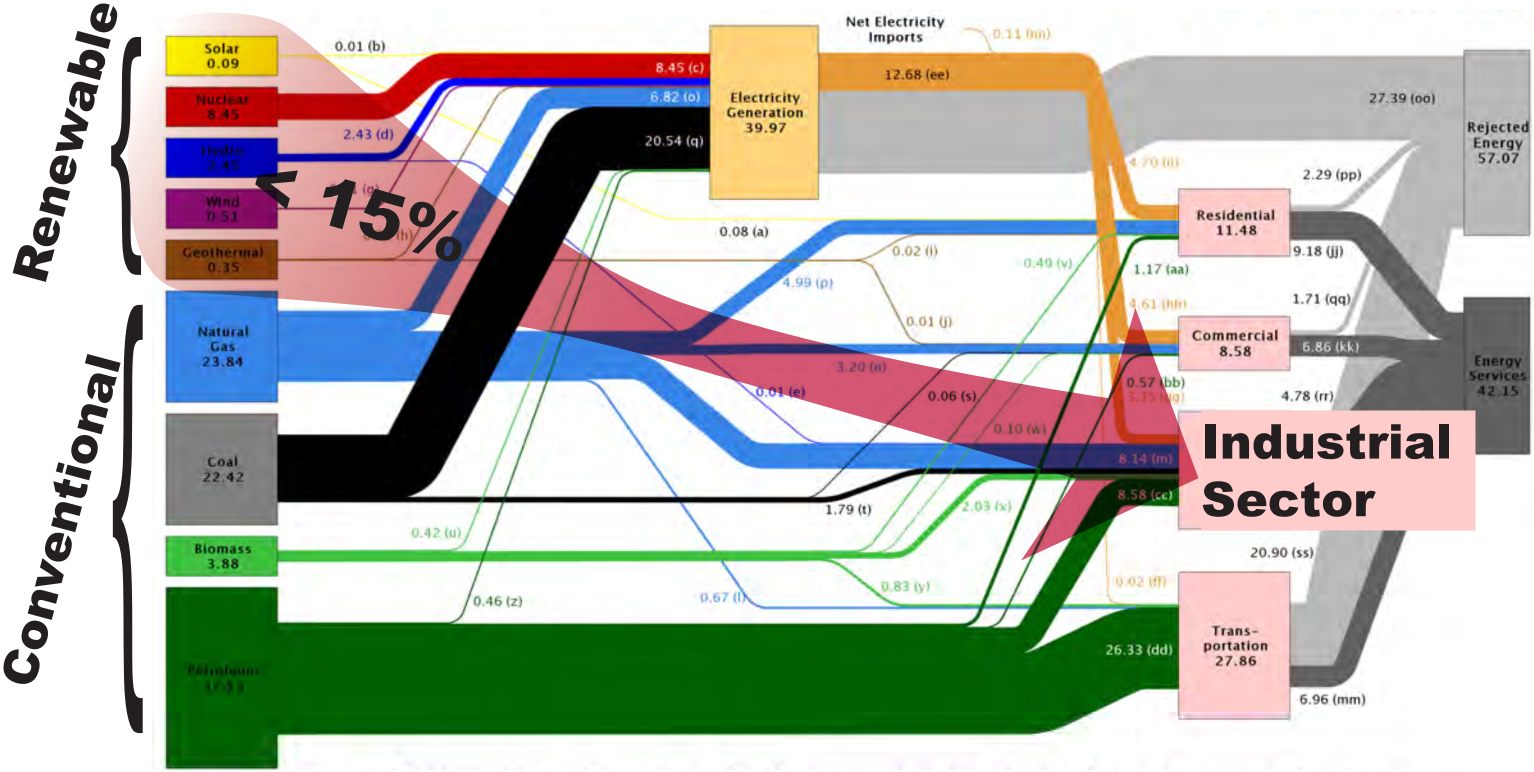
- **WAREHOUSES,**
- **BIG-BOX RETAILERS (eg. Ikea, Praxis ...),**
- **and many SUPERMARKETS.**



[source: Eurostat, 2009]



[source: LLNL, 2009]



[*source: LLNL, 2009*]

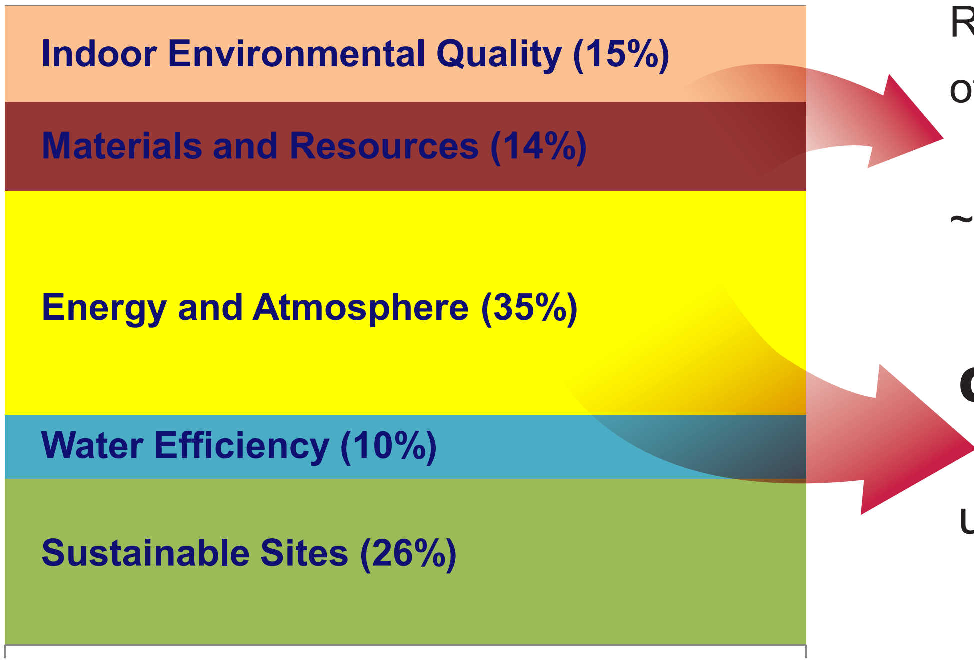
Less than 15% of the energy consumed by the industry is from

. . . Renewable Sources

High roof-to-floor ratio of typical industrial halls open up opportunities for incorporating renewable energy technologies, such as PV ....

What is Sustainability? — the many aspects

► green building rating system (eg. LEED certification ... or BREEAM)



LEED certification (distribution of points)

Recycling – Reuse – Source of Construction Materials

▼

~ **Embodied Energy**

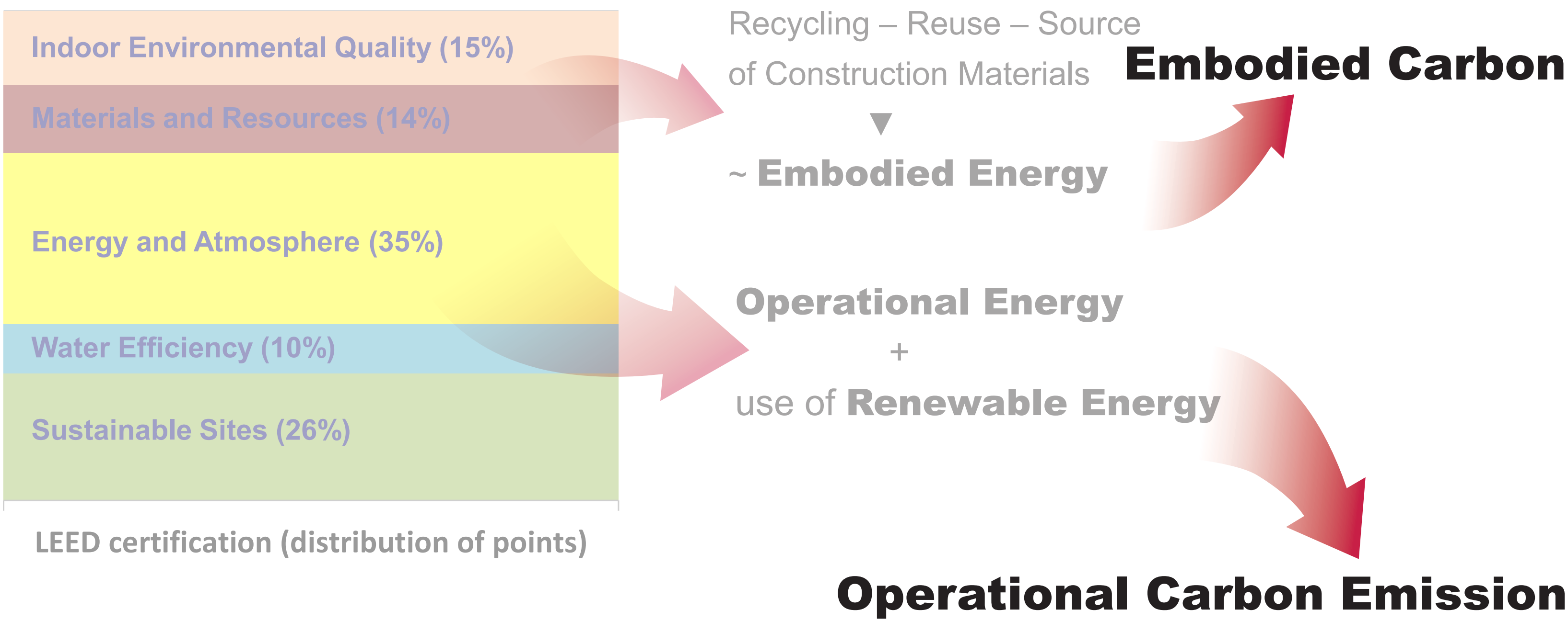
Operational Energy

+

use of **Renewable Energy**

What is Sustainability? — the many aspects

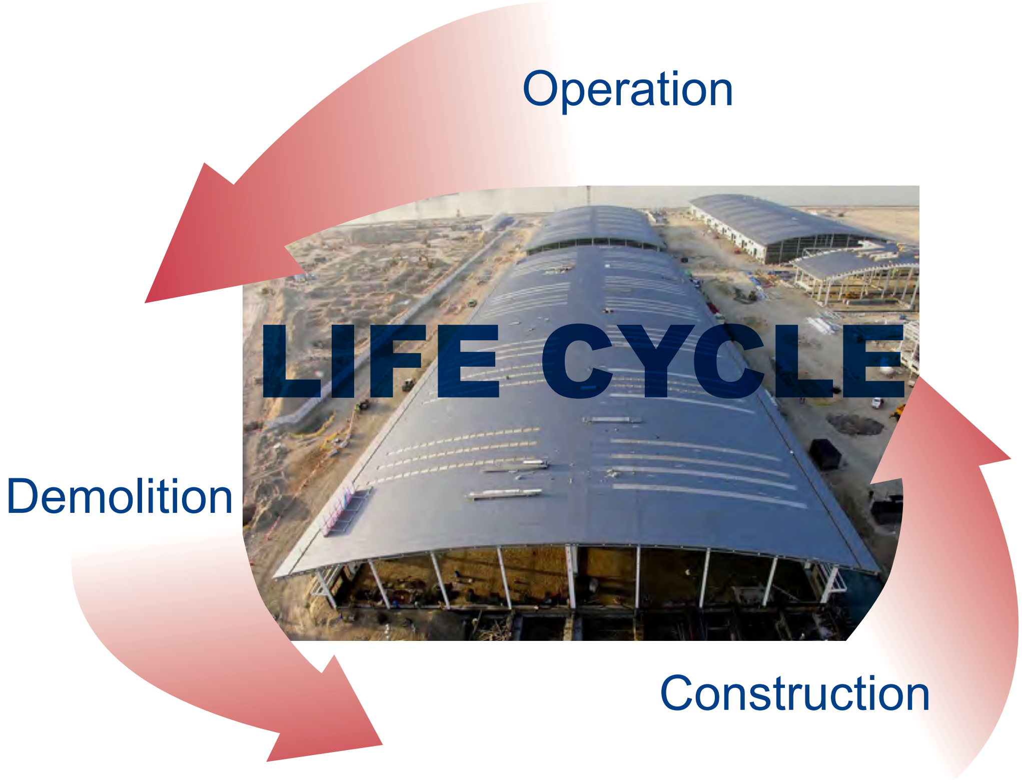
► green building rating system (eg. LEED certification ... or BREEAM)



Life-cycle Carbon Analysis

total Life-cycle Carbon Emission concept:
considers Carbon Emission during the

Construction Phase + **Operation Phase** + **Demolition Phase**



What is a typical industrial halls?

- **quite evenly distributed and relatively low process load**

Subsector and Industry	Equivalent Process Load (W/m2)	Portion of Energy consumed outside enclosure (if evenly distributed)
Furniture and Related Products	**23**	0%
Apparel	**23**	0%
Plastics and Rubber Products	**178**	8%
Fabricated Metal Products	**103**	10%
Electrical Appliances, and Components	**103**	18[illegible]
Transportation Equipment	**103**	[illegible]0%
Computer and Electronic Products	**65**	26%
Fruit and Vegetable Preserving	**239**	42%
Textile Product Mills	**92**	[illegible]2%
Foundries	**231**	6[illegible]%
Food	**212**	76%
Paper	**421**	82%
Chemicals	**574**	82%




characteristics : low process energy, labour intensive




characteristics : low-medium process energy, few workers, each oversees many lines







Industrial Halls ...

- **Chemical plants, metal foundries, paper making ...**

> 70% of energy is consumed outside the enclosure

Subsector and Industry	Equivalent Process Load (W/m2)	Portion of Energy consumed outside enclosure (if evenly distributed)
Furniture and Related Products	23	0%
Apparel	23	0%
Plastics and Rubber Products	178	8%
Fabricated Metal Products	103	10%
Electrical Appliances, and Components	103	18%
Transportation Equipment	103	20%
Computer and Electronic Products	65	26%
Fruit and Vegetable Preserving	239	42%
Textile Product Mills	92	52%
Foundries	231	69%
Food	212	76%
Paper	421	82%
Chemicals	574	82%




characteristics : low process energy, labour intensive




characteristics : low-medium process energy, few workers, each oversees many lines






- **halls with higher process load (>300 W/m²):**

— processes are located outside the building enclosures

Industrial Halls ...

from manufacturing to retail, **Typical Hall** is a structure of:

- rectangular geometry, simple construction, with negligible amount of openings
- single floor of non-partitioned space (~ 4,000 m^2 on average)
- features such as daylighting, and PV could be readily deployed

100m x 40m x 6m

Multidisciplinary Approach

Demand side : energy demand — heat gain, building construction (insulation, airtightness, daylighting ... etc) geometry, climate

- **through Lowering Energy Demand**

Supply side : energy consumption — building services equipment, in particular, HVAC

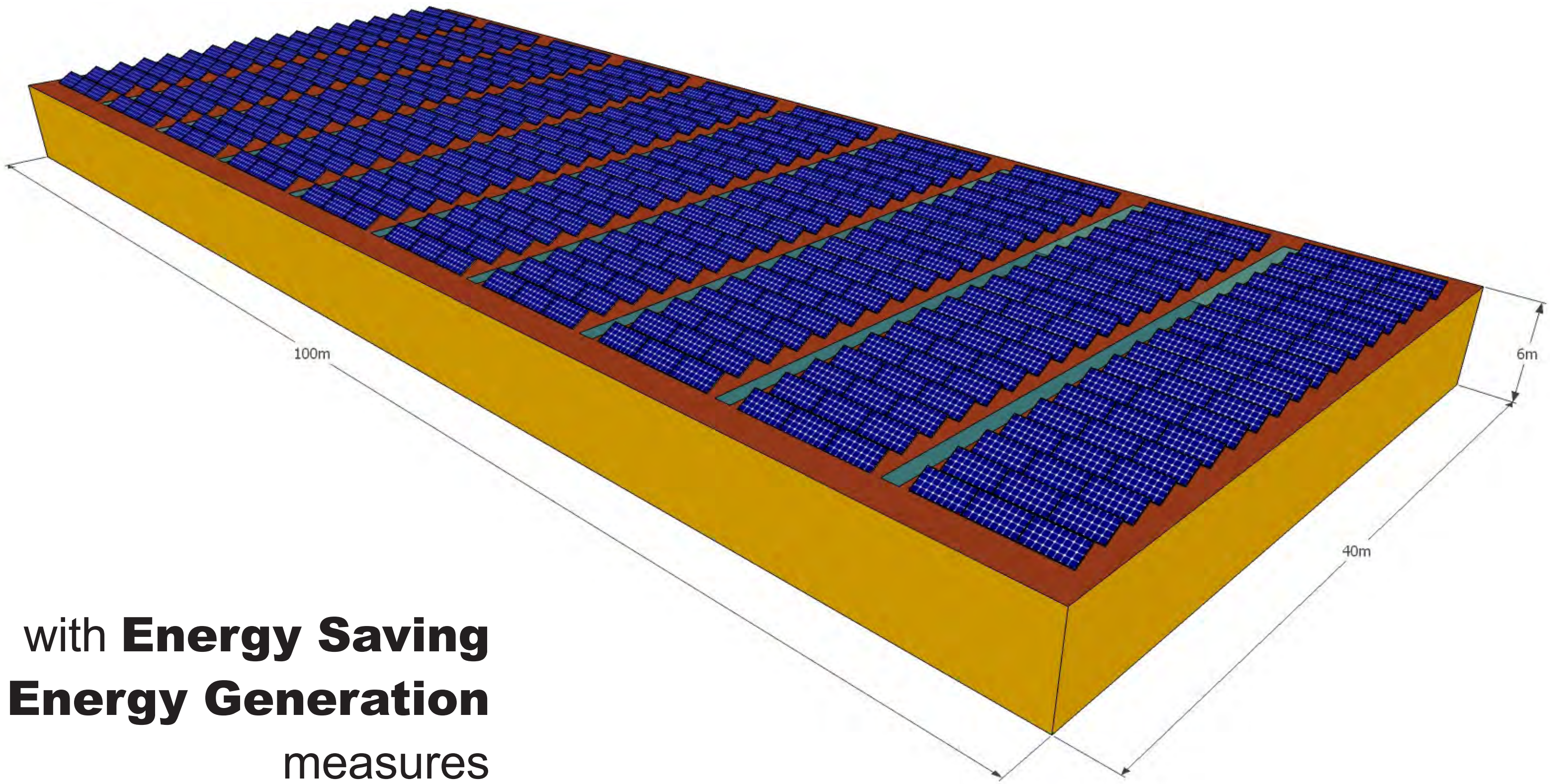
- **through Efficient Delivery of Heating and Cooling**

Generation side: electricity and thermal — PV, solar collector ... etc

- **together with Generation Technologies**

Energy Producing Halls

"Typical" Energy Producing Industrial Halls ...



with **Energy Saving**
and **Energy Generation**
measures

Aspects of the simulation models :

(based on the characteristics of industrial halls)

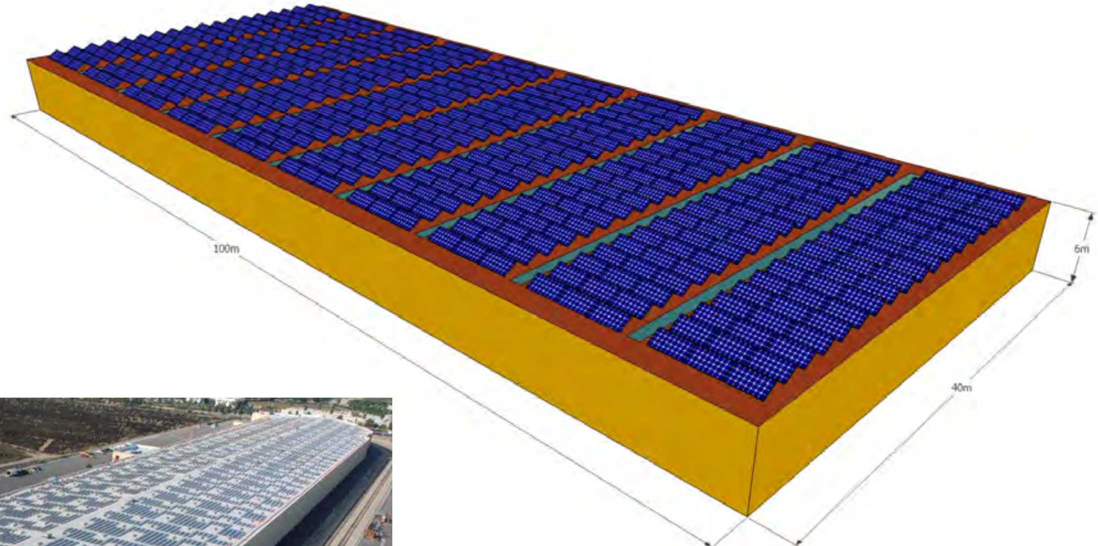
- **Single Zone** of non-partitioned space of uniformly distributed process load.
  Investigation of single zone verse multi-zone model

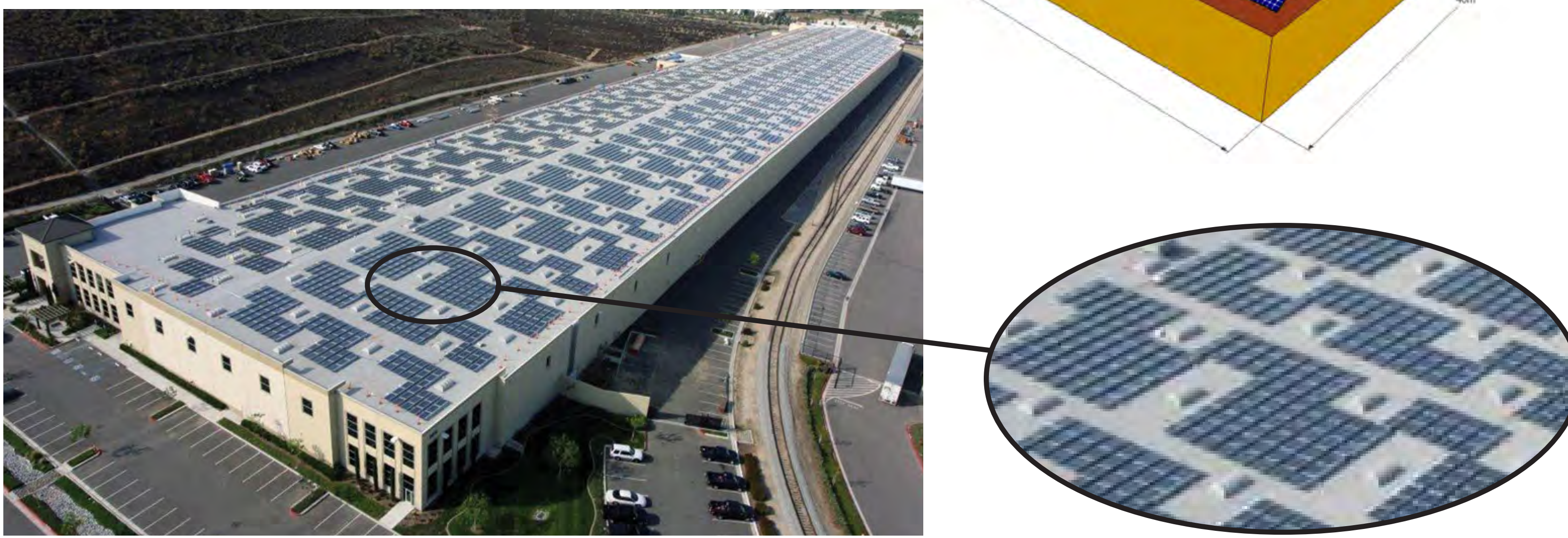
- **Loose thermal comfort requirement** wide temperature setpoint range from 18°C to 30°C, no specific requirement in temperature fluctuation. **Comparison between unconditioned, loose thermal comfort, and comfort oriented halls**

- **Generalized scenarios** industry dependent process load, discrete occupancy patterns.
  Future research : case specific scenario that involves varying occupancy pattern

- **Quantitative Approach** that investigates the performance due to varying the "quantity" rather than the "quality" of the element.

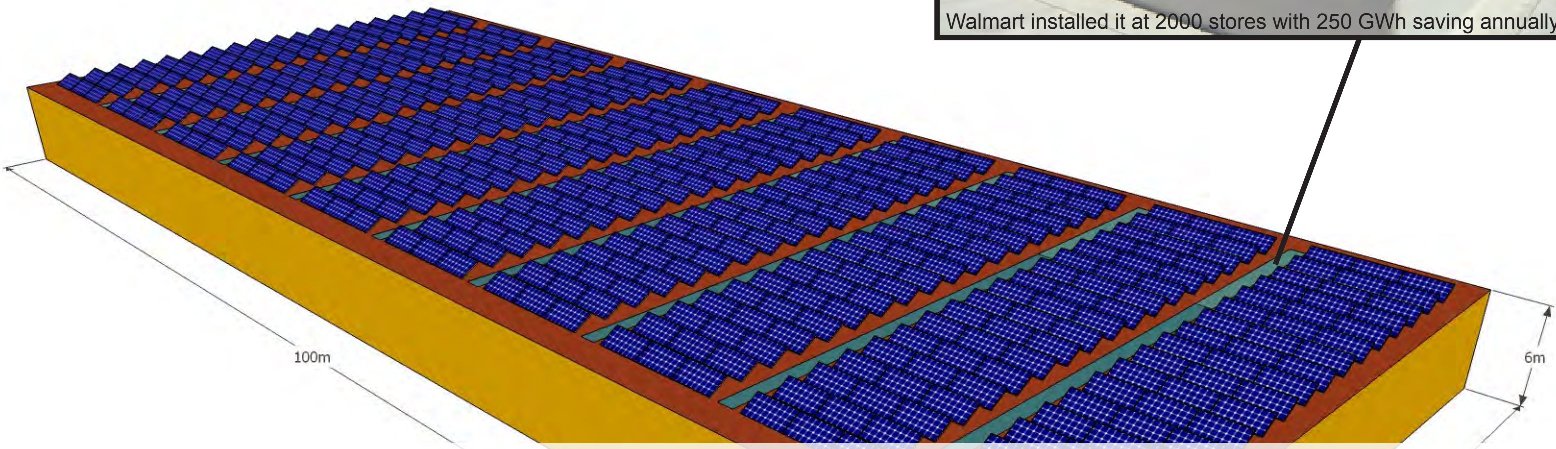
Investigation is about the **Quantity**





Real life issues :

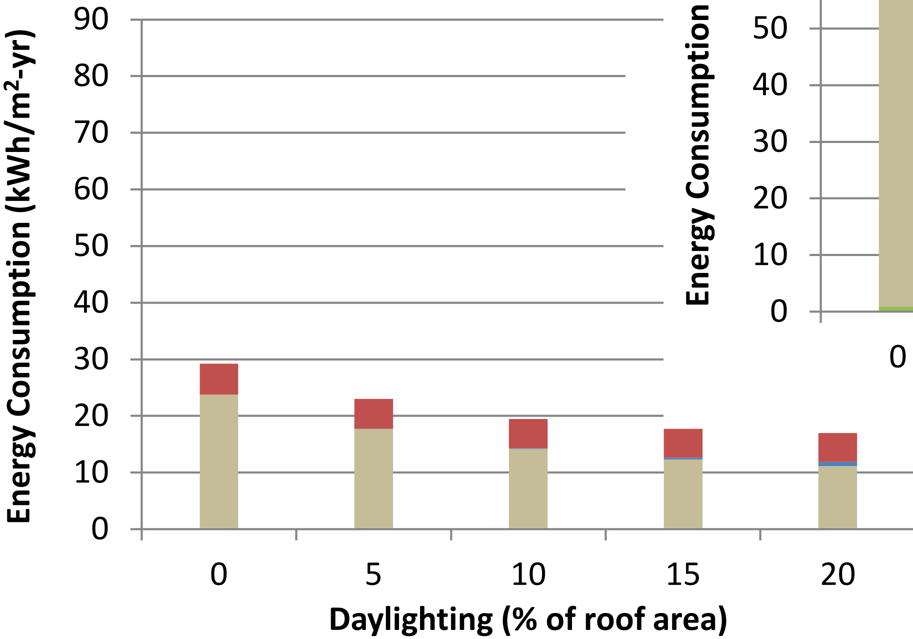

Walmart installed it at 2000 stores with 250 GWh saving annually

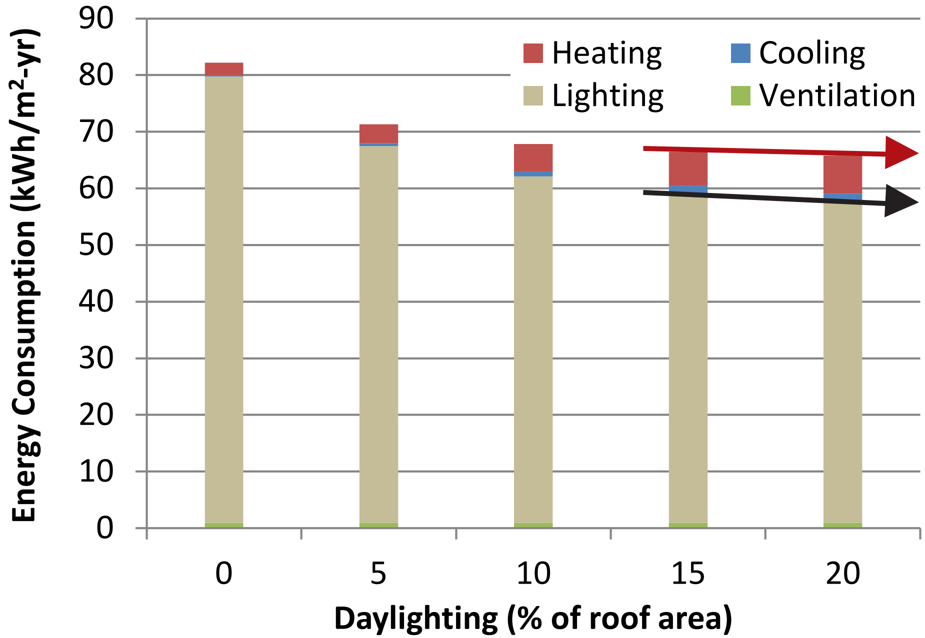


- **Skylight** ► many different cost-effective ways to implement skylight. For modelling purposes, just simple long strip of diffused double-glazing that could **distribute light evenly** on work surface. Only parameter is the **amount of skylight.**

Real life issues :

5W/m2; 1-shift and full-time



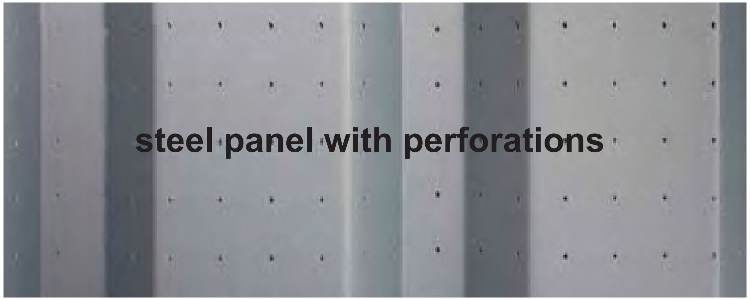


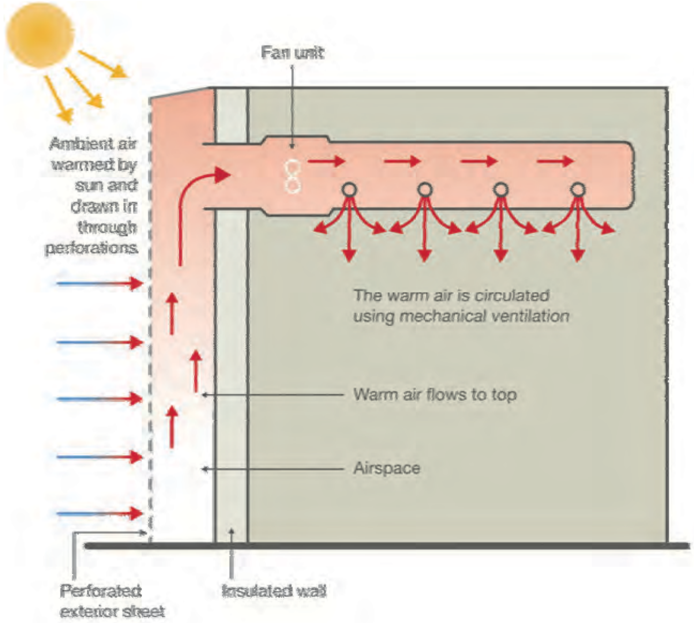
- **Multi-domains** ► for daylighting > 15% of roof area; saving in energy for lighting is roughly canceled out by heat gain or heat loss through skylight
- ASHRAE Standard 90.1 (2007) Perscriptive Building Envelope Option: skylight area < 5% gross roof area.

Real life technologies for heating/cooling

► Forced Ventilation for cooling

► **Transpired Solar Collectors (TSC)** for heating

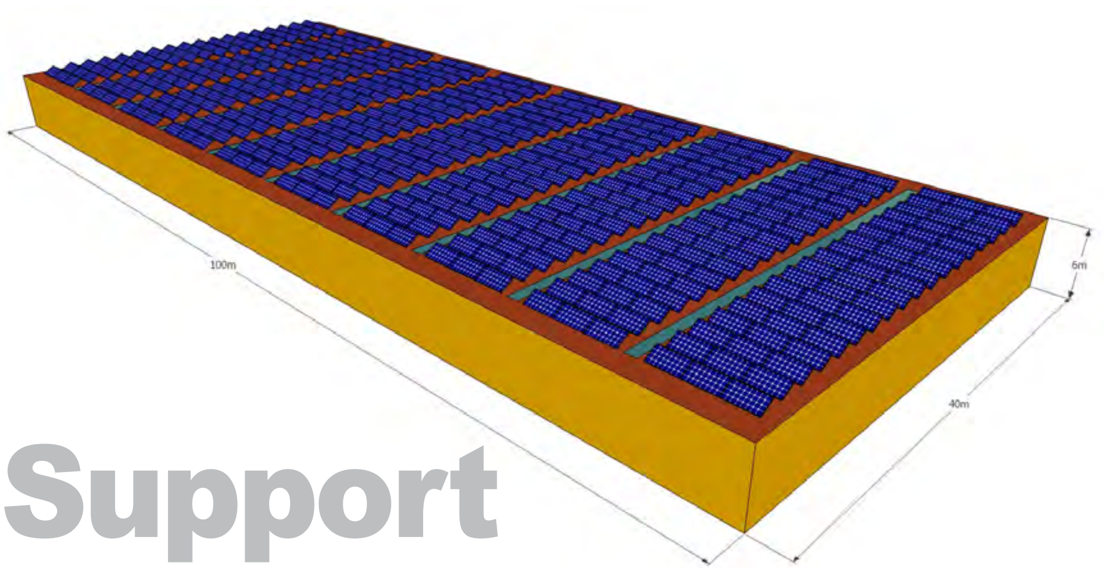




► modeled in TRNSYS based on empirical relationship (of Tata Steel's product):

- solar radiation (W/m^2) on the surface
- flow rate (m^3/s) in the air gap per m^2 of the surface
- color / reflectance of the surface
- temperature of the heated air

Investigation is about the **Quantity**



Decision Support

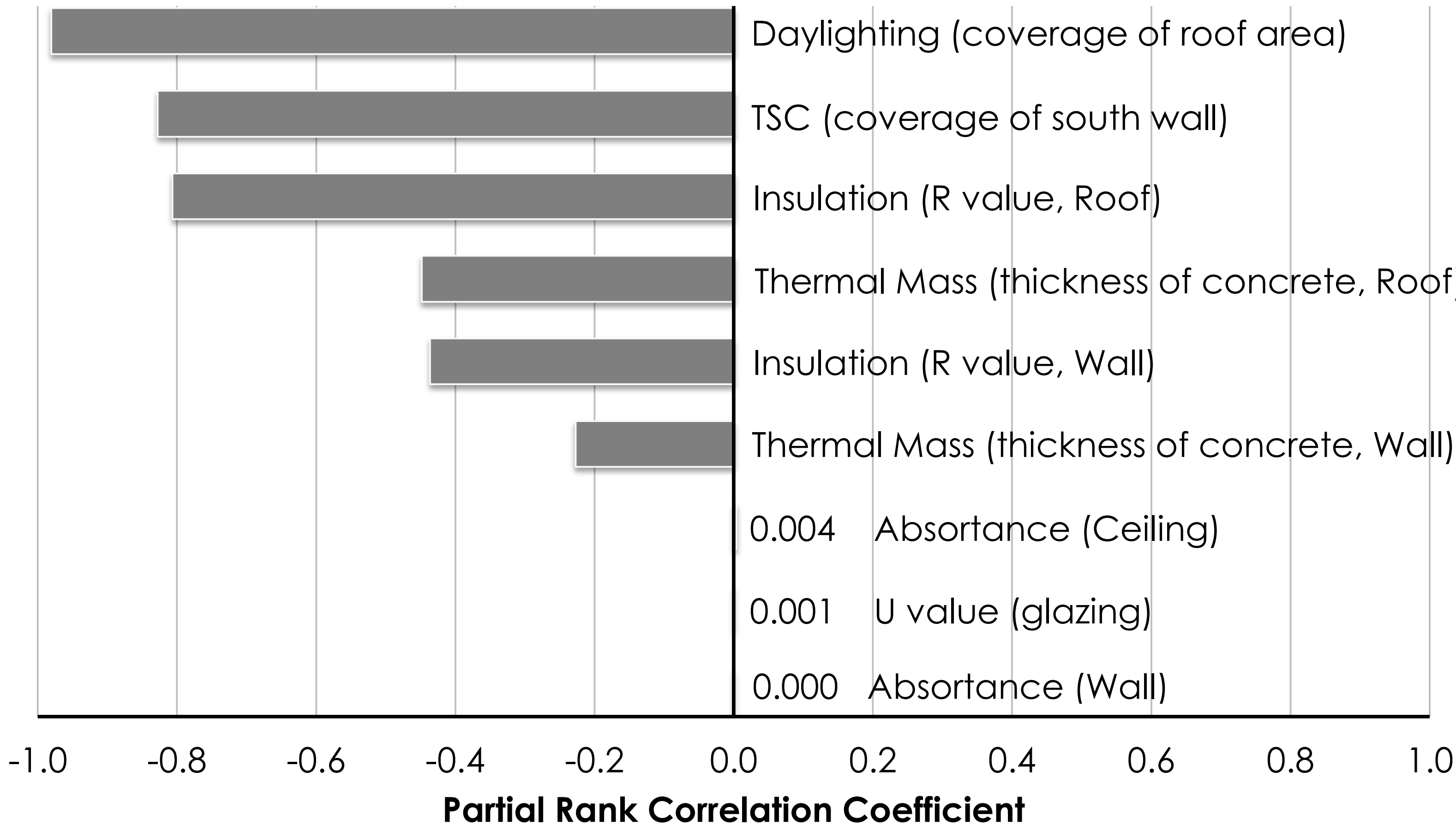
What shall be the optimal(?) amount of insulation?

How large the roof area shall be covered by skylight?

Which parameters are most influential?

Quick Screening Tool

Sensitivity Analysis : most influential parameters



Parameters and Scenarios (finally):

(that define configurations to be studied)

- **Climates** (mild - Amsterdam; cold - Shenyang, China; hot - Chennai, India)
- **Process Energy** (5, 25, 50, 125, 300 W/m^2)
- **Occupancy** (1, 2, 3 shifts)
- **Insulation – roof** (1.5 to 4.5 R_{SI}, in 7 levels)
- **Insulation – wall** (1.5 to 4.5 R_{SI}, in 7 levels)
- **Thermal mass – roof** (none or 200 mm of concrete)
- **Thermal mass – wall** (none or 200 mm of concrete)
- **Skylight area** (daylighting, 0 to 15% of roof area, in 4 levels)
- **TSC** (heating, transpired solar collector, 0 to 100% of south wall, in 6 levels)
- **PV** (length of panel, 0.4-1.6m, in 4 levels; tilt angle, 0-56°, in 29 levels; number of rows, max. 40 rows in 40 levels)

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▶ define Scenarios
15 (3 climates x 5 processes) **scenarios**
+ retail space
+ unconditioned space

▶ define Configurations
= 4704 configurations per occupancy schedule

▶ energy generation investigated separately

Comprehensive Design Space Evaluation

thousands of simulations ▶ **database**

- ▶ **Occupancy** (1, 2, 3 shifts)
- ▶ **Insulation – roof** (1.5 to 4.5 R_{SI}, in 7 levels)
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▶ define <u>Configurations</u>
= 4704 configurations
per occupancy schedule

Database of Energy Consumption :

ID	Schedule	Ins_Roof (R_{SI})	Ins_Wall (R_{SI})	Mass_Roof (m	Mass_Wall (m	Daylighting (% co	TSC (% coverage)
0	1	1.5	1.5	0.0	0.0	0	0
1	1	1.5	1.5	0.0	0.0	0	
2	1	1.5	1.5	0.0	0.0	0	
3	1	1.5	1.5	0.0	0.0	0	
4	1	1.5	1.5	0.0	0.0	0	
5	1	1.5	1.5	0.0	0.0	0	
6	1	1.5	1.5	0.0	0.0	5	
7	1	1.5	1.5	0.0	0.0	5	
8	1	1.5	1.5	0.0	0.0	5	
9	1	1.5	1.5	0.0	0.0	5	
10	1	1.5	1.5	0.0	0.0	5	
11	1	1.5	1.5	0.0	0.0	5	
12	1	1.5	1.5	0.0	0.0	10	
13	1	1.5	1.5	0.0	0.0	10	
14	1	1.5	1.5	0.0	0.0	10	
15	1	1.5	1.5	0.0	0.0	10	
16	1	1.5	1.5	0.0	0.0	10	
17	1	1.5	1.5	0.0	0.0	10	
18	1	1.5	1.5	0.0	0.0	15	
19	1	1.5	1.5	0.0	0.0	15	
20	1	1.5	1.5	0.0	0.0	15	
21	1	1.5	1.5	0.0	0.0	15	
22	1	1.5	1.5	0.0	0.0	15	
23	1	1.5	1.5	0.0	0.0	15	
24	1	1.5	1.5	0.0	0.2	0	
25	1		1.5	0.0	0.2	0	
26	1			0.0	0.2	0	
27				0.0		0	
						0	

in 7 levels)

n 7 levels)

mm of concrete)

mm of concrete)

5% of roof area, in 4 levels)

ector, 0 to 100% of south wall, in 6 levels)

▶ **define <u>Configurations</u>**
= 4704 configurations
per occupancy schedule

Performance indicators :

erage)	Total Energy Consumption (kWh/m²-yr)	Net CO_2 Emission (kg CO_2/m²-yr)	Annualized Relative Cash Flow (wrt. Baseline, €/m²)
0	32.3	12.1	0.86
20	31.4	12.6	-6.82
40	30.3	13.2	-14.49
60	29.7	13.8	-22.18
80	29.2	14.5	-29.87
100	29.0	15.2	-37.57
0	25.7	9.5	1.01
20	25.0	10.1	-6.68
40	24.1	10.7	-14.35
60	23.5	11.4	-22.04
80	23.2	12.0	-29.74
100	22.9	12.7	-37.44
0	22.0	8.1	0.84
20	21.4	8.8	-6.85
40	20.6	9.4	-14.53
60	20.1	10.0	-22.22
80	19.7	10.7	-29.92
100	19.5	11.4	-37.62
0	19.9	7.4	0.47
20	19.4	8.1	-7.22
40	18.7	8.7	-14.91
60	18.3	9.4	-22.60
80	18.0	10.1	-30.30
100	17.7		-38.00
0	[illegible]		0.74
20			

- ▶ **Total Energy Consumption (operational)**
- ▶ **Net CO_2 Emission (operational + embodied)**
- ▶ **Annualized Relative Cash Flow (Operational + Investment)**

Database(s) :

▶ **six** input parameters :

- Insulation – roof (1.5 to 4.5 R_{SI}, in 7 levels)
- Insulation – wall (1.5 to 4.5 R_{SI}, in 7 levels)
- Thermal mass – roof (none or 200 mm of concrete)
- Thermal mass – wall (none or 200 mm of concrete)
- Skylight area (0 to 15% of roof area, in 4 levels)
- TSC (transpired solar collector, 0 to 100% of south wall, in 6 levels)

▶ **three** performance indicators :

- Energy Consumption
- Net CO_2 Emission
- Annualized Relative Cash Flow

Total Energy Consumption (kWh/m^2-yr)	Net CO_2 Emission (kg CO_2/m^2-yr)	Annualized Relative Cash Flow (wrt. Baseline, €/m^2)
32.3	12.1	0.86
31.4	12.6	-6.82
30.3	13.2	-14.49
29.7	13.8	-22.18
29.2	14.5	-29.87
29.0	15.2	-37.57
25.7	9.5	1.01
25.0	10.1	-6.68
24.1	10.7	-14.35

Ins_Roof (R_{SI})	Ins_Wall (R_{SI})	Mass_Roof (m	Mass_Wall (m	Daylighting (% co	TSC (% coverage)
1.5	1.5	0.0	0.0	0	0
1.5	1.5	0.0	0.0	0	20
1.5	1.5	0.0	0.0	0	40
1.5	1.5	0.0	0.0	0	60
1.5	1.5	0.0	0.0	0	80
1.5	1.5	0.0	0.0	0	100

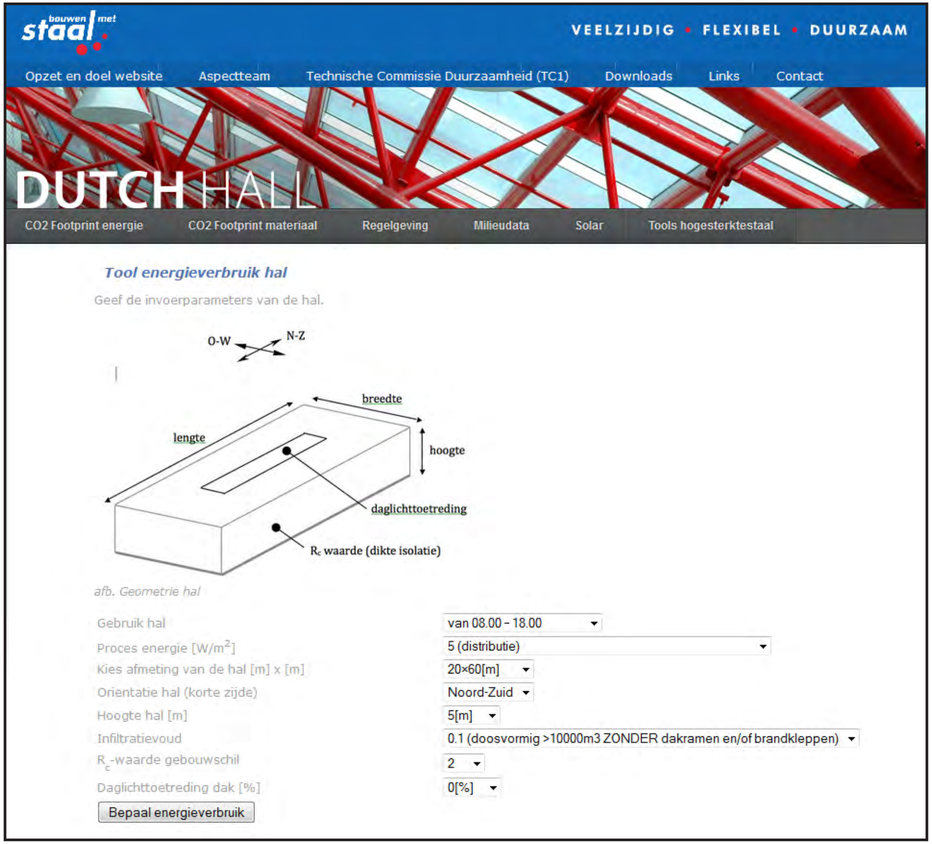
Schedule	Ins_Roof (R_{SI})	Ins_Wall (R_{SI})	Mass_Roof (m	Mass_Wall (m	Daylighting (% co	TSC (% coverage)	Total Energy Consumption (kWh/m^2-yr)	Net CO_2 Emission (kg CO_2/m^2-yr)	Annualized Relative Cash Flow (wrt. Baseline, €/m^2)	Expected Risk (€/m^2)	Pareto_Solutions
1	1.5	1.5	0.0	0.0	0	0	32.3	12.1	0.86	-0.10	-
1	1.5	1.5	0.0	0.0	0	20	31.4	12.6	-6.82	-0.09	-
1	1.5	1.5	0.0	0.0	0	40	30.3	13.2	-14.49	-0.09	-
1	1.5	1.5	0.0	0.0	0	60	29.7	13.8	-22.18	-0.08	-
1	1.5	1.5	0.0	0.0	0	80	29.2	14.5	-29.87	-0.07	-
1	1.5	1.5	0.0	0.0	0	100	29.0	15.2	-37.57	-0.06	-
1	1.5	1.5	0.0	0.0	5	0	25.7	9.5	1.01	-0.04	P+
1	1.5	1.5	0.0	0.0	5	20	25.0	10.1	-6.68	-0.03	P
1	1.5	1.5	0.0	0.0	5	40	24.1	10.7	-14.35	-0.02	P

Economic and other assumptions	
Discount Rate (%)	4.59%
Life Cycle of Building (yr)	50
Cost of Electricity (€/kWh)	0.118
Cost of Gas (€/kWh)	0.040
CO_2 Emission of Electricity Generation (kg CO_2/kWh)	0.415
CO_2 Emission of Gas Consumption (kg CO_2/kWh)	0.202

Material Costs (€)

Webtool

- valorization : the database was turned into a webtool by Bouwen met Staal, and will be updated soon



Invoer
Gebruik= 08.00-18.00
Procesenergie= 5 [W/m^2]
Infiltratievoud= 0.1
R_c-waarde= 2.0 [m^{2}K/W]
Daglichtopening= 0 [%]
Hoogte hal= 5 [m]

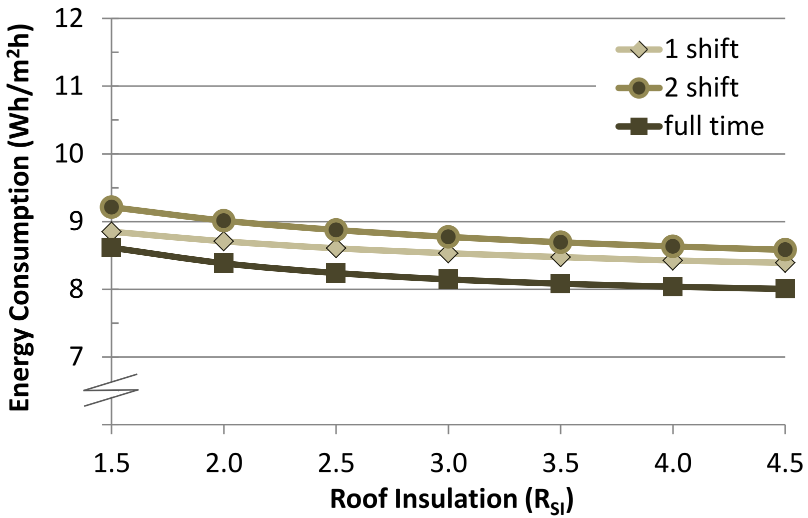
Orientatie Noord-Zuid (W= 20 [m], D= 60 [m])

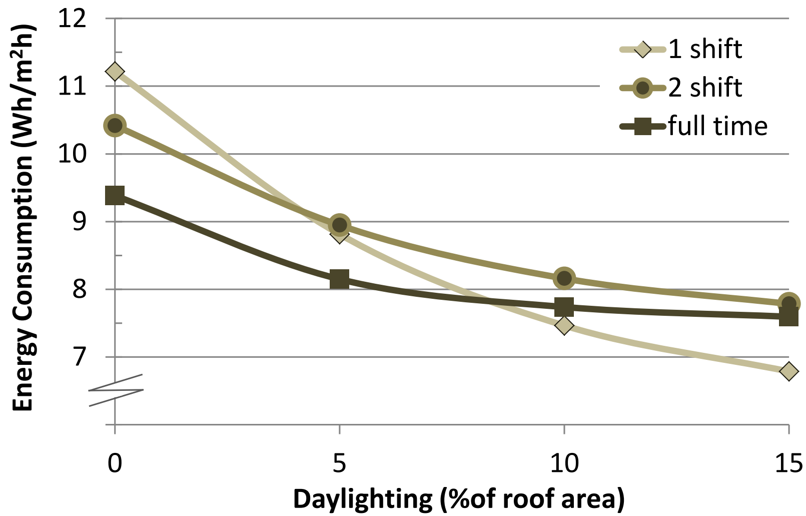
Vast amount of data – Data Analysis :

to observe Design Trends (examples shown — warehouse 5W/m² process)

- ► Data Analysis for each scenario (process load)
- ► Design Trend for each Design Parameter
- ► unit in per operating hour to facilitate comparison among schedules (also to facilitate business decision, e.g. hourly wages, hourly production rate)

Total (Heating, Cooling, Ventilation, Lighting) **Energy Consumption Per Occupied Hour**





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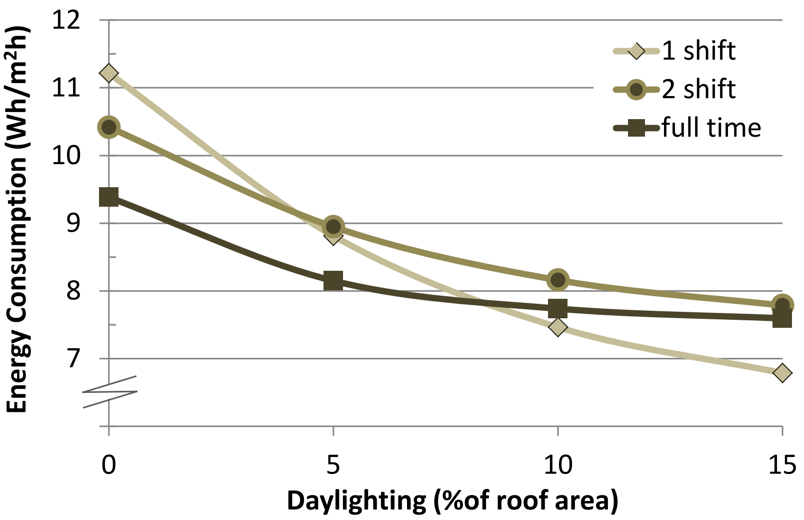
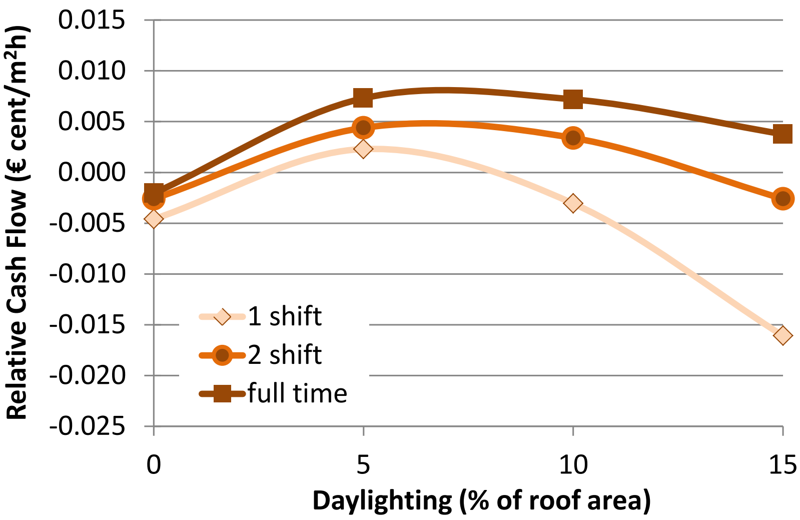
Cost Related Trends :

multi-objective consideration

► Trends depend on performance indicators

► Per occupied hour rate — capital investment (for energy saving measures) is more worthwhile if the facility is occupied for more shifts to spread out the cost

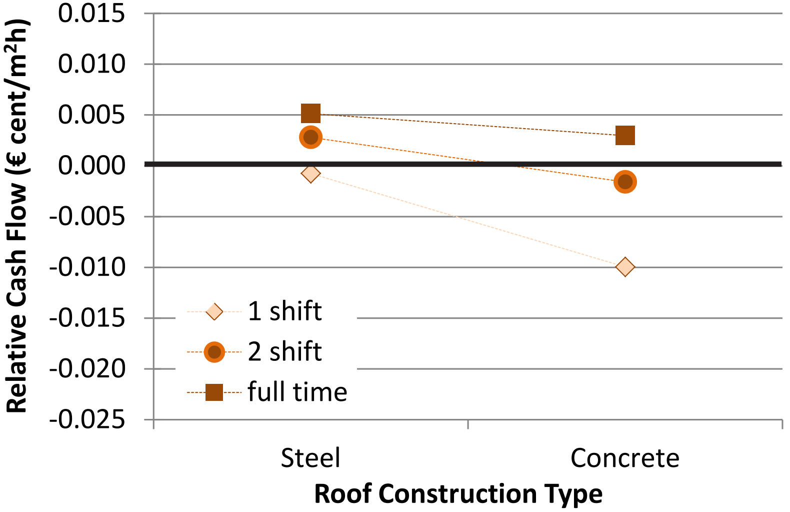


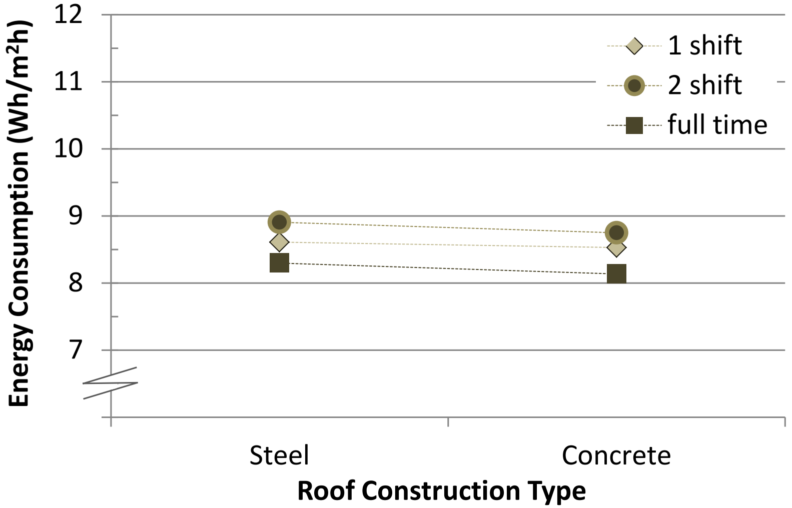


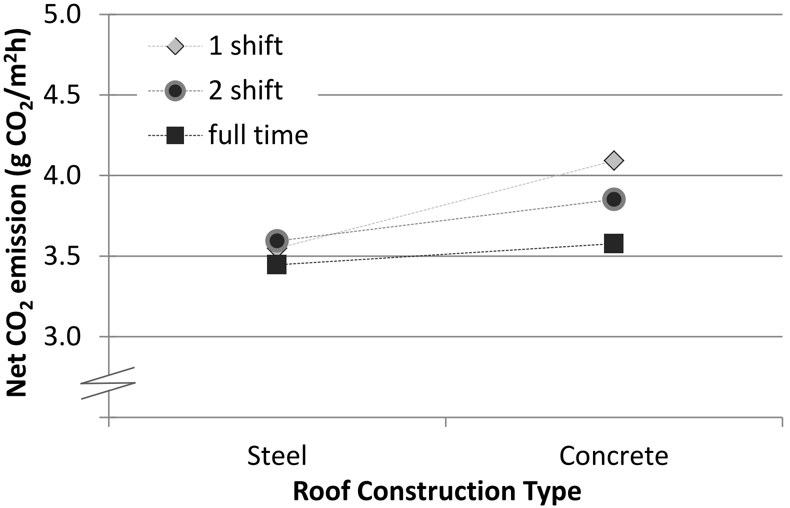
Material Choices :

multi-objective consideration

- ► design decision might have greater impact on one objective but not the others
- ► steel or concrete?





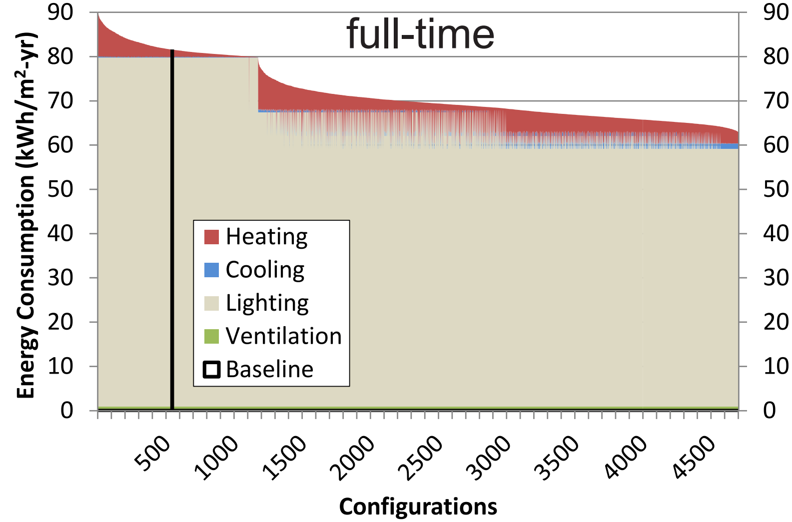


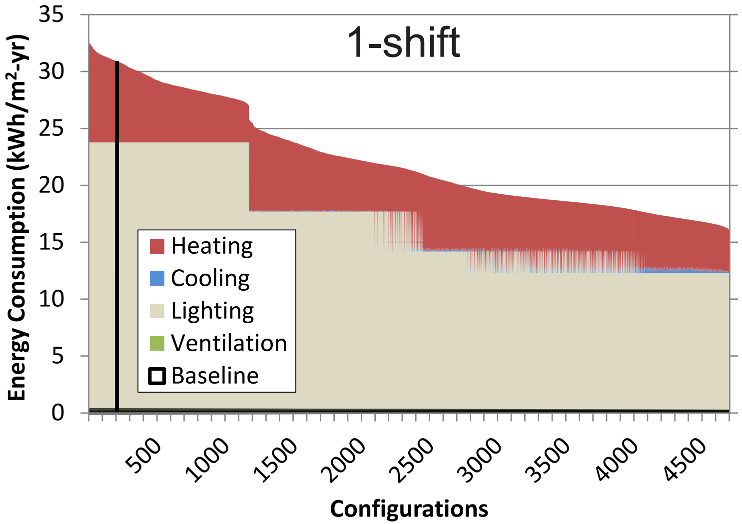
Configurations :

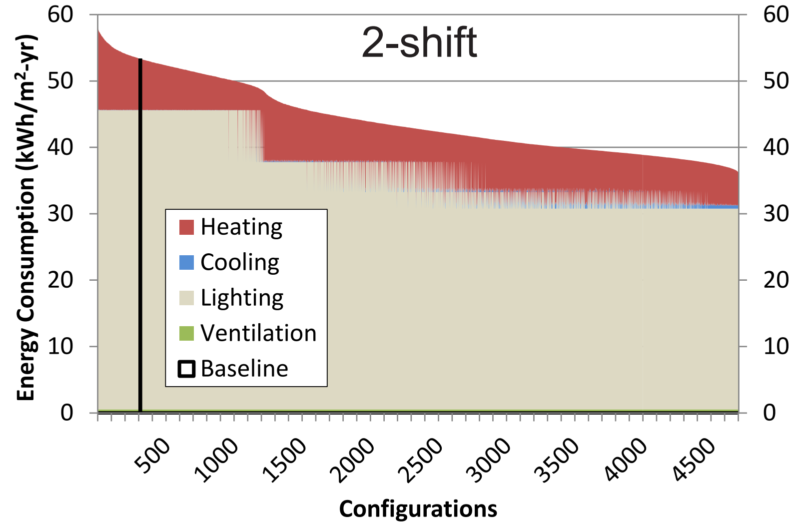
put energy performance into perspective

▶ baseline building configuration is among the poorer performers under all schedules

▶ cooling is insignificant in a mild climate with a low process load (5 W/m²)



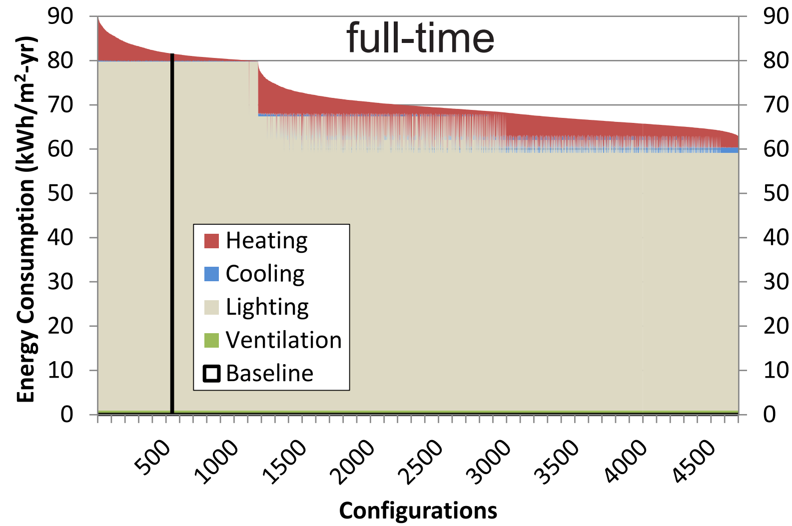


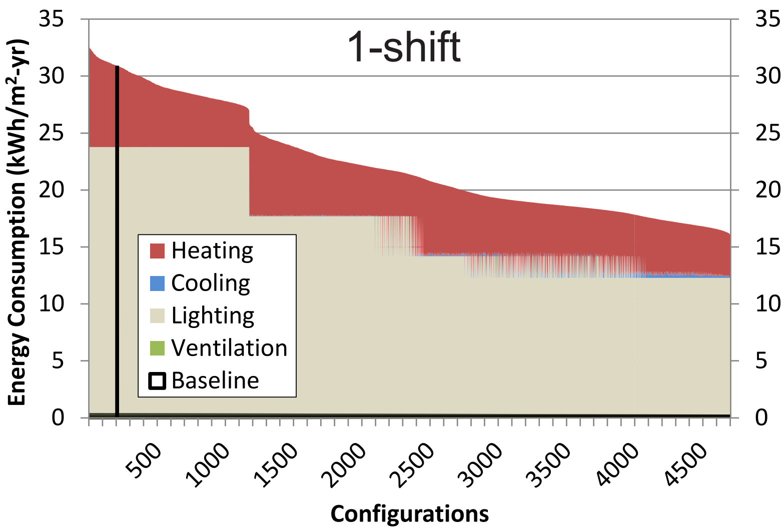


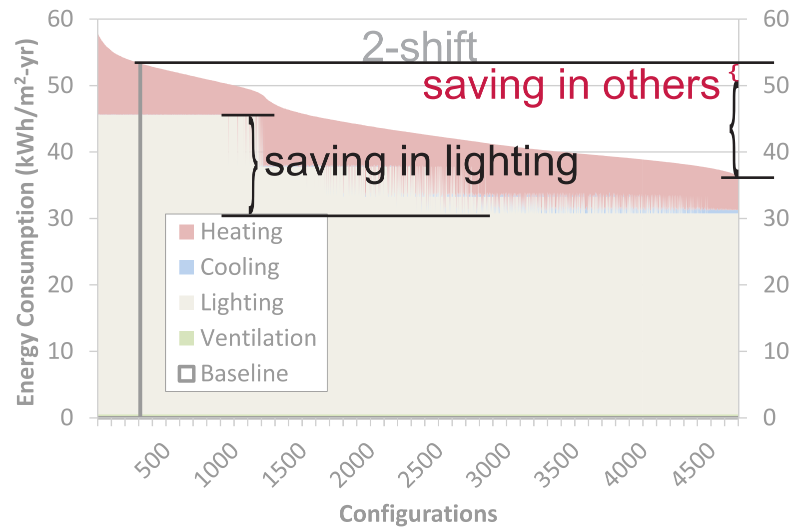
Configurations :

put energy performance into perspective

- ► lighting is the heaviest consumer. Most energy saving is due to daylighting.
- ► as process load increases, cooling can be significant







Conclusions

- industrial halls — high energy consumption, great energy production potential → requires a multidisciplinary and integrated design approach

- industrial halls in most cases — simple geometry and construction → **quick screening tool** to offer performance advice (driven by database based on pre-executed comprehensive design space evaluation)

- **life-cycle analysis** and **multi-objective considerations** provide fairer assessment on performance

THANK YOU

QUESTIONS?

Side Note on Performance indicators :

(…erage)	Total Energy Consumption (kWh/m^2-yr)	Net CO_2 Emission (kg CO_2/m^2-yr)	Annualized Relative Cash Flow (wrt. Baseline, €/m^2)
0	32.3	12.1	0.86
20	31.4	12.6	-6.82
40	30.3	13.2	-14.49
60	29.7	13.8	-22.18
80	29.2	14.5	-29.87
100	29.0	15.2	-37.57
0	25.7	9.5	1.01
20	25.0	10.1	-6.68
40	24.1	10.7	-14.35
60	23.5	11.4	-22.04
80	23.2	12.0	-29.74
100	22.9	12.7	-37.44
0	22.0	8.1	0.84
20	21.4	8.8	-6.85
40	20.6	9.4	-14.53
60	20.1	10.0	-22.22
80	19.7	10.7	-29.92
100	19.5	11.4	-37.62
0	19.9	7.4	0.47
20	19.4	8.1	-7.22
40	18.7	8.7	-14.91
60	18.3	9.4	-22.60
80	18.0	10.1	-30.30
100	17.7		-38.00
0	32.[illegible]		0.74
20			

, 3 shifts)

f (1.5 to 4.5 R_{SI}, in 7 levels)

(1.5 to 4.5 R_{SI}, in 7 levels)

of (none or 200 mm of concrete)

ll (none or 200 mm of concrete)

ighting, 0 to 15% of roof area, in 4 levels)

ed solar collector, 0 to 100% of south wall, in 6 levels)

- ▶ **Total Energy Consumption (operational)**
- ▶ **Net CO_2 Emission (operational + embodied)**
- ▶ **Annualized Relative Cash Flow (Operational + Investment)**

Total Energy Consumption :

Energy Demand	**Heating Energy Demand**		**Cooling Energy Demand**	**Daylighting Supply**
	base heating demand with transpired solar collector that consumes energy for fans	*supplementary heating demand fulfilled by infrared gas radiator, assumed gas of equivalent energy content*	*forced ventilation (energy for fans) + air-cooled chiller based on system efficiency curve of industrial partner*	*required amount of artificial lighting based on dimmable lighting characteristics*
Energy Distribution	**Electricity Consumption**	**Gas Consumption**	**Electricity Consumption**	**Electricity Consumption**

fossil fuel offset based on site energy accounting

Total Energy Consumption (kWh/m^2-yr)

Net CO_2 Emission :

Energy Demand — **Heating Energy Demand** — **Cooling Energy Demand** — **Daylighting Supply**

Energy Distribution — **Electricity Consumption** — **Gas Consumption** — **Electricity Consumption** — **Electricity Consumption**

	CO_2 emission factors (kg CO_2/kWh)
Electricity consumption	0.415 IEA (2012)
Gas consumption	0.202 EU (2010)

Ins_Roof (R_{SI})	Ins_Wall (R_{SI})	Mass_Roof (m	Mass_Wall (m	Daylighting (% cov	TSC (% coverage)
1.5	1.5	0.0	0.0	0	0
1.5	1.5	0.0	0.0	0	20
1.5	1.5	0.0	0.0	0	40
1.5	1.5	0.0	0.0	0	60
1.5	1.5	0.0	0.0	0	80
1.5	1.5	0.0	0.0	0	100

Material Carbon Footprint (kg CO_2)	
Insulation (per R_{SI} per m^2)	2.4
Steel panel (per m^2)	12.3
Precast Concrete (per m^2, 0.2m thickness)	93.4
Skylight (per m^2)	93.0
TSC (per m^2 of coverage)	12.3

Operational CO_2 Emission (kg CO_2)

Embodied Carbon Footprint (kg CO_2)

per unit area / annualized

Net CO_2 Emission (kg CO_2/m²-yr)

Annualized Relative Cash Flow :

$$I_A = I / \left[\frac{(1+r)^n - 1}{r(1+r)^n} \right]$$

r = discount rate

n = number of years of the life-cycle

I = initial capital investment

$$\textit{Amortized Relative Investment Cost} = \sum_{m} I_A - I_{A,baseline\ building}$$

► **relative to the baseline building**

m = different energy saving and generation measures

$$\textit{Annual Relative Operating Cost} = \sum_{Utilities} \left[\left(\textit{Energy Consumption}_{configuration} - \textit{Energy Consumption}_{baseline} \right) \times \textit{Utility Prices} \right]$$

Annualized Relative Cash Flow (€/m²) $= -\left(\textit{Annual Amortized Relative Investment Cost} + \textit{Annual Relative Operating Cost} \right)$

Annualized Relative Cash Flow :

$$I_A = I / \left[\frac{(1+r)^n - 1}{r(1+r)^n} \right]$$

r = discount rate

n = number of years of the life-cycle

I = initial capital investment

- ► **why Amortized Cost ?**
- ► **why NOT Simply Payback Period ?**

- ► does not account for the **financing cost**
- ► cannot handle cases, which **payback period > lifespan** of the equipment itself. For example, PV installation. Performance beyond lifespan decreases significantly
- ► not correct to compare **different energy saving or generation measures of different lifespans** that are shorter than that of the building. Multiple cycles of a measure?

Annualized Relative Cash Flow :

$$I_A = I / \left[\frac{(1+r)^n - 1}{r(1+r)^n} \right]$$

r = discount rate
n = number of years of the life-cycle
I = initial capital investment

$$\text{Amortized Relative Investment Cost} = \sum_m I_A - I_{A,baseline\ building}$$

► **relative to the baseline building**

m = different energy saving and generation measures

► why relative ?

► cost of the **baseline building** (by definition. It can be anything common to standard practice) is what has to be or expected to be paid.

► concern about the additional (**relative**) cost. It can be LOWER than baseline building cost.

so what is the baseline building ?

- **Process Energy** (5, 25, 50, 125, 300 W/m²)
- **Occupancy** (1, 2, 3 shifts)
- **Insulation – roof** (1.5 to 4.5 R_{SI}, in 7 levels, **3.5 R_{SI}**)
- **Insulation – wall** (1.5 to 4.5 R_{SI}, in 7 levels, **3.5 R_{SI}**)
- **Thermal mass – roof** (none or 200 mm of concrete, **none**)
- **Thermal mass – wall** (none or 200 mm of concrete, **none**)
- **Skylight area** (daylighting, 0 to 15% of roof area, in 4 levels, **no skylight**)
- **TSC** (heating, transpired solar collector, 0 to 100% of south wall, in 6 levels, **no TSC**)
- **PV** (length of panel, 0.4-1.6m, in 4 levels; tilt angle, 0-56°, in 29 levels; number of rows, max. 40 rows in 40 levels)

Annualized Relative Cash Flow :

$$I_A = I / \left[\frac{(1+r)^n - 1}{r(1+r)^n} \right]$$

r = discount rate

n = number of years of the life-cycle

I = initial capital investment

$$\boxed{\begin{matrix}Amortized\ Relative\\ Investment\ Cost\end{matrix}} = \sum_m I_A - I_{A,baseline\ building}$$

▶ **relative to the baseline building**

m = different energy saving and generation measures

$$\boxed{\begin{matrix}Annual\ Relative\\ Operating\ Cost\end{matrix}} = \sum_{Utilities} \left[\left(\begin{matrix}Energy\\ Consumption\end{matrix}_{configuration} - \begin{matrix}Energy\\ Consumption\end{matrix}_{baseline} \right) \times \begin{matrix}Utility\\ Prices\end{matrix} \right]$$

Annualized Relative Cash Flow (€/m²) $= -\left(\boxed{\begin{matrix}Annual\ Amortized\ Relative\\ Investment\ Cost\end{matrix}} + \boxed{\begin{matrix}Annual\ Relative\\ Operating\ Cost\end{matrix}} \right)$

Side Note on Unconditioned Halls :

design parameters

► considers multiple design parameters for different occupancy patterns