ENERGY EFFICIENT BUILDINGS

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20140626

Introduction

- „Energy efficient buildings & Renewables“

DI Markus BRYCHTA (markus.brychta@uibk.ac.at)

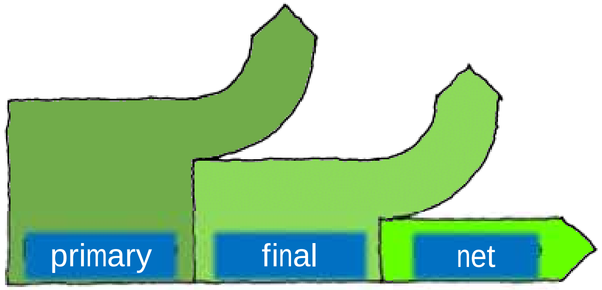
- Scientific staff at University of Innsbruck
- Engineer at AIT Austrian Institute of Technology/Energy (2009-2013)
- Fields of activities…
  - Sustainable building technologies
  - Integration of renewables
  - Solar Cooling
  - Modeling and simulation of buildings, HVAC, controls, ‘specials’
- Projects: research & consulting, internal, funded, direct industry funded
- Teaching: FH OÖ, FH Technikum Wien, GreenBuildingSolutions
- Background: Physics @ TU Vienna

Demand in buildings

- What do we need?
  - Electricity
  - Gas
  - Oil
  - Water
  - … ?

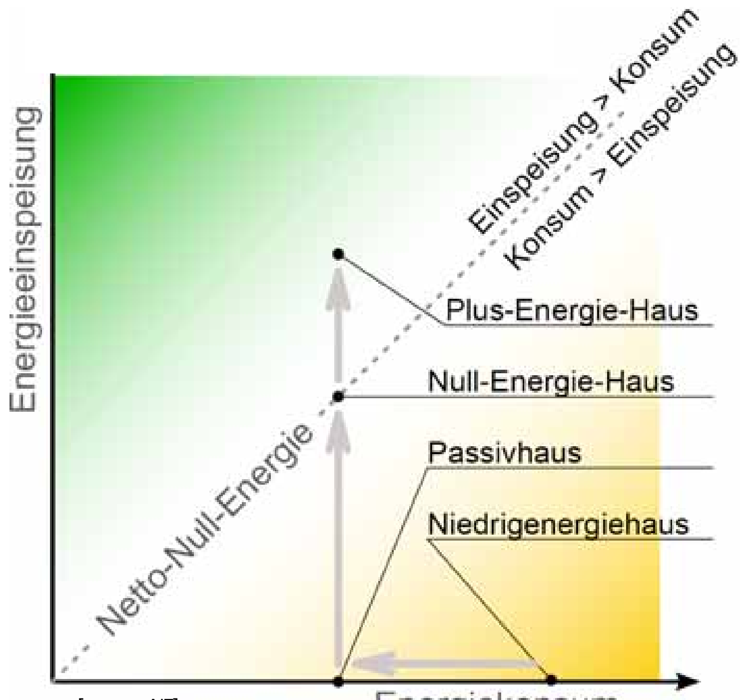
- Service instead of energy!
  - Shelter
  - Light
  - Hygienic environment
  - …

Plus Energy Buildings



Primary energy demand per year
<
Energy produced from RES at location

- <u>Reduction of net energy demand</u>
  Building, usage, comfort criteria,…
- <u>Reduction of remaining final energy demand</u>
  Efficient HVAC,…
- <u>Production of primary energy from RES</u>

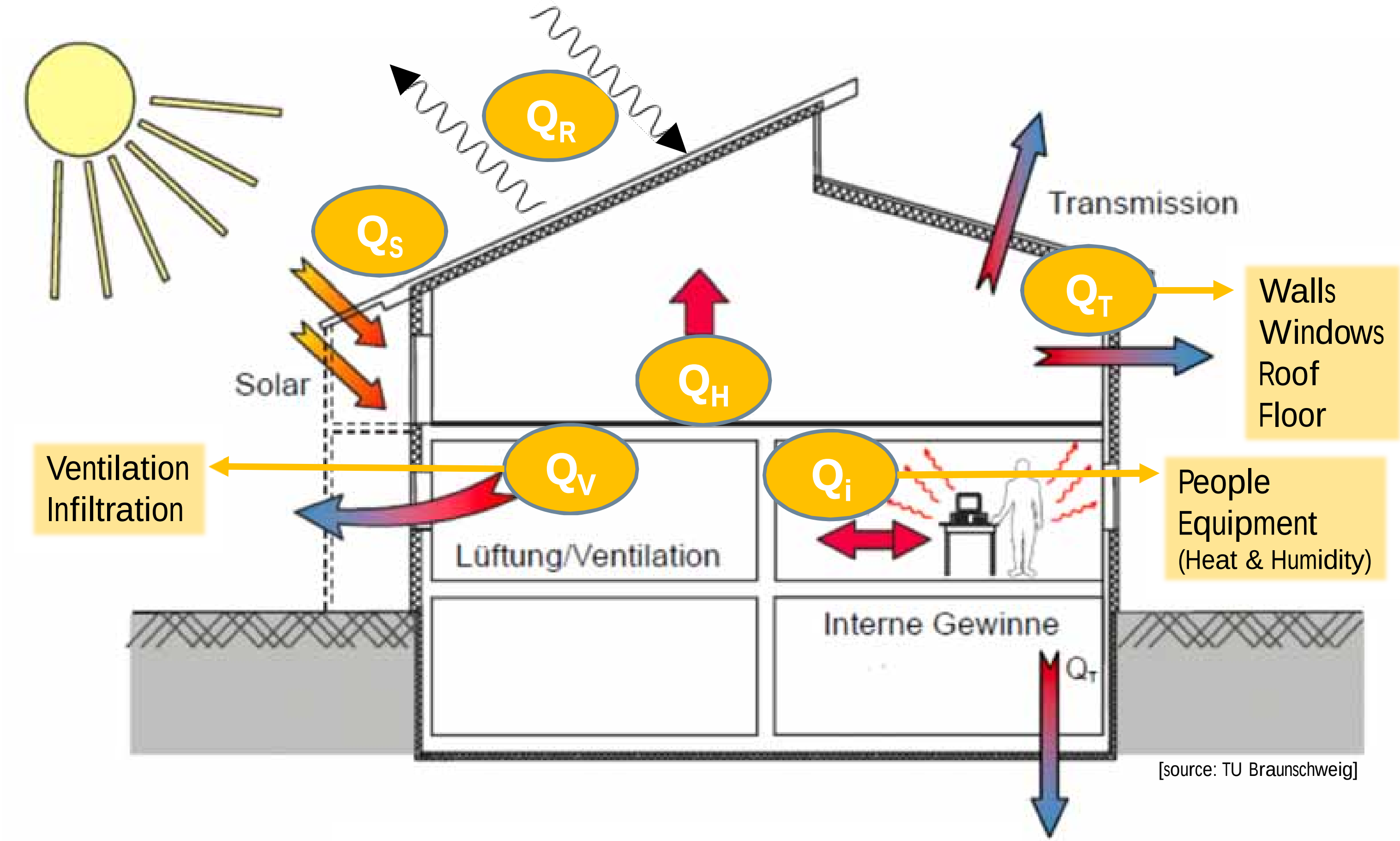


[source: AIT]

Passive vs. Active systems

- Definition?
- **Passive**: No auxiliary energy needed
- **Hybrid**: “A bit” of auxiliary energy…
- **Active**: Fully driven with auxiliary energy

Energy flows in a building

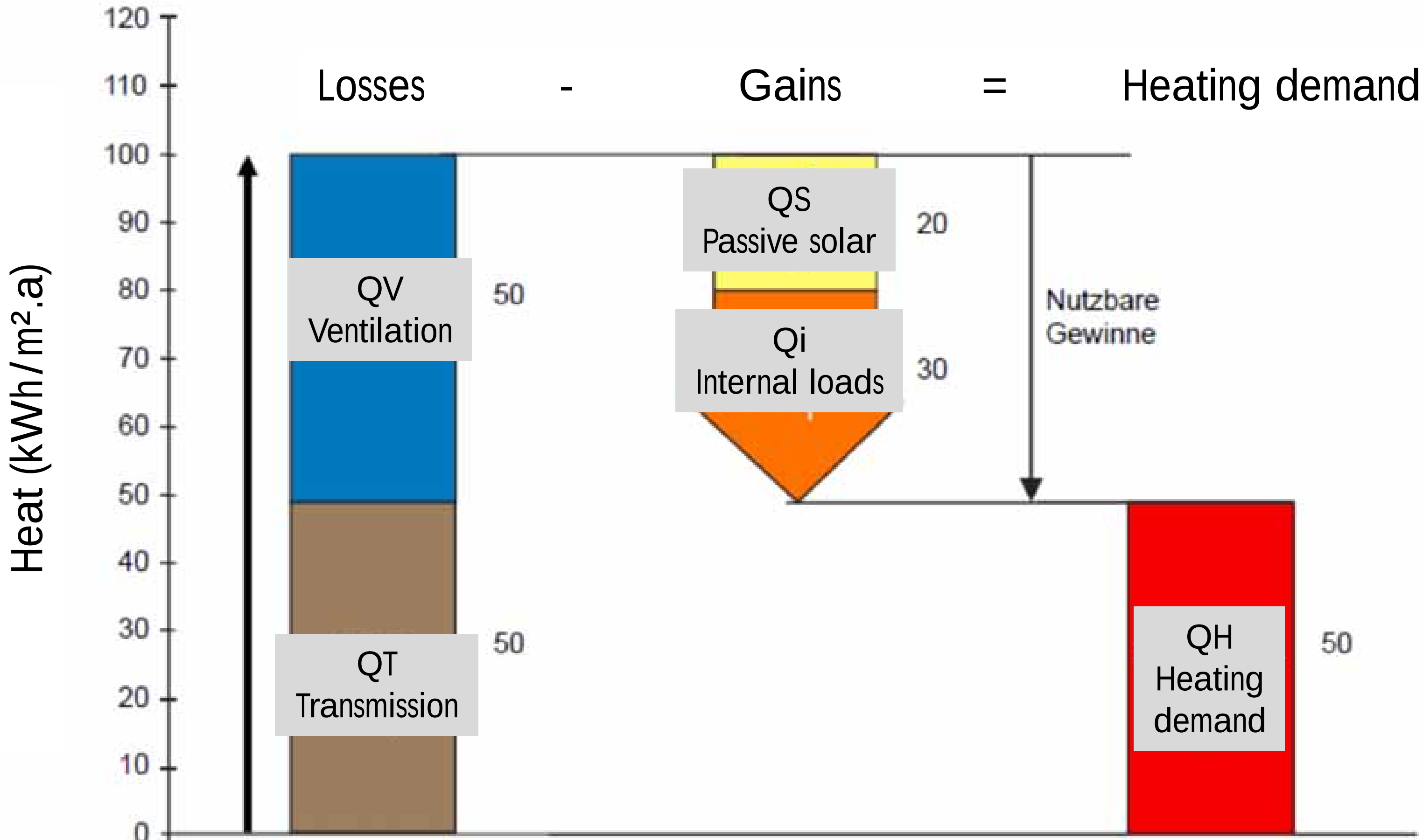


[source: TU Braunschweig]

Heating demand:

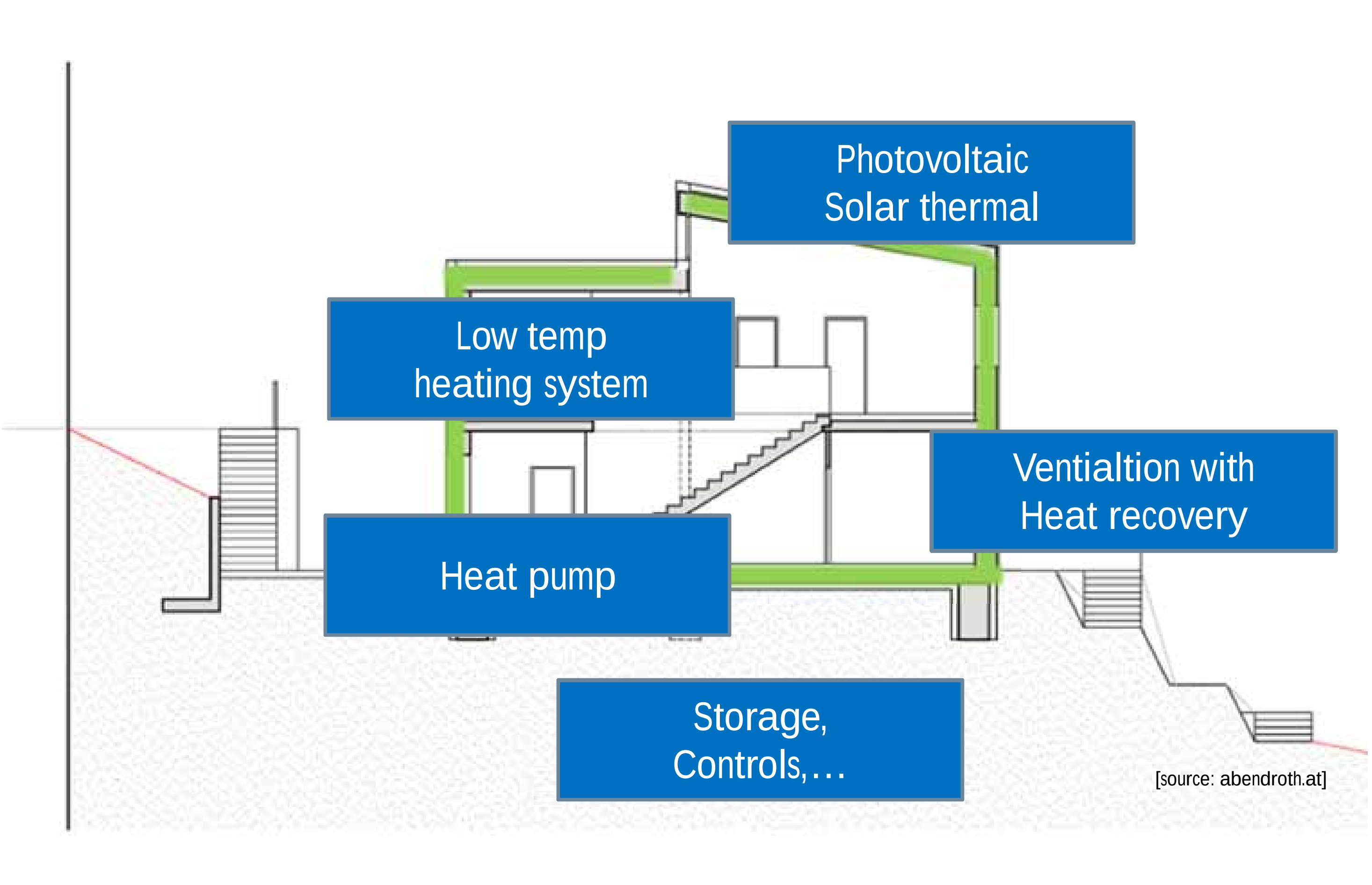
$$Q_h = Q_T + Q_V - \eta (Q_s + Q_i)$$

Energy flows in a building



[source: TU Braunschweig]

Building optimization…

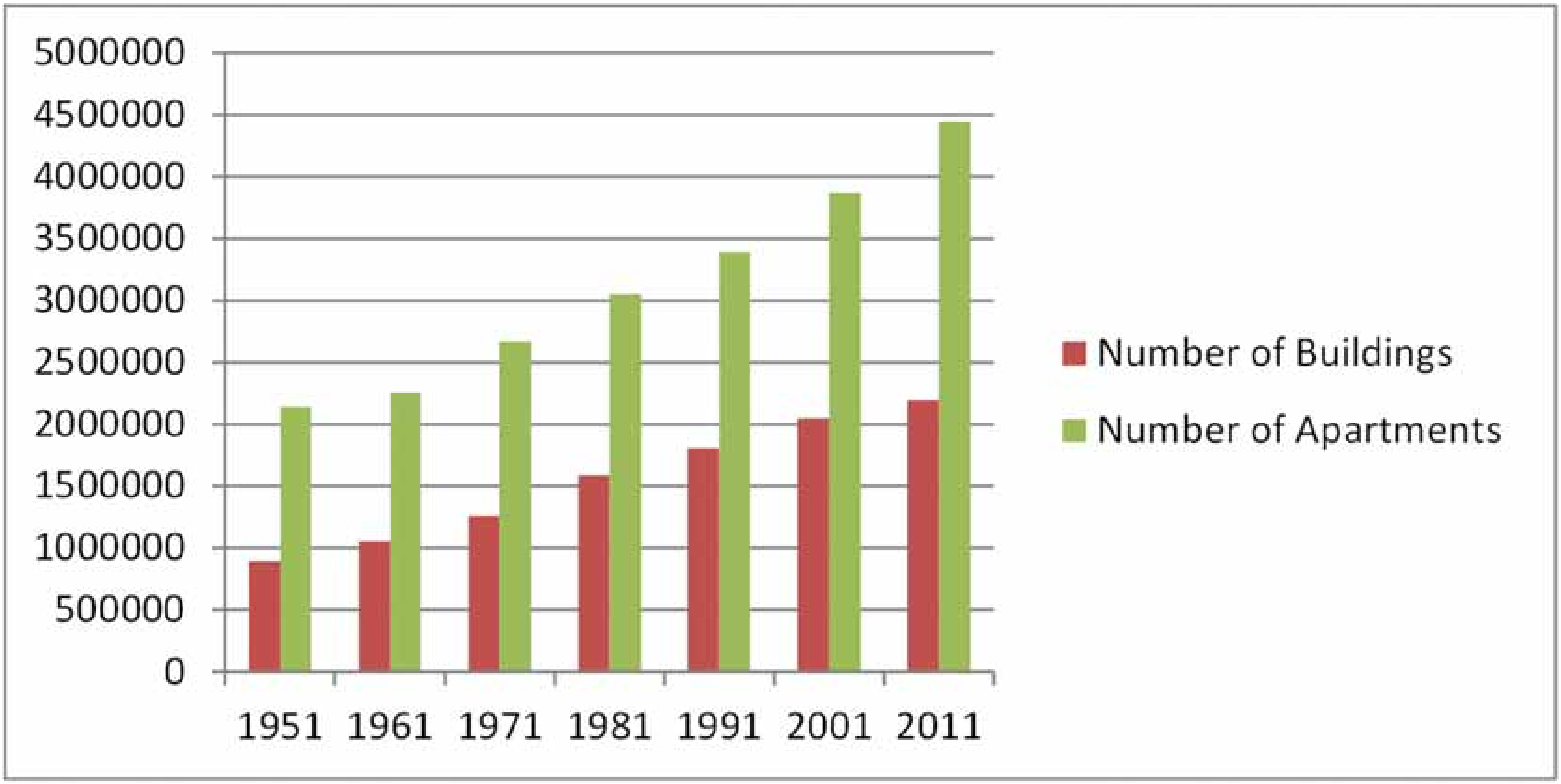


Basics

- Just a few equations…
- Heat energy and temperature change $\Delta Q = m \cdot c_p \cdot \Delta\vartheta$
- Heat transmission (e.g. through walls) $\dot{Q} = U \cdot A \cdot \Delta\vartheta$
- Electrical power needed for pumping, ventilation $P_{el} = \Delta p \frac{\dot{V}}{\eta}$
- Energy flux due to radiation $\dot{q} = \sigma T^4$
- Heat conduction $\frac{\partial}{\partial t} T = a \Delta T$

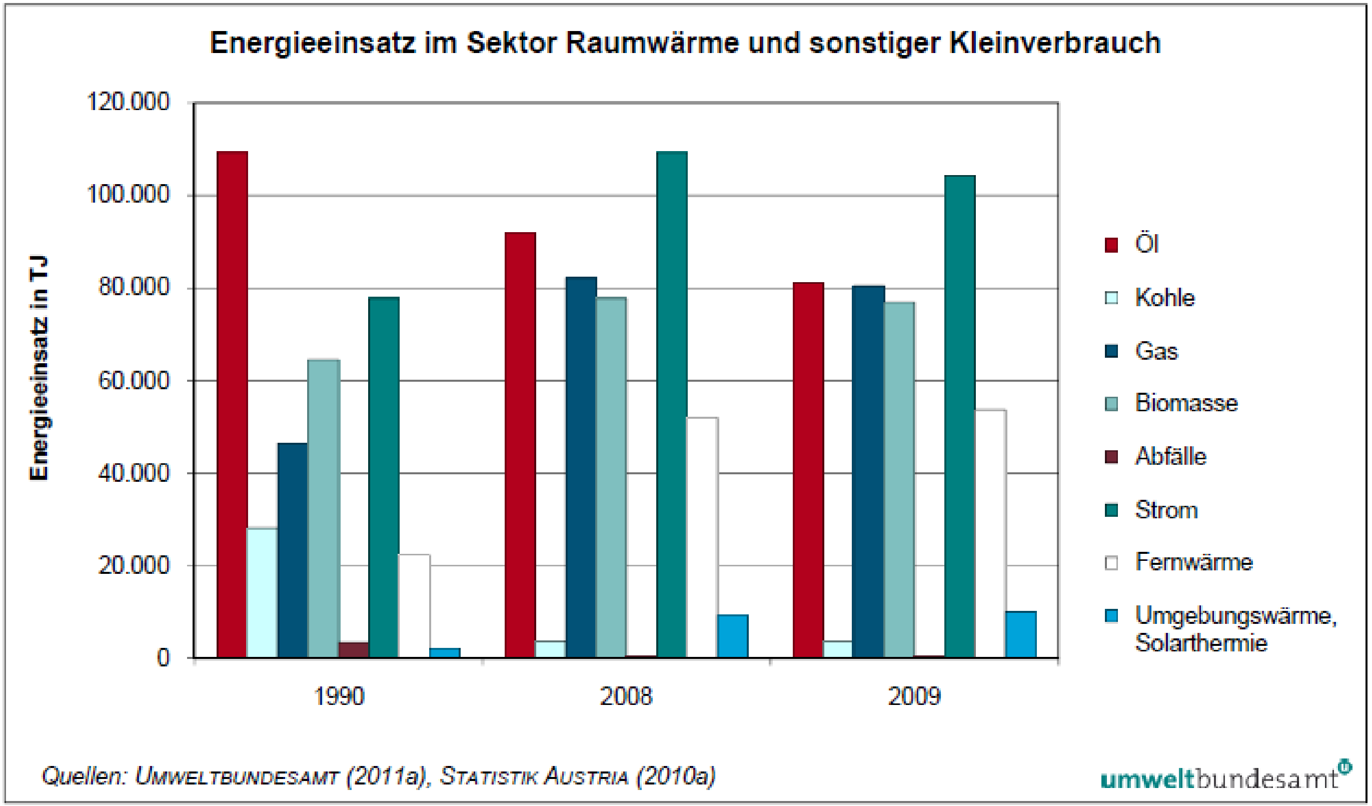
Buildings in Austria

- Number of buildings and apartments is increasing



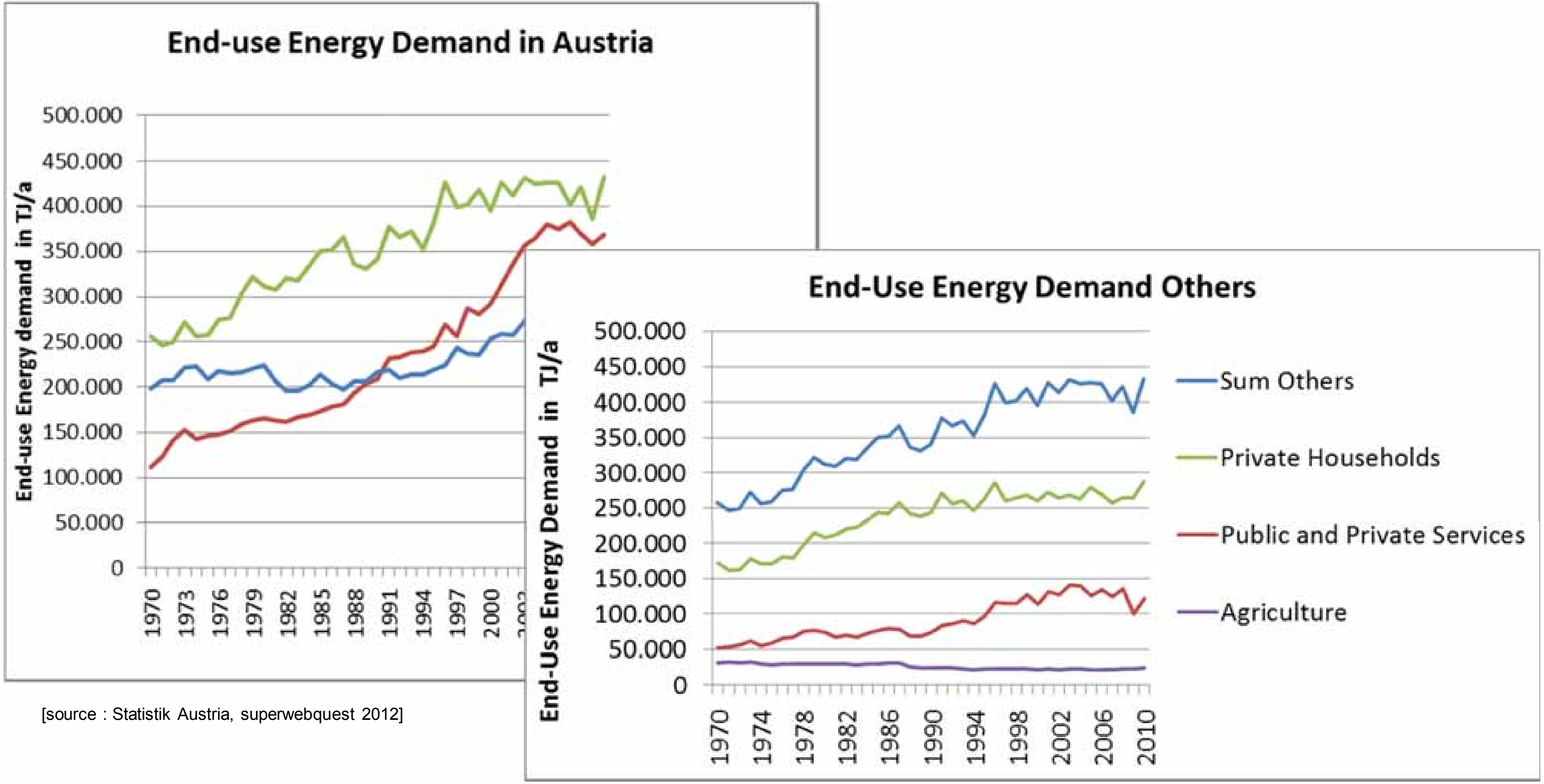
Energy carriers

- Fossile (except gas) decreasing
- Electrical an d district heating increasing
- Small share of solar thermal



End-use energy demand

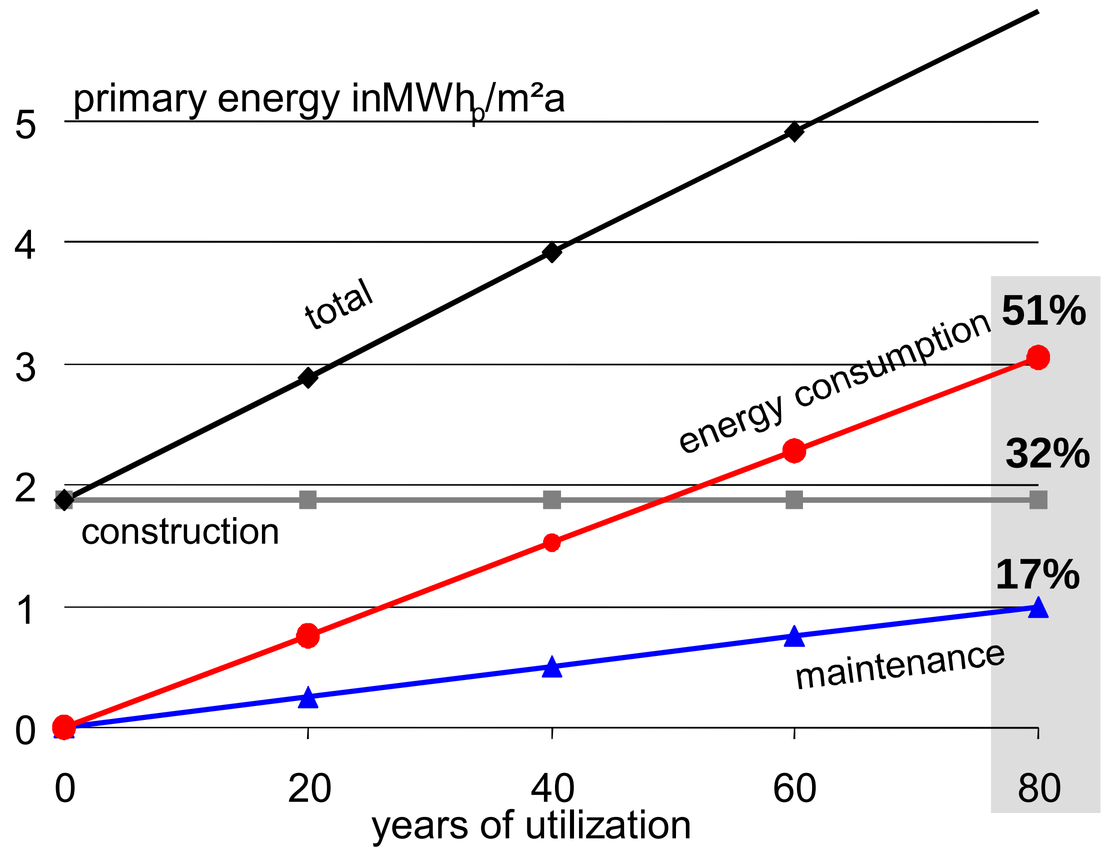
- End energy demand for “Others” roughly constant since mid of 90ies



[source : Statistik Austria, superwebquest 2012]

Life cycle energy

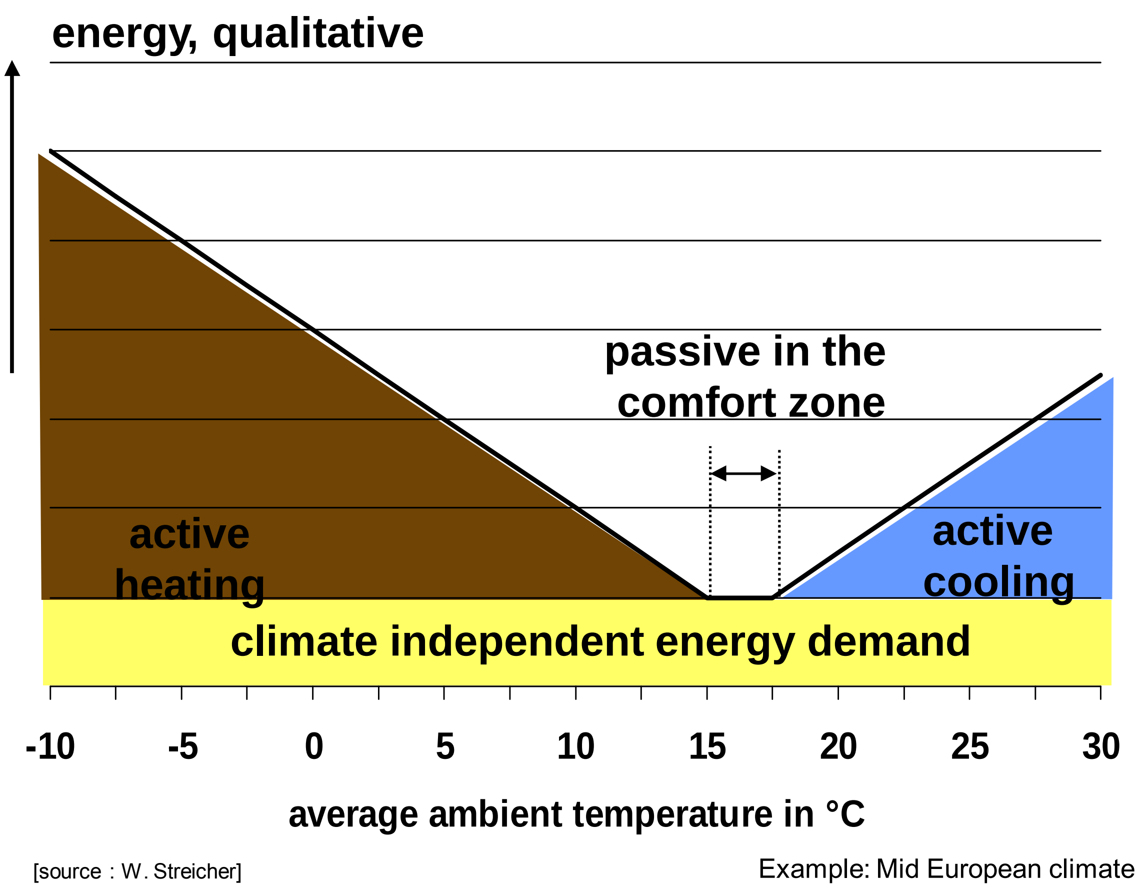
- “Break even” for energy (construction vs. operation) exists



[source : W. Streicher]

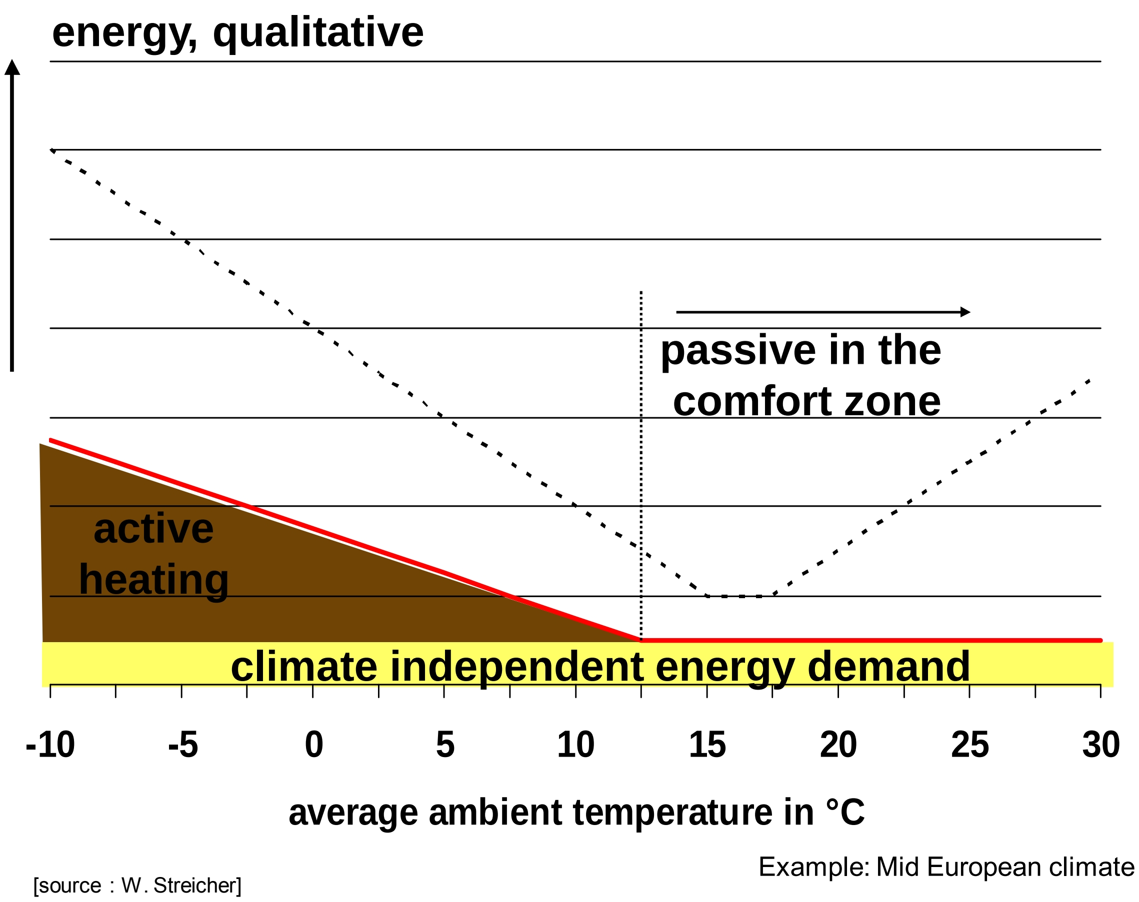
Dependency on ambient conditions

- Current buildings…
- Energy demand for: heating, cooling, ventilation, lighting, utilization

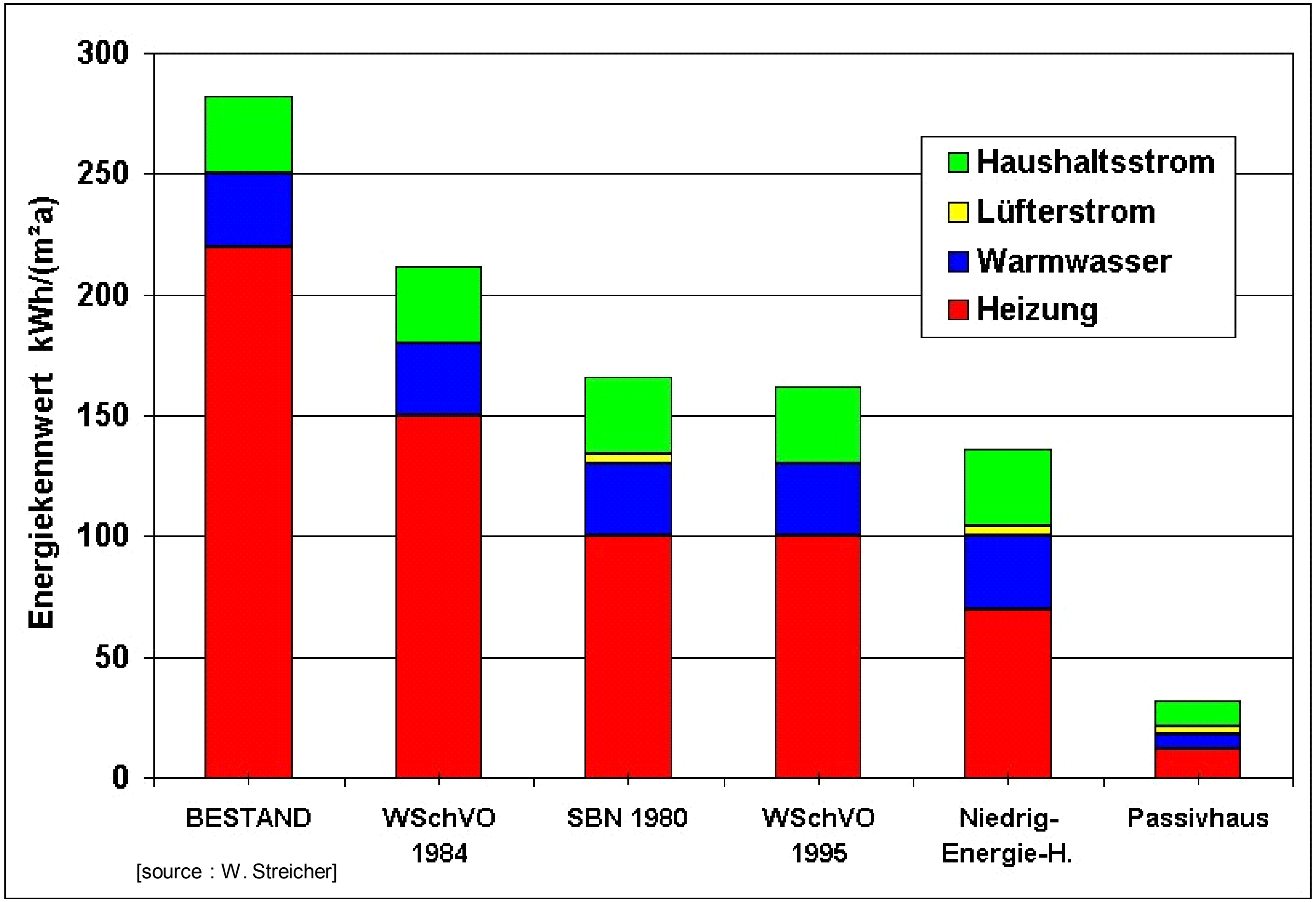


Dependency on ambient conditions

- Lean buildings…
- Energy demand for: heating, cooling, ventilation, lighting, utilization

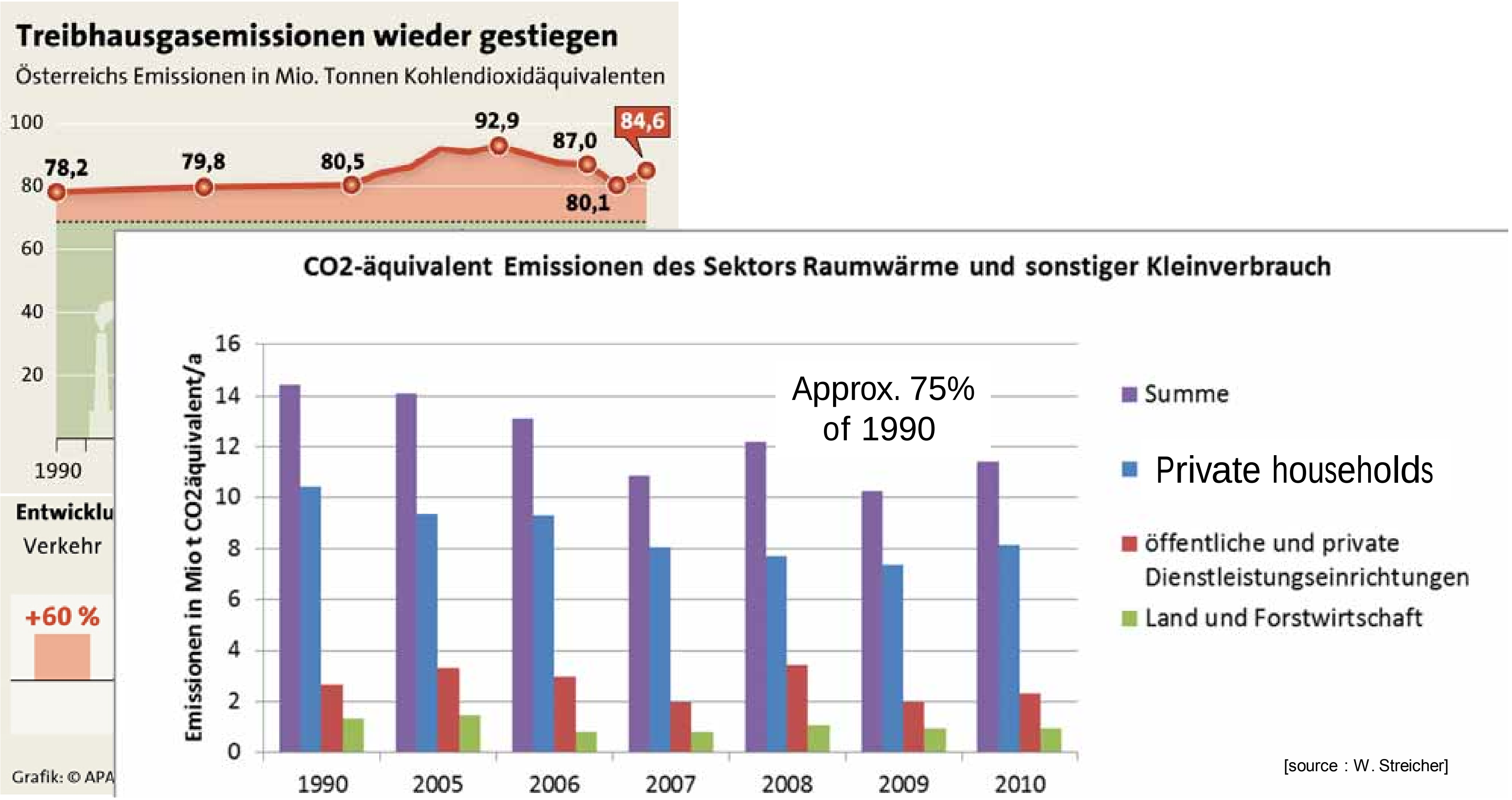


Building energy demand over time



CO_2 emissions

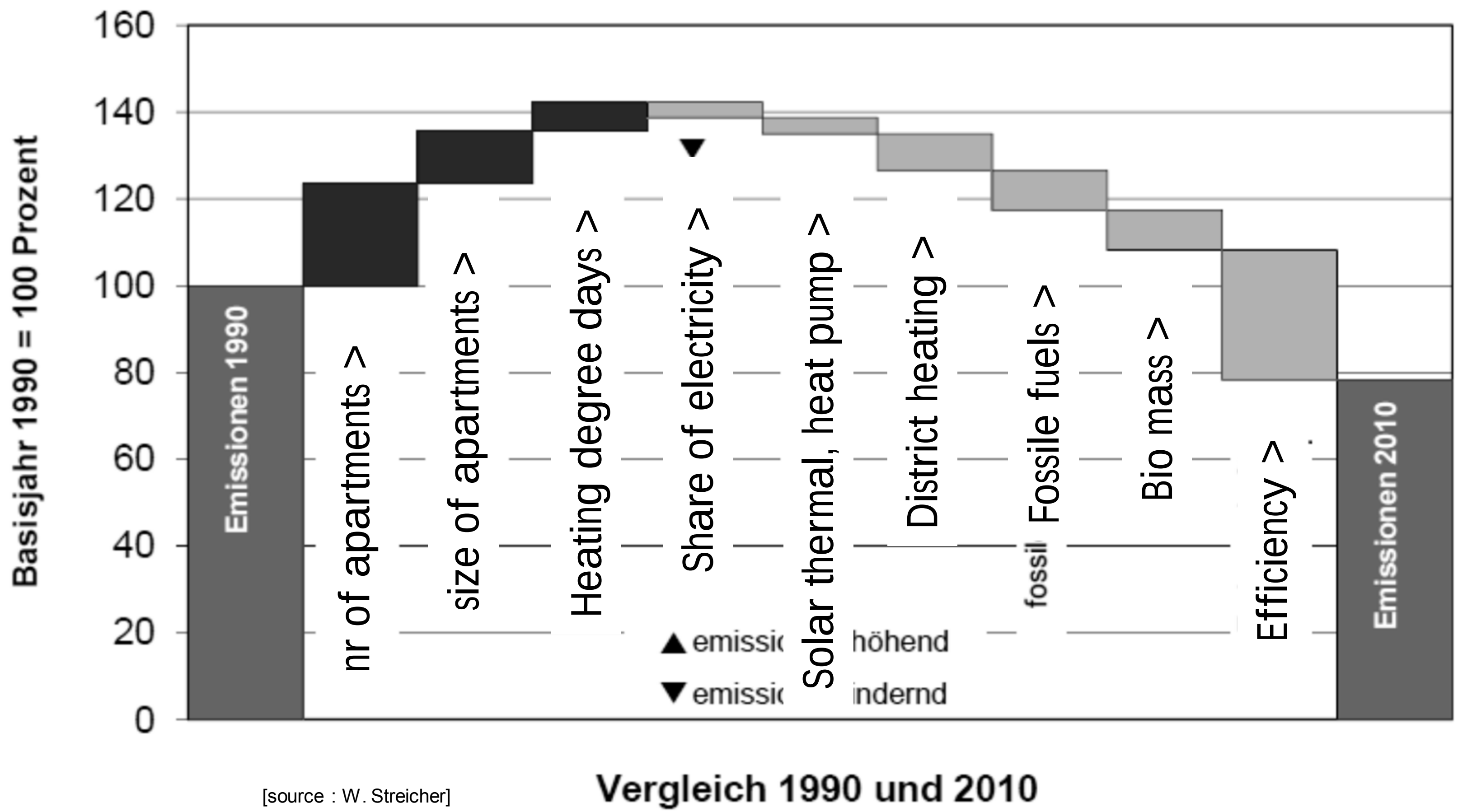
- Emission caused by households decreasing



[source : W. Streicher]

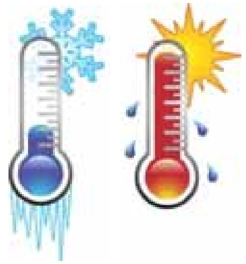
Effects on CO_2 emissions

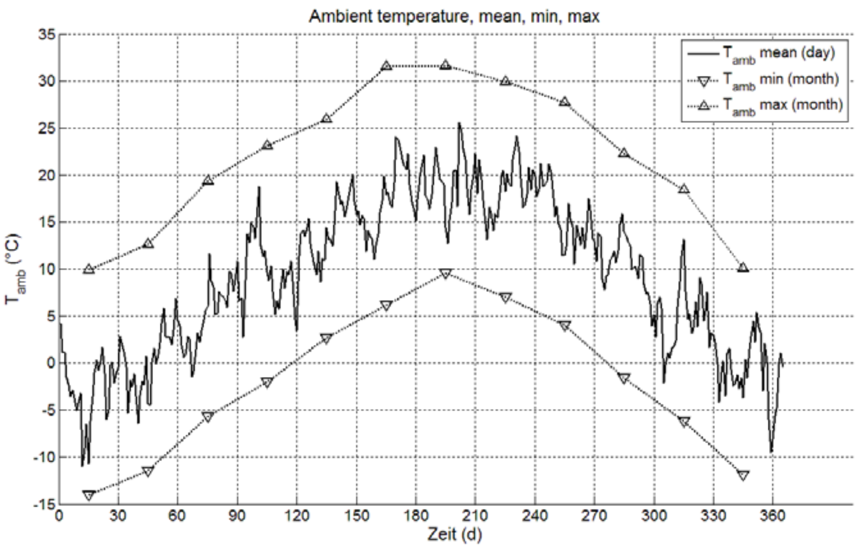
- Different competing effects

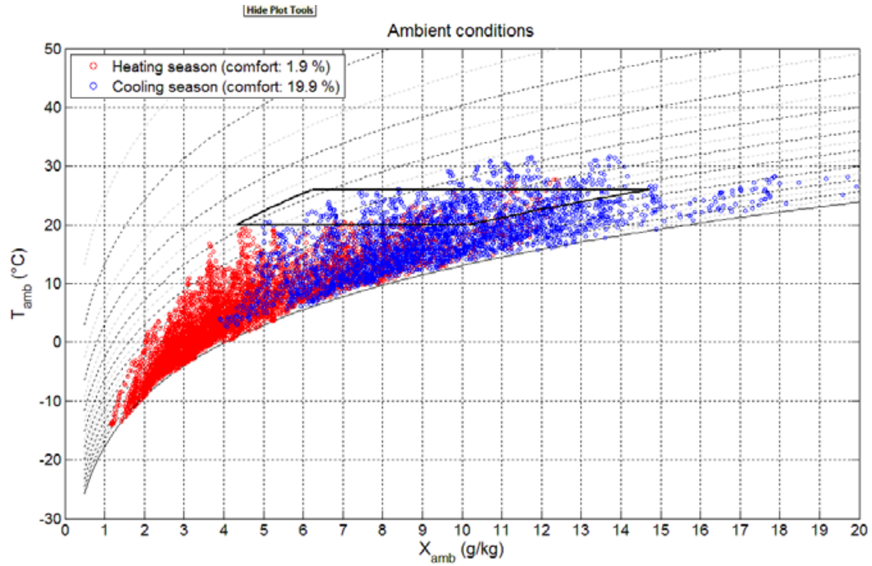


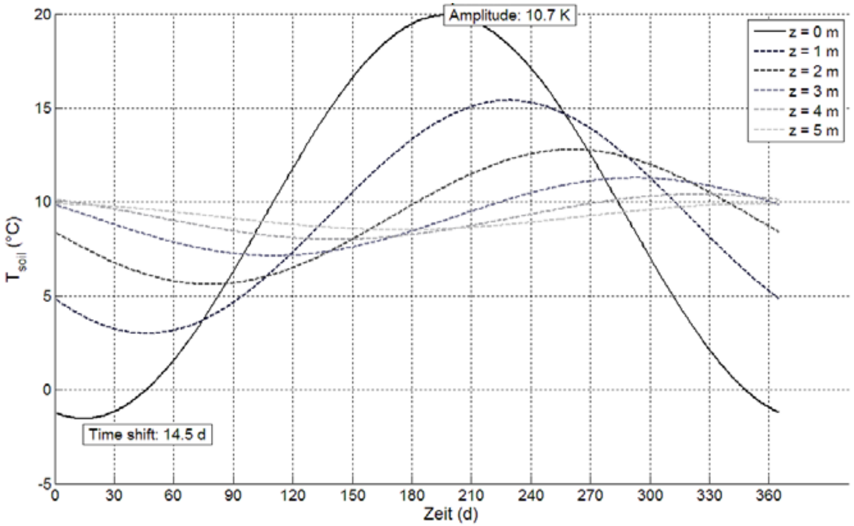
[source : W. Streicher]

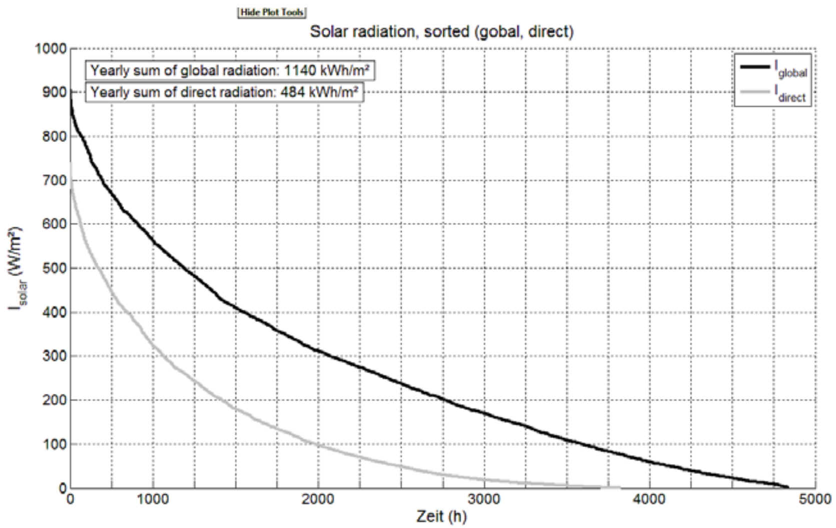
Weather analysis – Location A



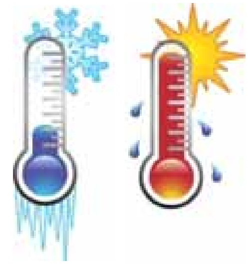


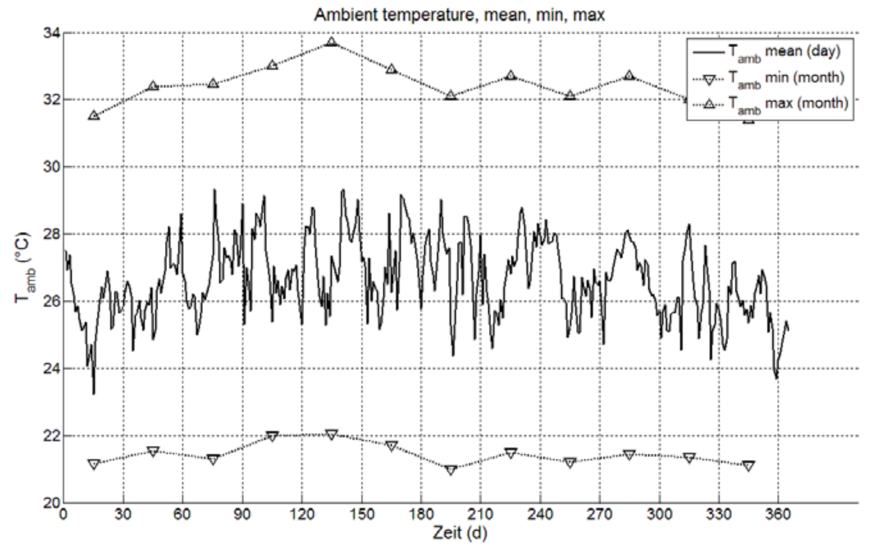


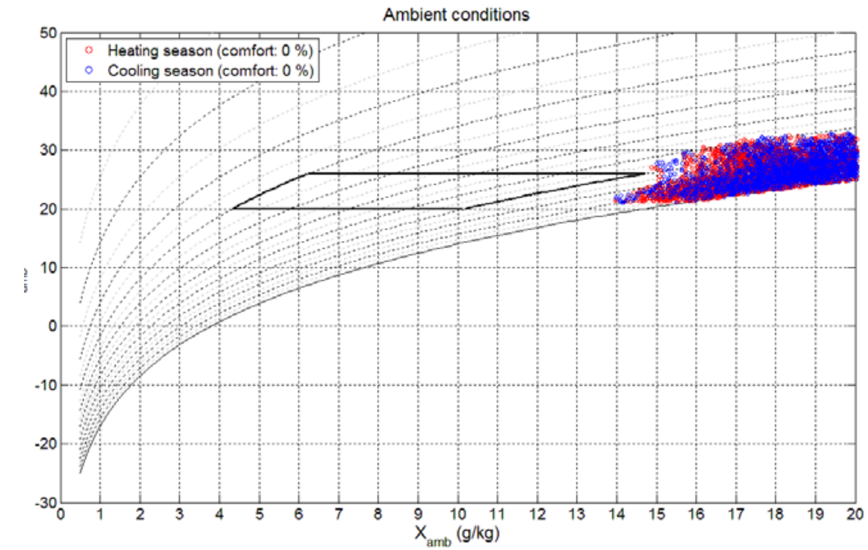


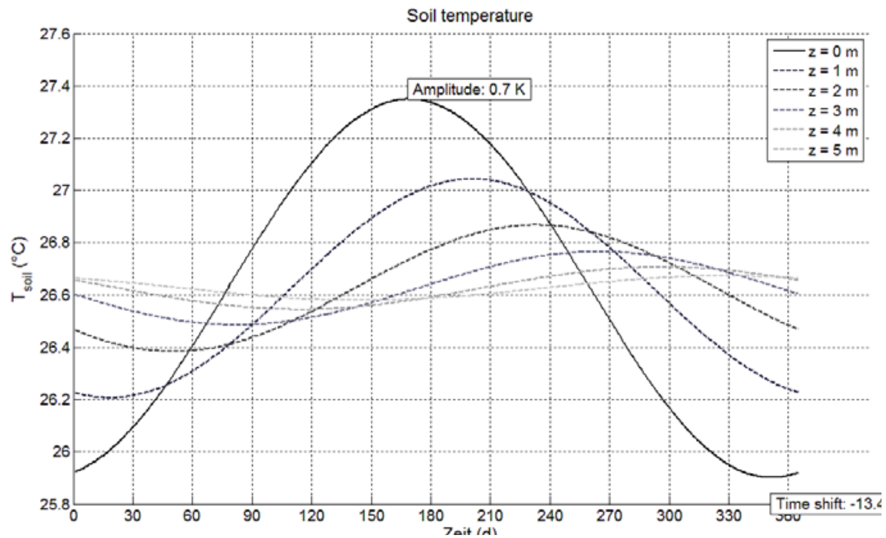


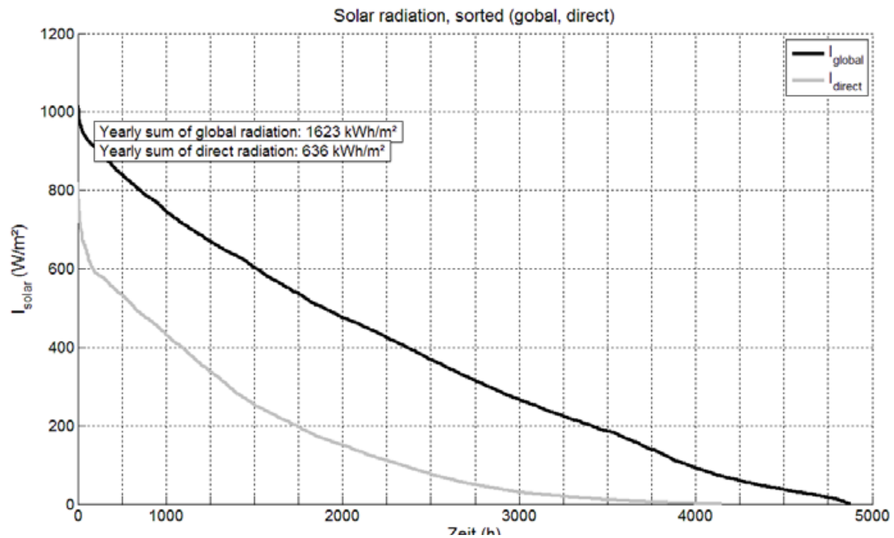
Weather analysis – Location B

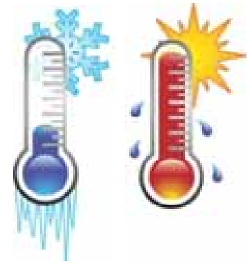






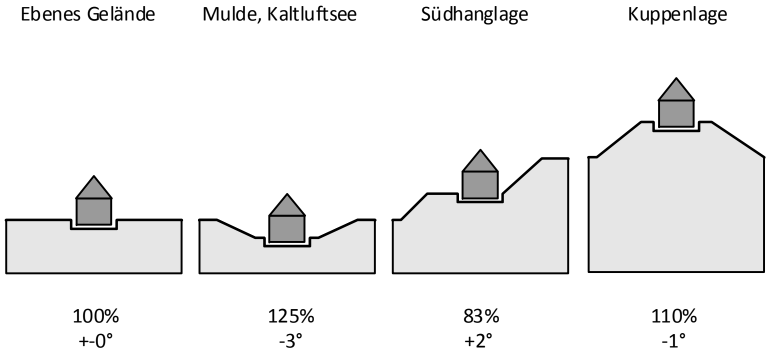


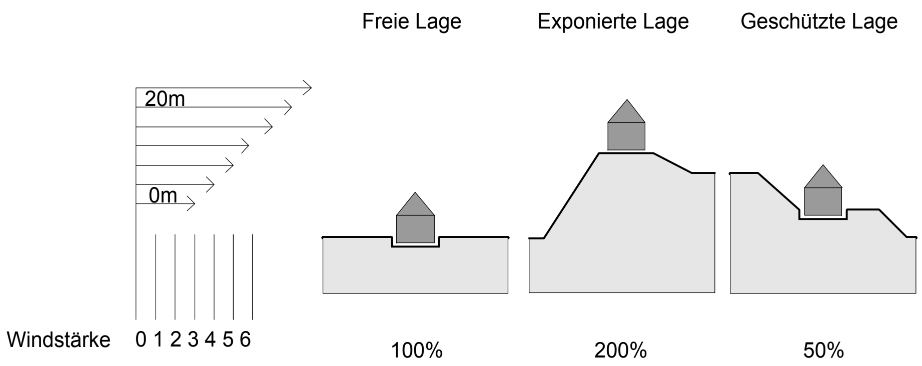




Location - topology

- Exposed location influences heating demand





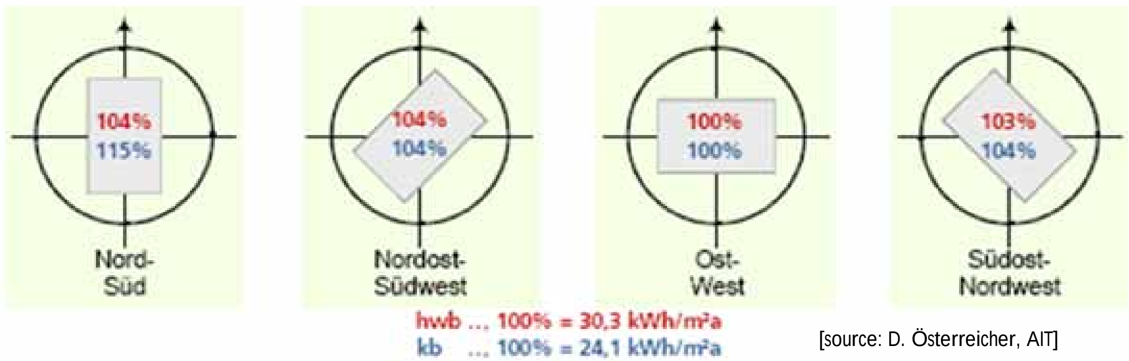
[source: D. Österreicher, AIT]

- Bernoulli equation

$$p + \frac{1}{2}\rho v^2 = p_0$$

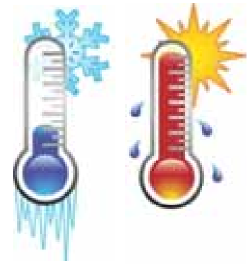
- Wind velocity profile due to height

$$\overline{v}_2 = v_1 \cdot \left(\frac{h_2}{h_1}\right)^{\alpha}$$



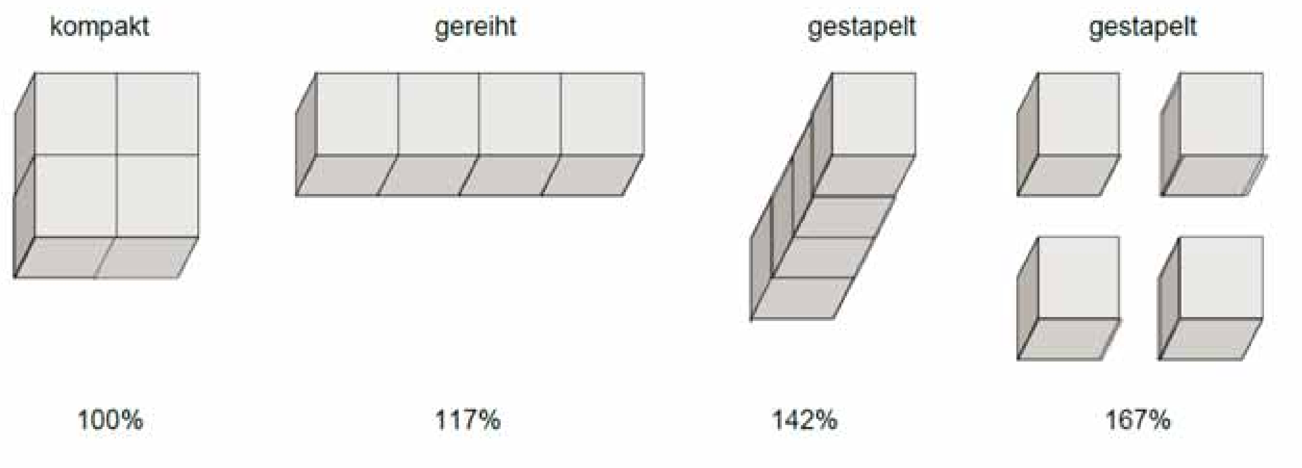
[source: D. Österreicher, AIT]

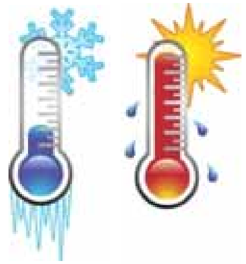
Form - A/V ratio



- Characteristic parameter: Ratio of surface area / volume „A/V“
- Typical values of A/V ratio:
  - Single family home, stand alone: 0,7 to above 1,0
  - Double houses: 0,6 to 0,9
  - Serial house: 0,4 to 0,6
  - Multi family home: 0,3 to 0,5
- Heating demand ,
  some simplified examples
  (Exact numbers not valid in a general way)

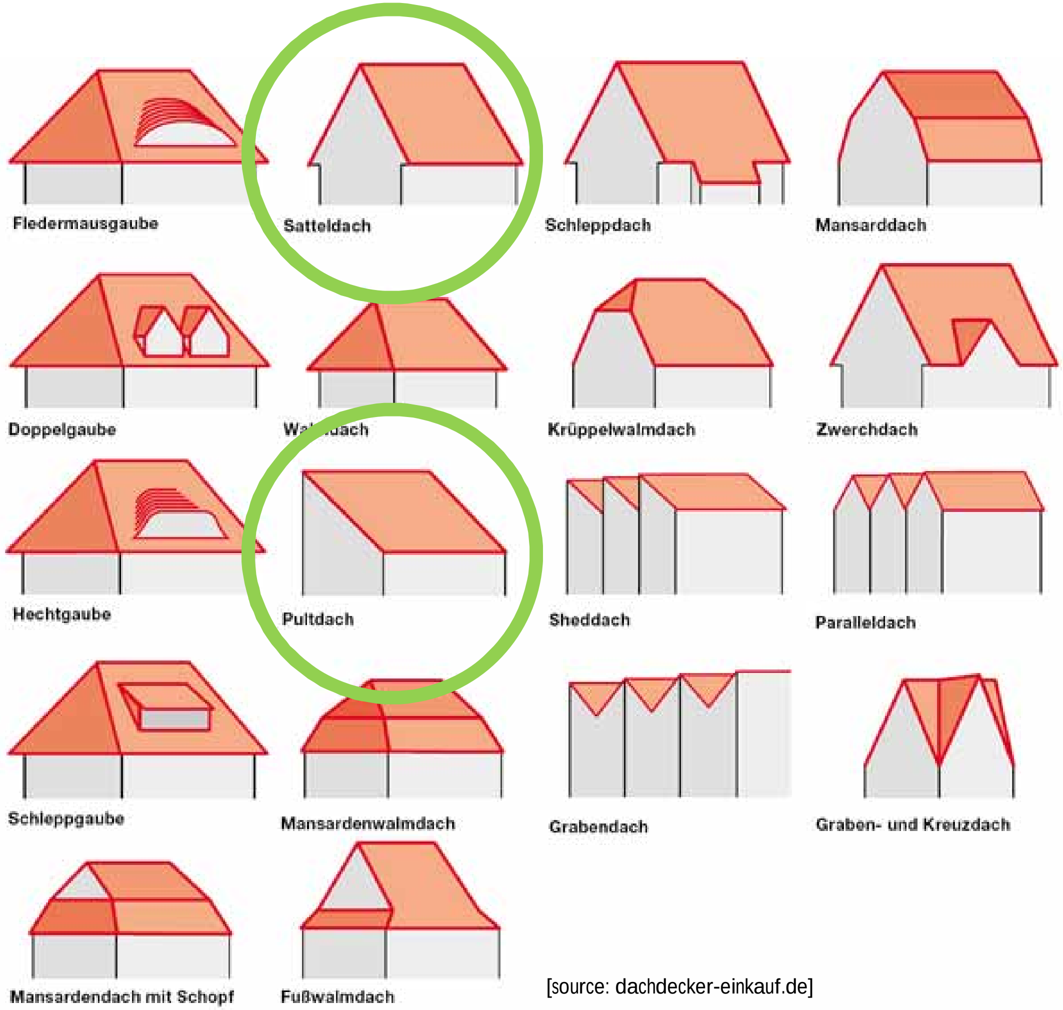
[source: D. Österreicher, AIT]





Form of roof

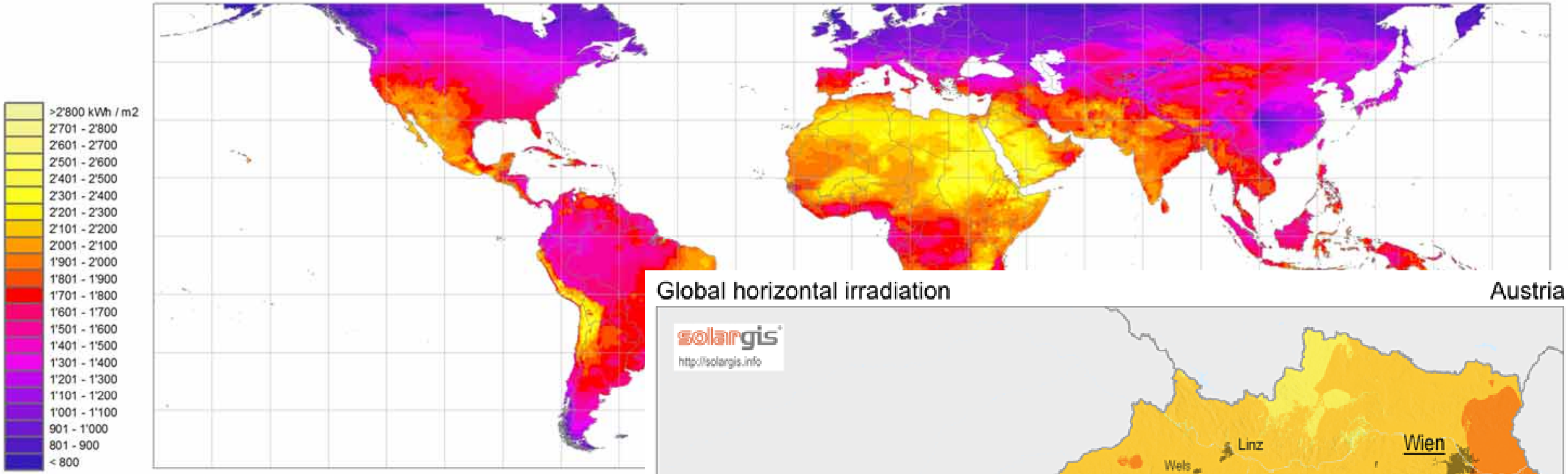
- “Satteldach”, “Pultdach” good (and common) approach



[source: dachdecker-einkauf.de]

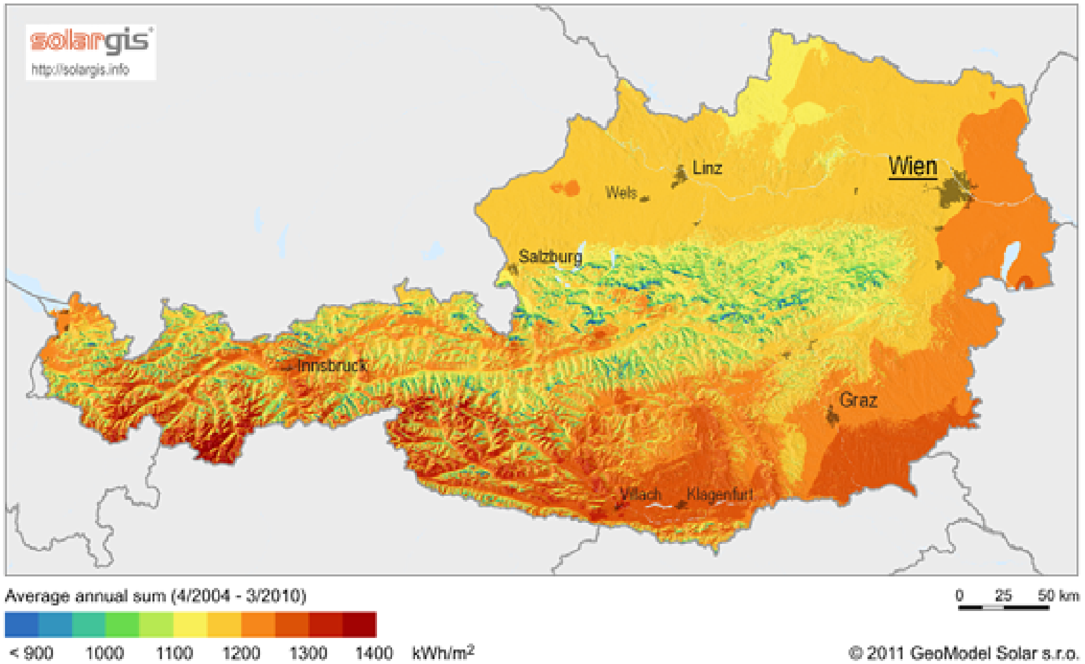
Solar potential

Yearly sum of Global Horizontal Irradiation (GHI)



Source: Meteonorm 7.0 (www.meteonorm.com); uncertainty 8%
Period: 1986 - 2005; grid cell size: 0.25°

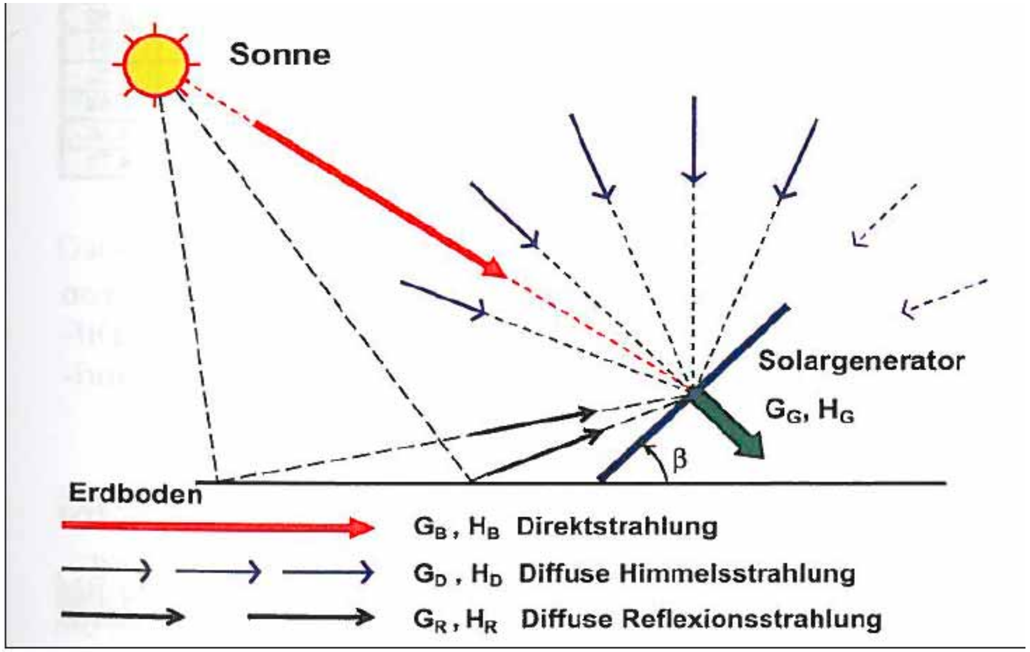
Global horizontal irradiation Austria



Average annual sum (4/2004 - 3/2010)

© 2011 GeoModel Solar s.r.o.

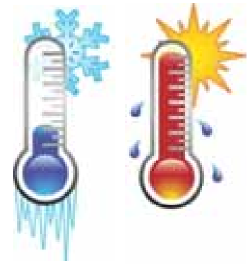
Solar radiation



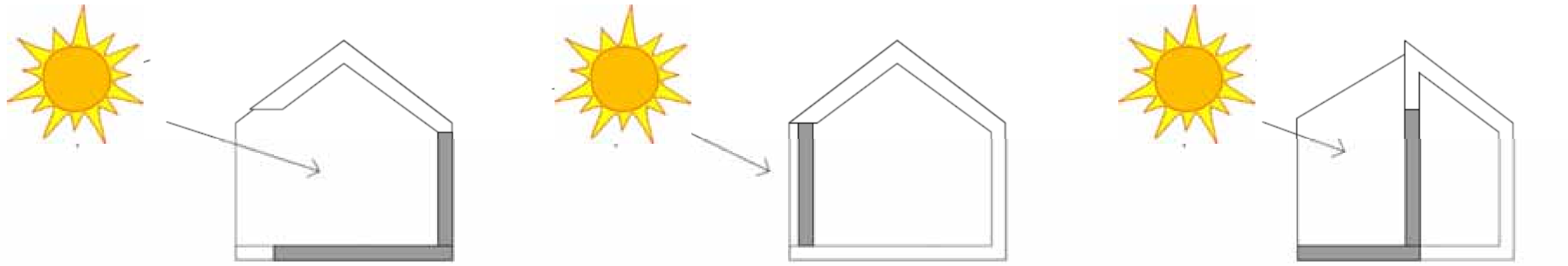
Quelle: Häberlin (2010)

Beschaffenheit des Erdbodens	Reflexionsfaktor ρ (Albedo)
Asphalt	0.1 - 0.15
Grüner Wald	0.1 - 0.2
Nasser Erdboden	0.1 - 0.2
Trockener Erdboden	0.15 - 0.3
Grasbedeckter Boden	0.2 - 0.3
Beton	0.2 - 0.35
Wüstensand	0.3 - 0.4
Altschnee (je nach Verschmutzung)	0.5 - 0.75
Neuschnee	0.75 - 0.9

Passive solar design



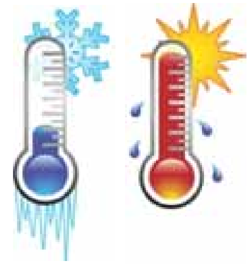
- Basic principles
  - Collect…
  - Store…
  - Distribute…
- Goal
  - Passive solar heating in winter
  - Improved Daylighting
  - Reject solar heat in summer
  - Improved ventilation
  - Higher comfort



Direct solar gain | Indirect solar gain | Independent solar gain

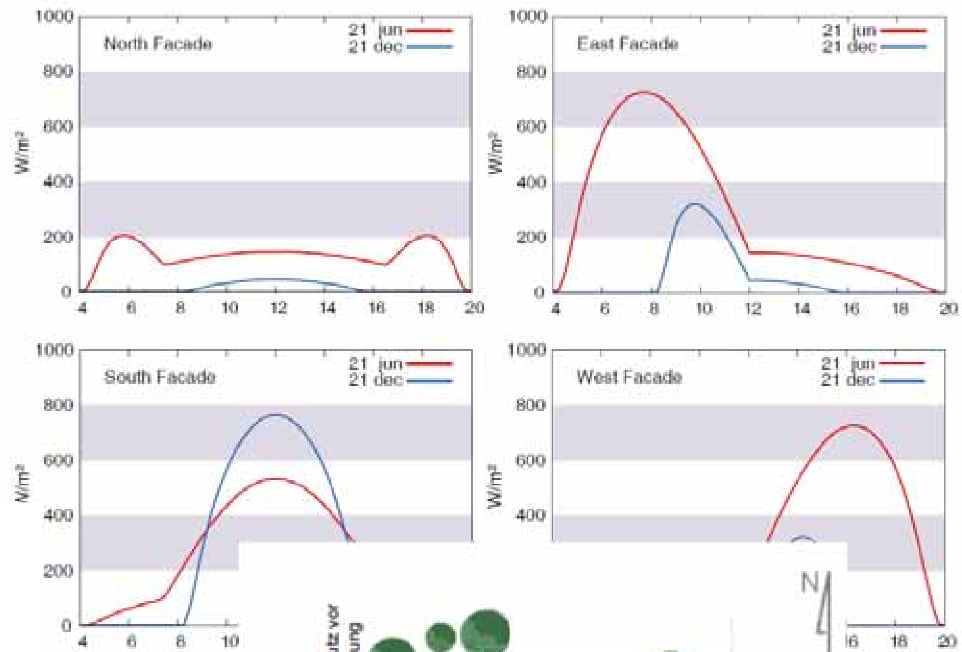
[source: D. Österreicher, AIT]

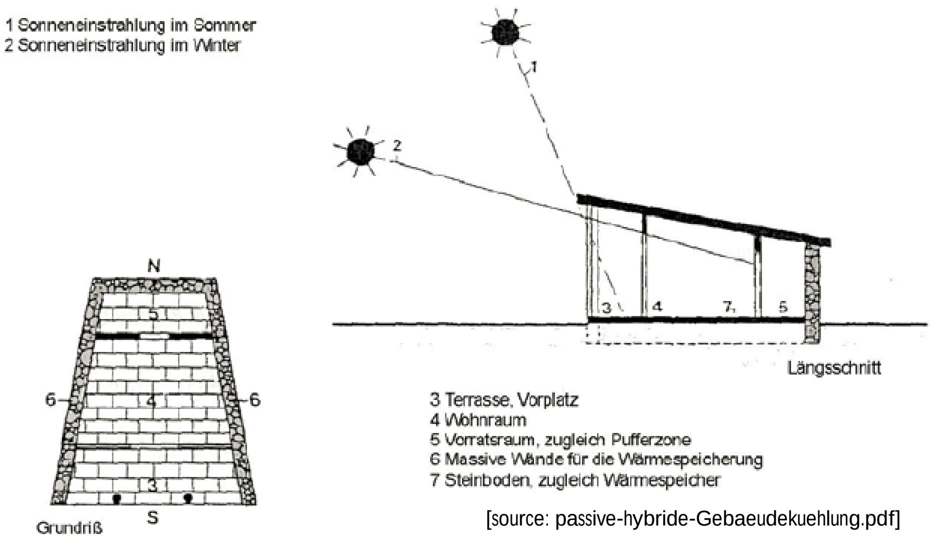
Passive solar design



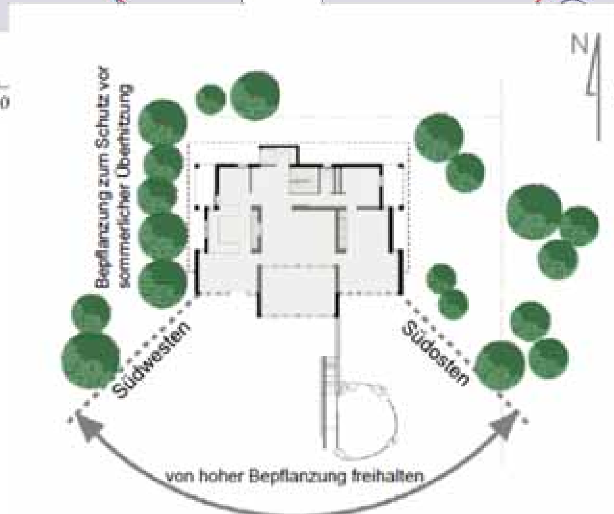
- Important parameters
  - window placement
  - glazing type
  - thermal insulation
  - thermal mass
  - shading
- .

[source: REHVA Guidebook] – Solar Shading





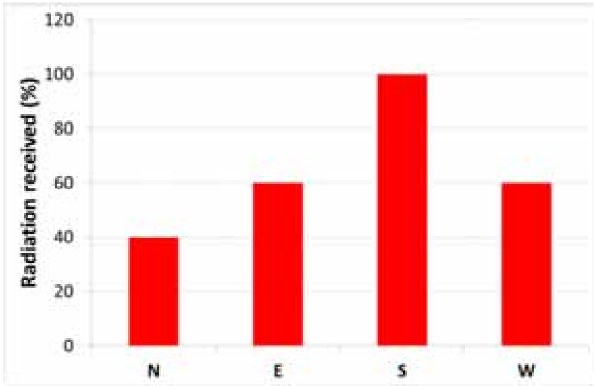
[source: passive-hybride-Gebaeudekuehlung.pdf]

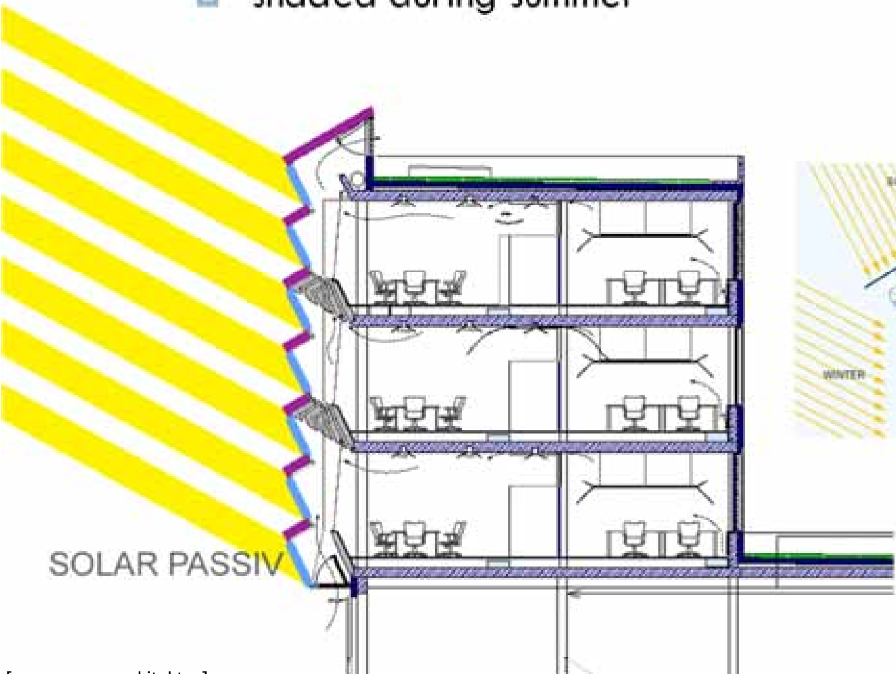


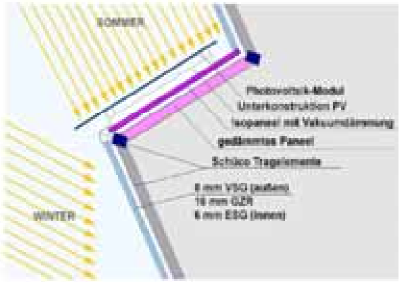
[source: https://www.tu-braunschweig.de/igs/]

Solar design ideas (temperate climates)

- Major **axis** parallel to equator
- Increased **orientation** of windows towards equator
  (Approx: Passive house max. 10°C, others max 30° angle difference)
- **Windows**, openings:
  - collecting during winter
  - shaded during summer



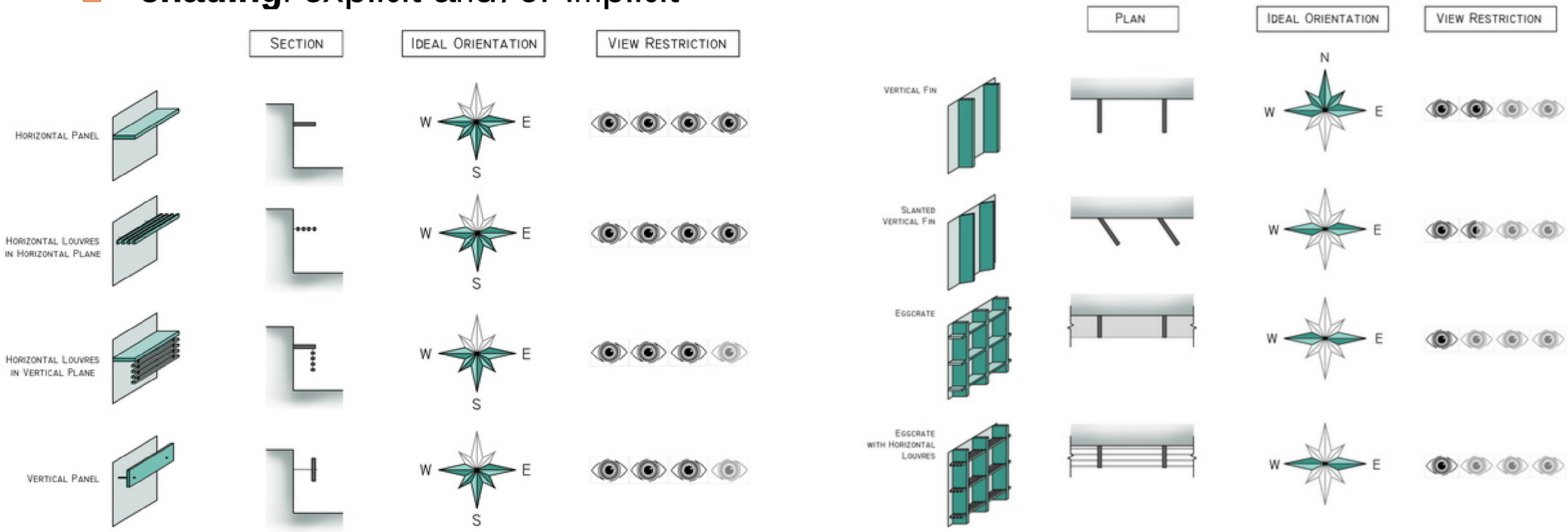


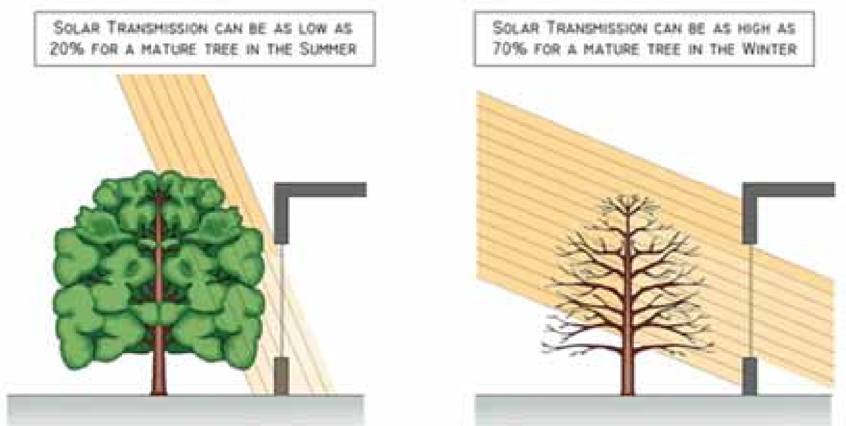


[source: pos architekten]

Solar design ideas (temperate climates)

- **Shading**: explicit and/or implicit

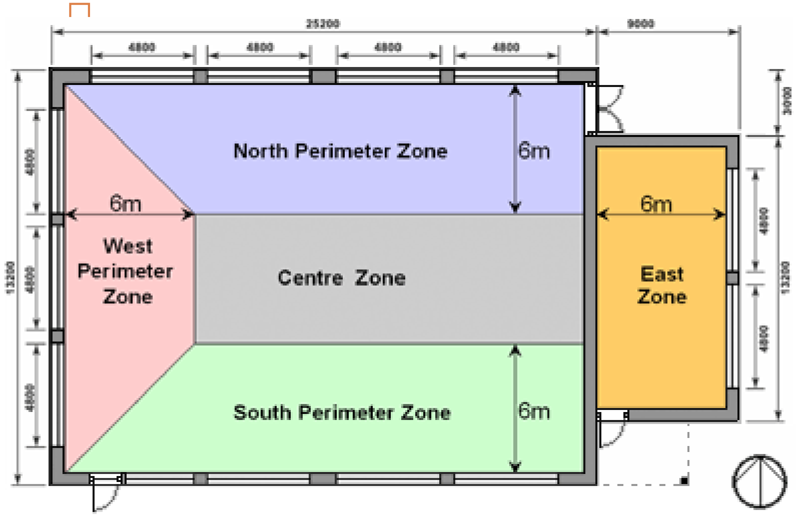




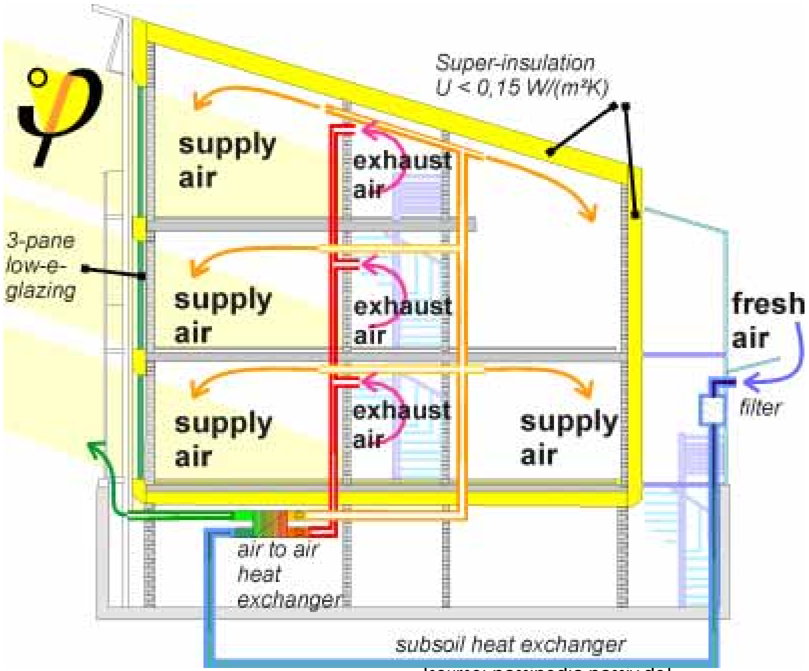
[source: tboake.com]

Solar design ideas (temperate climates)

- **Thermal zoning**
  - Grouping of rooms with similar conditions and/or similar comfort criteria
  - Optimization of location of room types
  - Adopt interior to solar concept
  - South: e.g. living room, social rooms,…
  - North: e.g secondary rooms, stairs, circulation areas,… (evtl. possible lower temperature during winter)



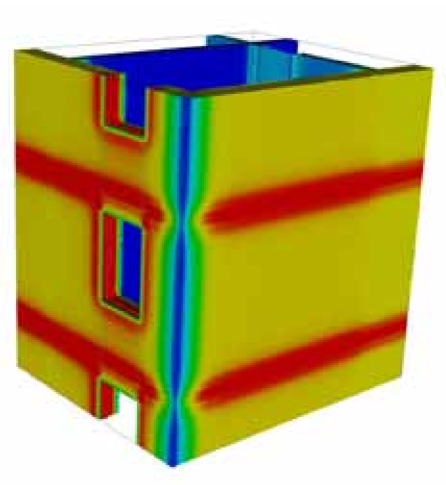
[source: naturalfrequency.com]

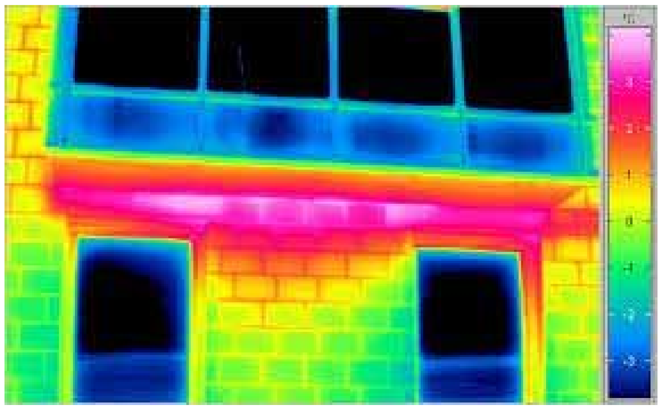


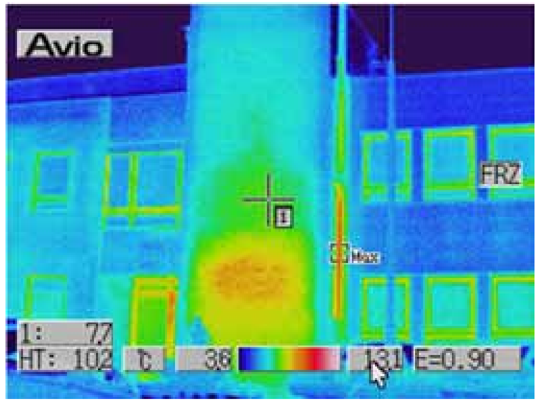
[source: passipedia.passiv.de]

Solar design ideas (temperate climates)

- Appropriate insulation: thickness, type, location
- Avoiding cold bridges
- Utilization of thermal mass as storage (for free) → load shift



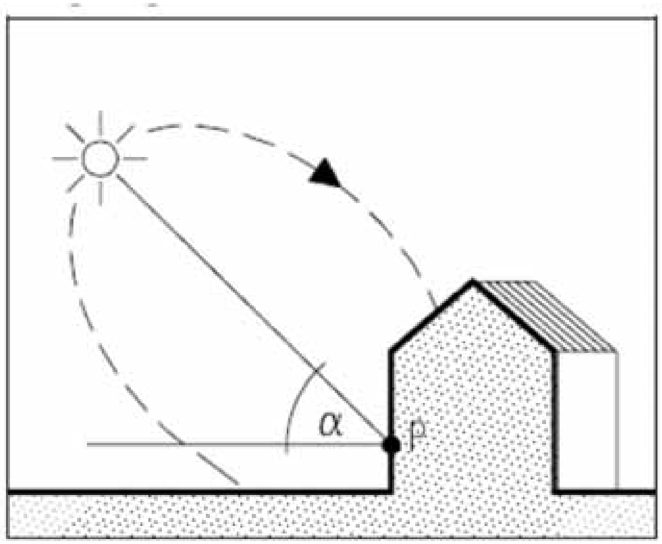


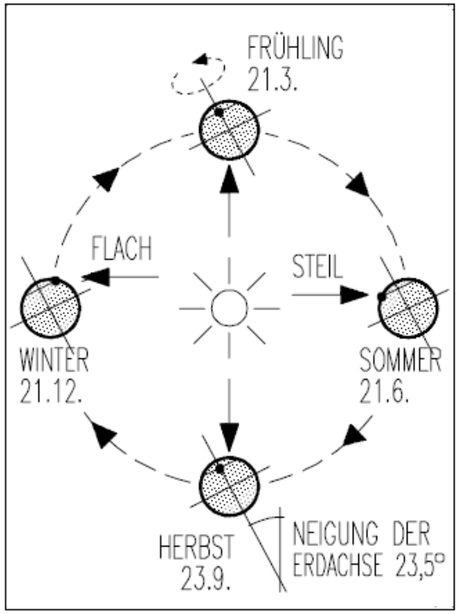


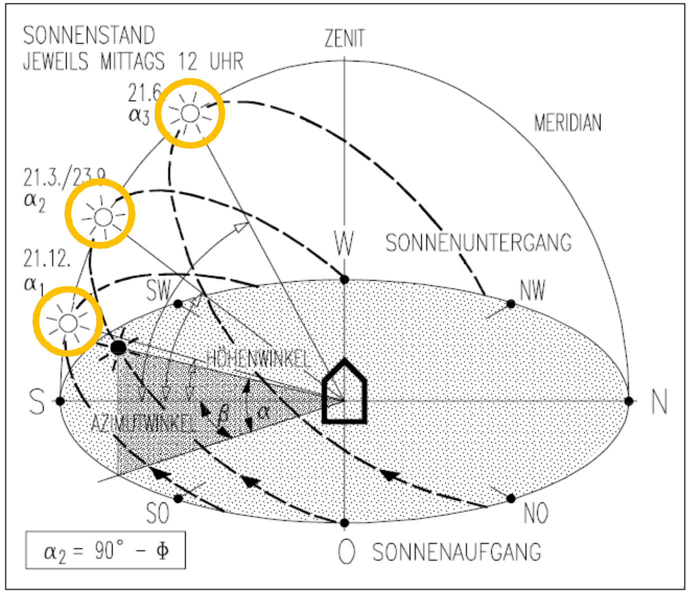
- To be considered: climatic conditions, latitude, altitude and comfort requirements!

Sun and earth

- Solar elevation angle α:







Source: Handbuch der Gebäudetechnik, W. Pistohl]

α_2 (21.03., 23.09.) = 90° - Φ
α_3 (21.06.) = α_2 + 23,5°

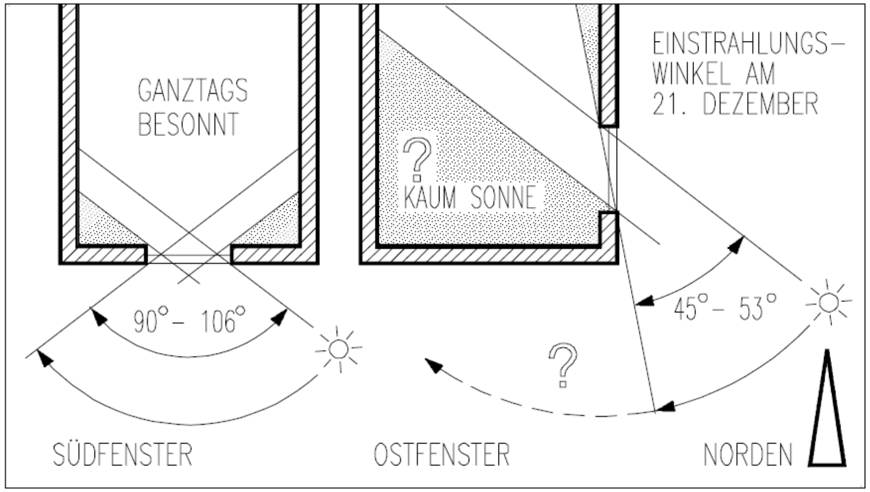
- Wels: α_1, α_2, α_3 ?

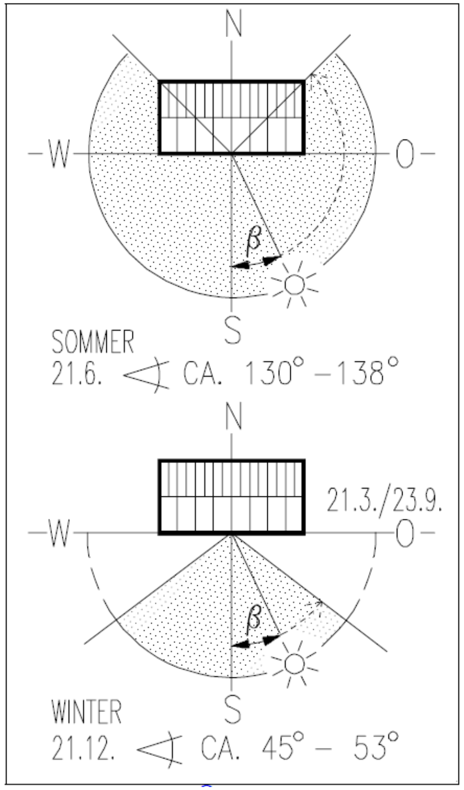
α_1 =18,35° α_2 = 41,85° α_3= 65,35°

Sun and earth

- Solar azimuth angle β

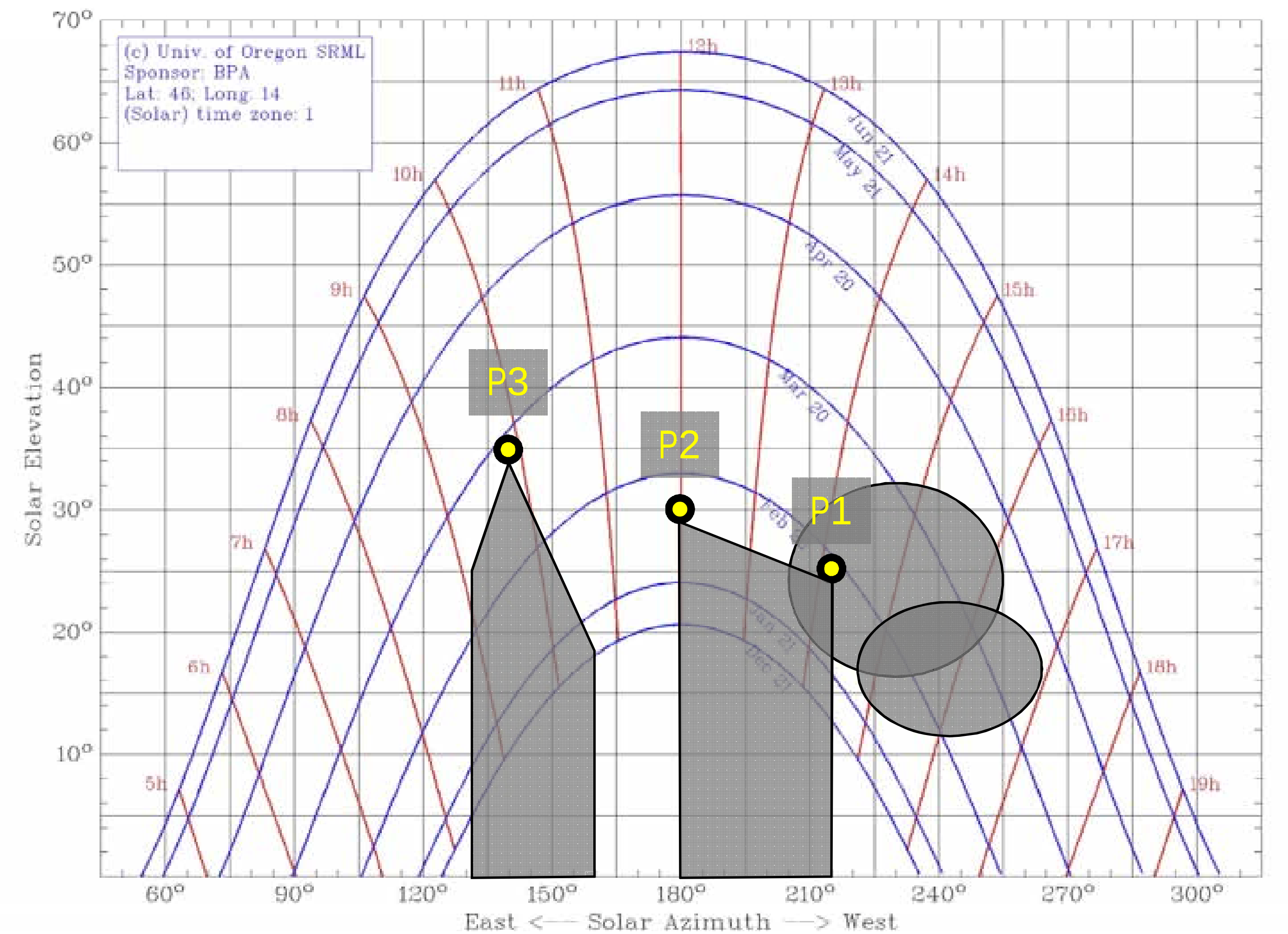
- Impact on building
  - Location openings
  - Orientation openings
  - Room shape
  - Interior design
  - Shading design





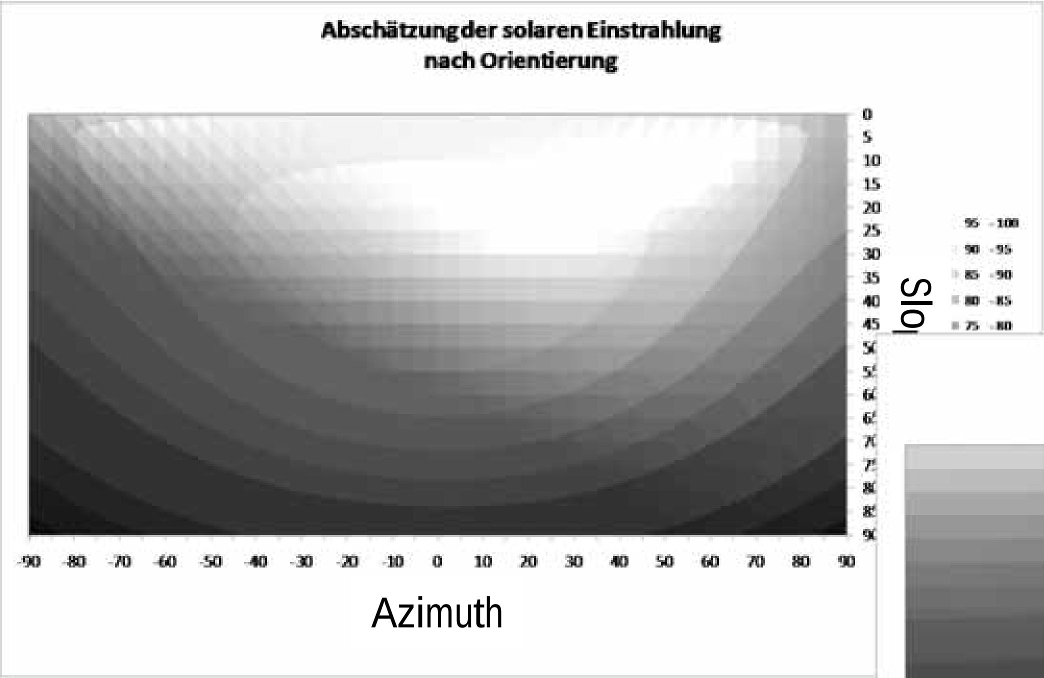
Source: Handbuch der Gebäudetechnik, W. Pistohl]

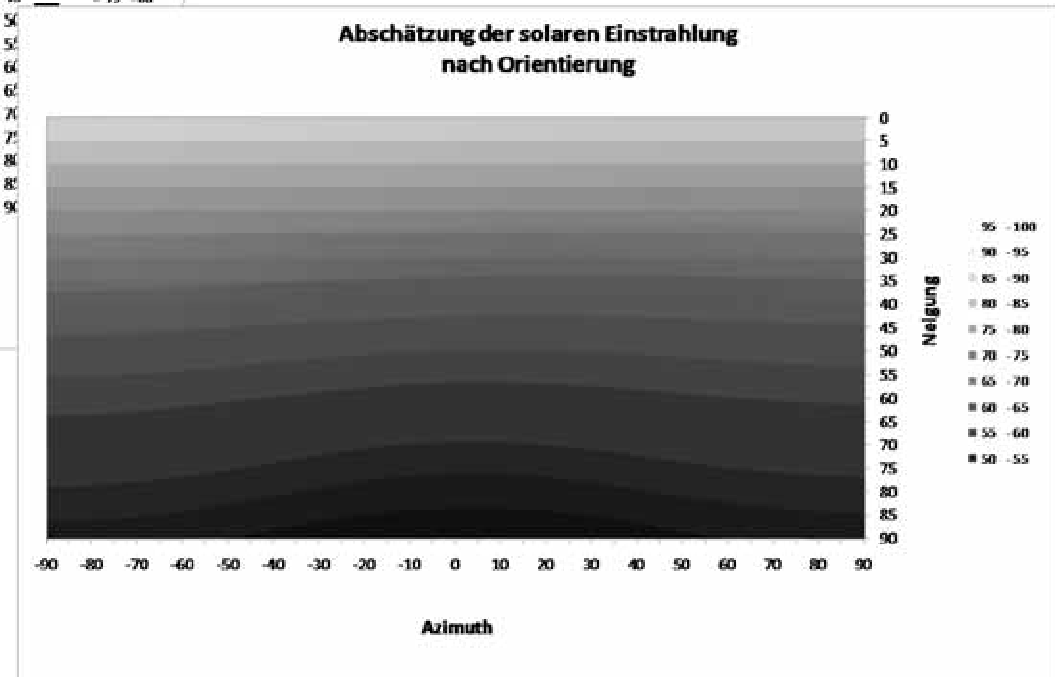
Sunpath diagramm



Analysis of slope & azimuth

- Estimated collector gain: f(slope, azimuth) – Yearly sum, % of optimal orientation





Requirements for glazing

Design
- Urban layout
- Corporate design
- Individual style
- Materials

Comfort & Efficiency
- Indoor climate
- Protection: heat, sun
- Protection: wind, rain
- Fresh air

Construction
- Mechanical loads
- Motion
- time
- workflow

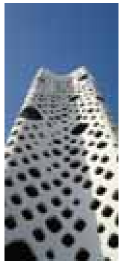
Function & Features
- Barrier free
- Flexible
- Controlable
- HVAC Integration
- RES

[source: stapletonsolicitors.biz]

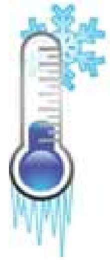
Acoustics
- To outside: Sound insulation
- To inside: Sound absorption

Safety
- Radiation
- Destruction
- Fire
- Fall down
- Escape path

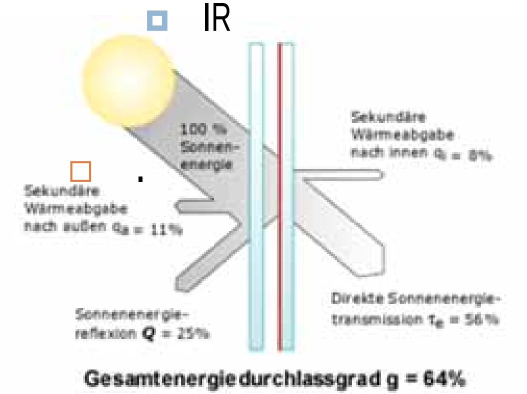
Visual comfort
- Daylighting
- View to outside
- Anti-glare
- Light directing
- cleaning

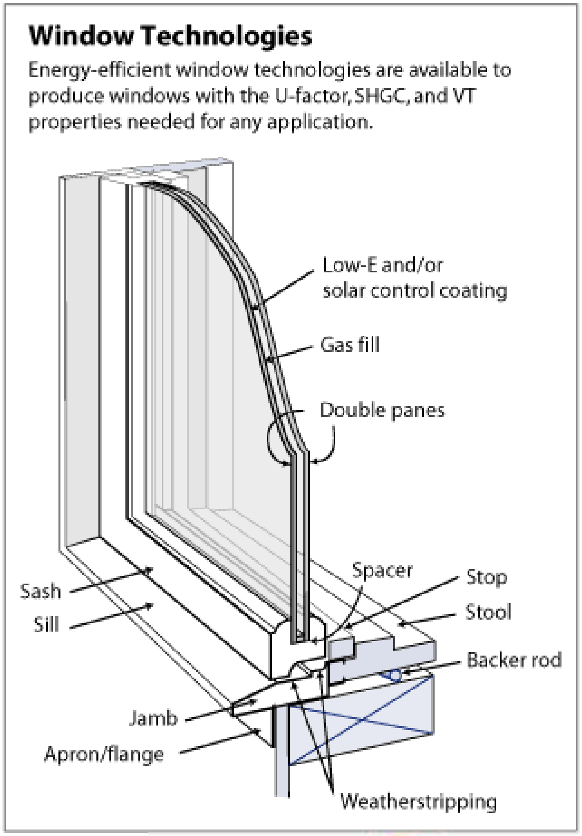


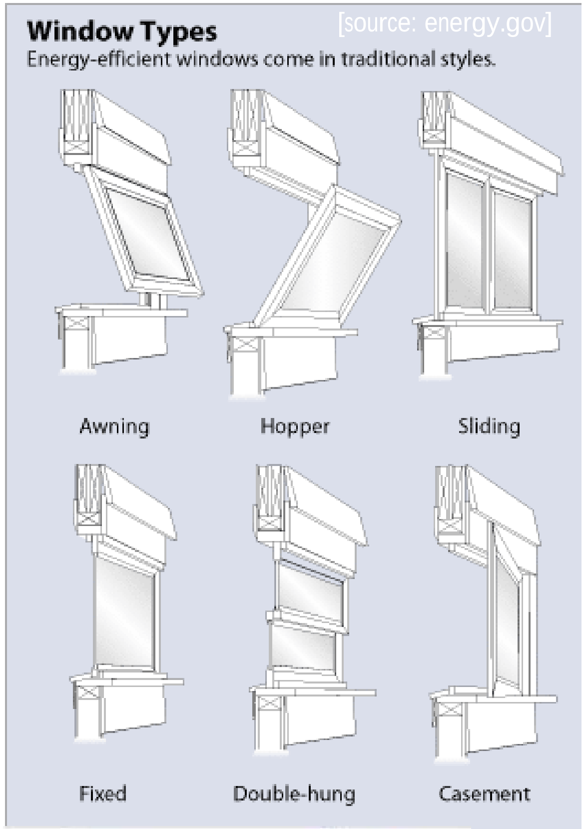
Glazing

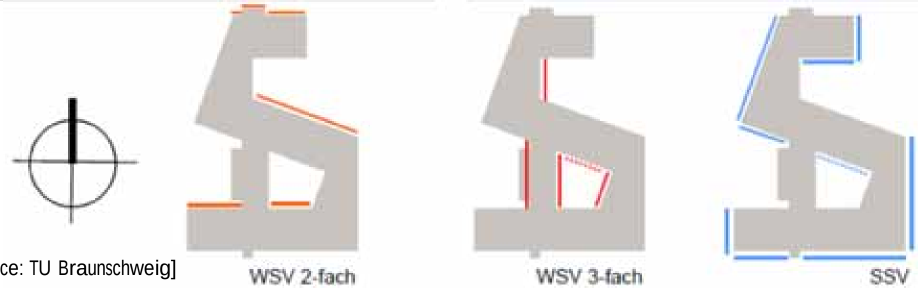


- Important parameters
- U-Value
  - Heat transfer
  - Glass
  - Frame
- SHGC (g) - Value
  - Transmitted energy
  - Visible
  - UV
  - IR
- .









[source: TU Braunschweig]

Daylighting

- Provides internal lighting
- Source: Sun light

→ Reduction of artificial lighting demand

→ Increase of comfort

[source: lightingcontrolsassociation.org]

Daylight legal requirements

Daylighting

- Area of windows, skylights min. 10 % of floor area
- Area of windows providing view to outside: min 5 % of floor area
- Glare has to be avoided (shading…)
- Homogenous lighting

Artificial lighting:

- No dominant colours, homogenous
- 300 lux (shops) – (85 cm above floor)
- 500 lux (office) – (85 cm above floor)
- 1500 lux (special applications, e.g. watchmaker…) – (85 cm above floor)

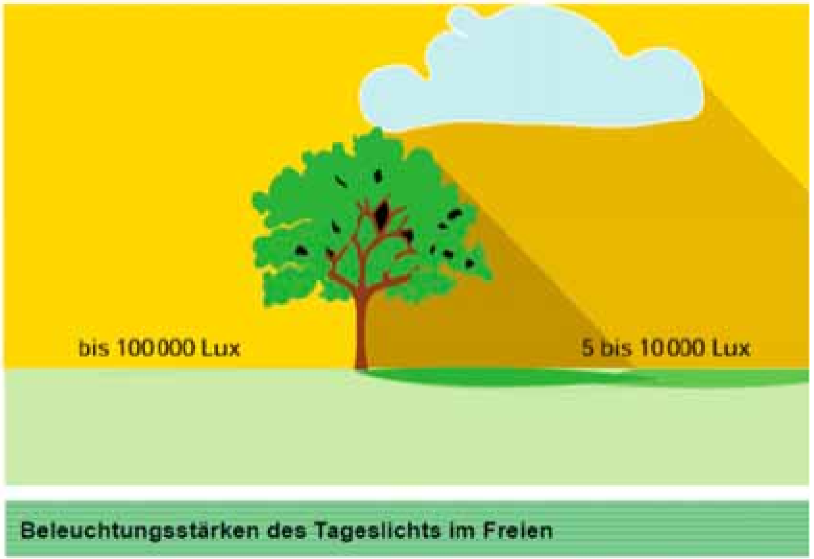
Legal framework

- §§ 21, 22 ArbeitnehmerInnenschutzgesetz (ASchG)
- Arbeitsstättenverordnung (AStV)
- § 6 Bildschirmarbeitsverordnung (BS-V)

Daylighting properties

Physical energy flux of radiation?

- Luminous flux Φ - *Lichtstrom*
  - Radiant flux sent by a light source
  - Unit: Lumen [lm]
- Luminous intensity I - *Lichtstärke*
  - Luminous flux sent by a light source in specific direction
  - Unit: Candela [cd], Φ/Ω
- Illuminance E – *Beleuchtungsstärke*
  - Radiation flux on a surface
  - Unit: Lux [lx], lm/m^2
  - $E=\Phi/A$ (A… area)
- Luminance L - *Leuchtdichte*
  - Luminous Intensity on a surface
  - Unit: $[cd/m^2]$
  - Photometric dimension of administered brightness
  - $L=I/A$ (A… area)

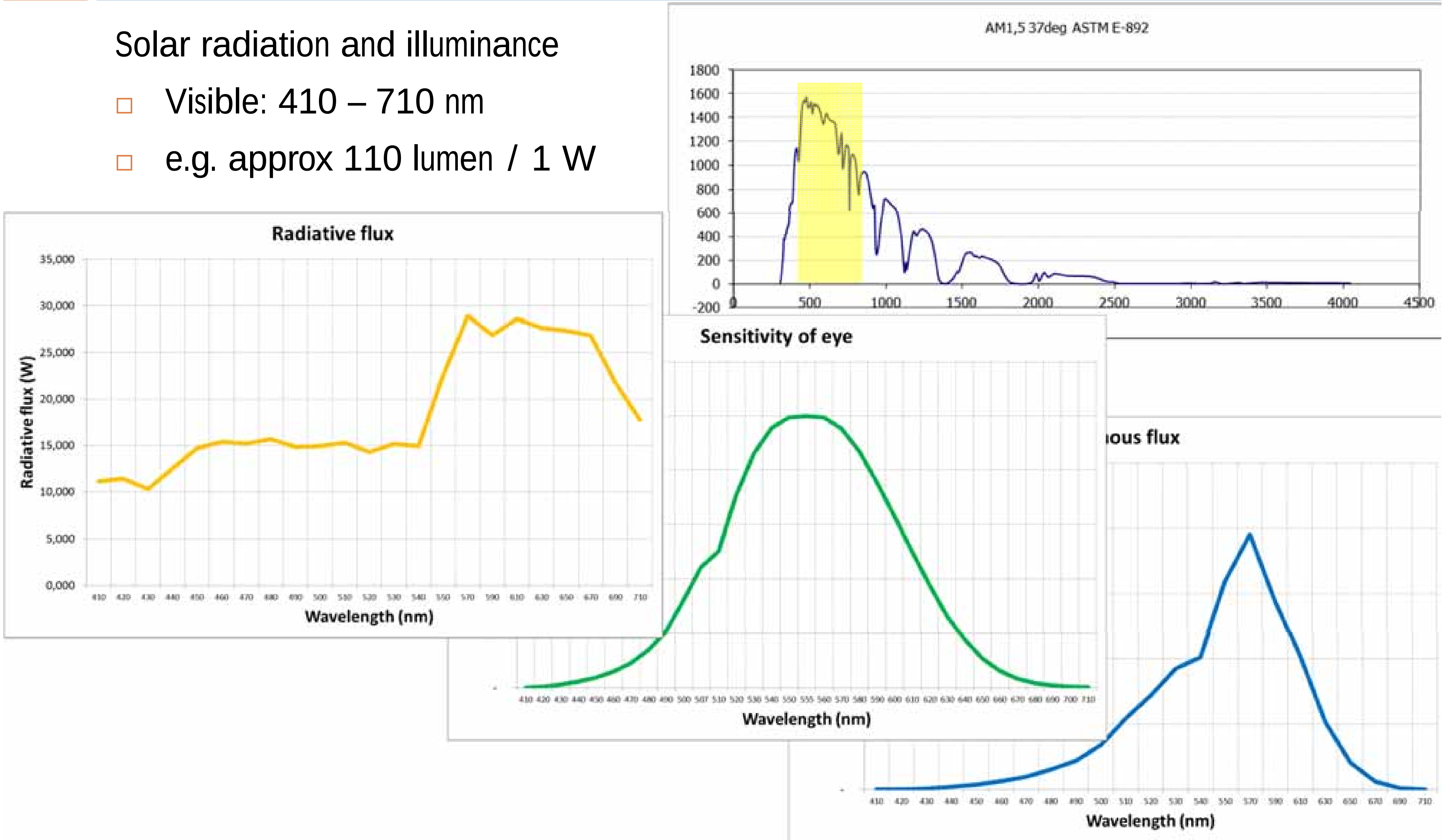


[source: TU Braunschweig]

Radiation and light

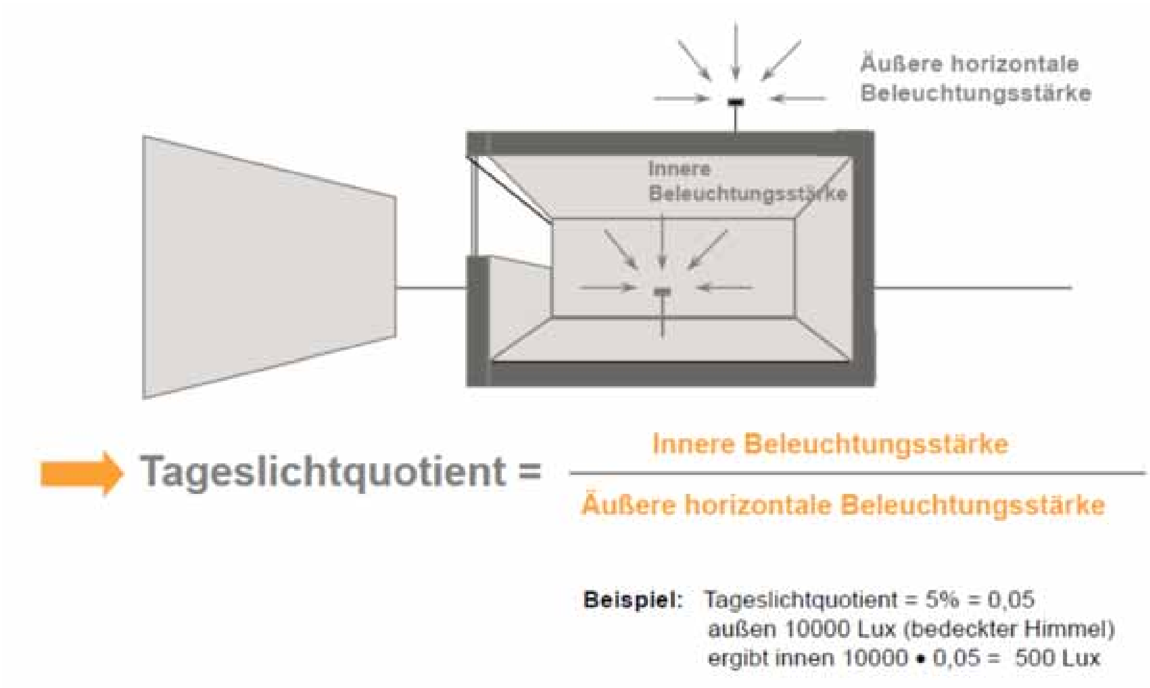
Solar radiation and illuminance

- Visible: 410 – 710 nm
- e.g. approx 110 lumen / 1 W



Daylight factor

- Ratio of internal light level to external light level:
  D = Ei/Eo * 100%



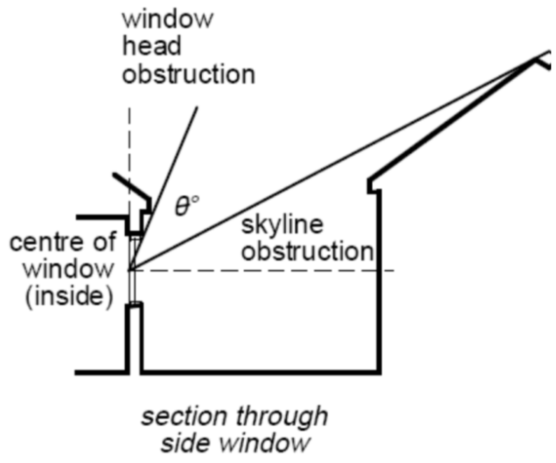
[source: TU Braunschweig]

Mean daylight factor

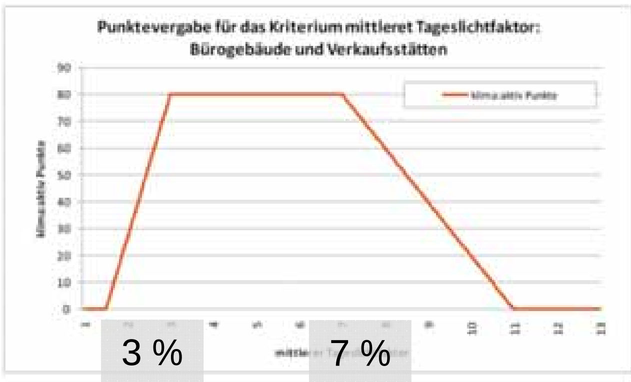
[source: klima:aktiv Bauen und Sanieren Kriterienkatalog, Bürogebäude Neubau - Nachweis OIB]

- Mean daylight factor (e.g. 3% - 7%)

$$\overline{D} = \frac{A_g \cdot \theta \cdot \tau_{D65}}{A \cdot (1 - R^2)} \quad \text{in } \%$$

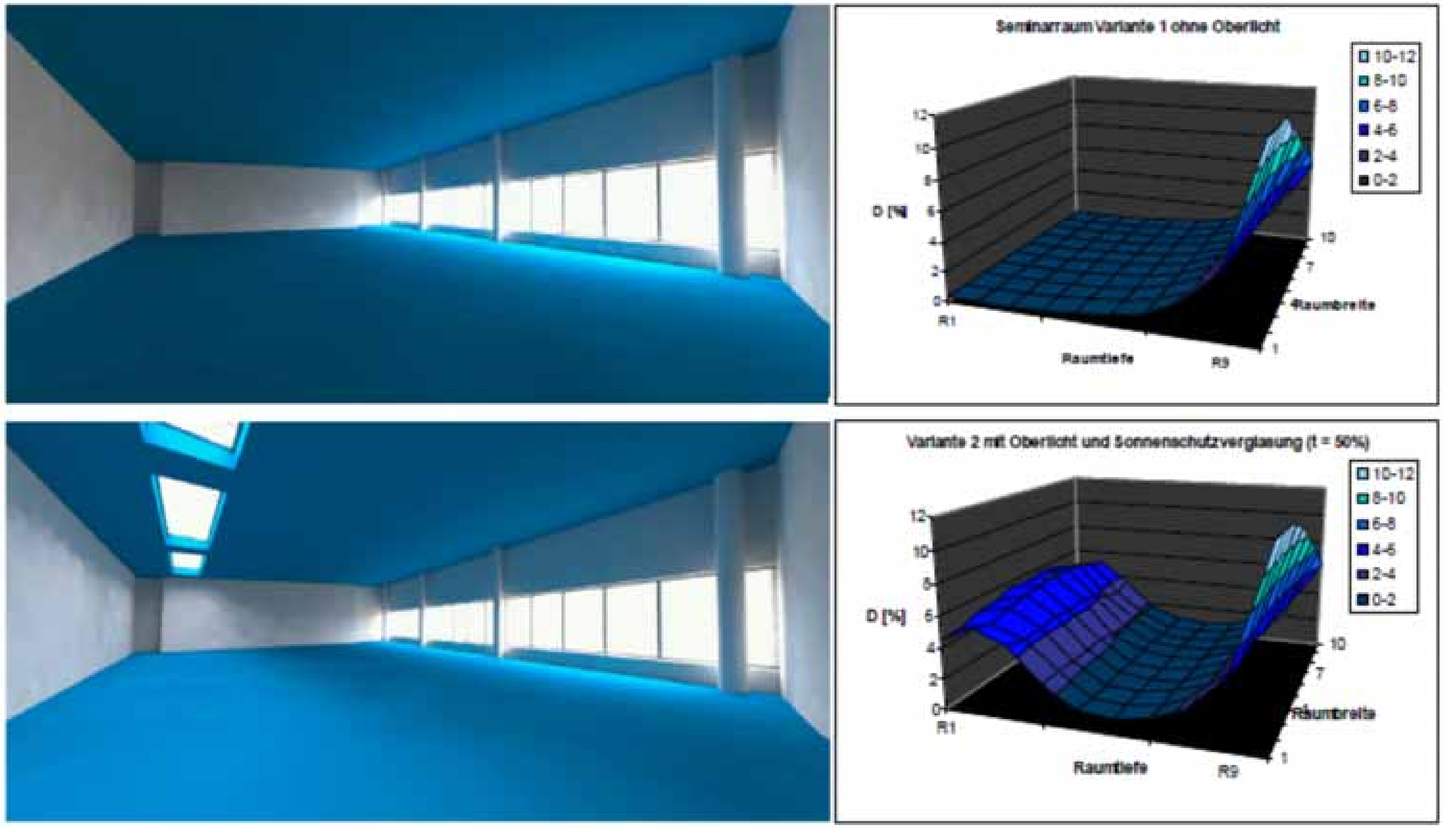


Formel	Bezeichnung	Einheit
A	umschließende Flächen des Innenraumes	m²
a_D	Tiefe des Tageslichtbereichs	
A_D	Tageslichtfläche des Gebäudes	m²
$A_{D,j}$	Tageslicht-Teilfläche des Bereichs j	m²
A_g	Verglasungsanteil des Fensters (beinhaltet nicht den Rahmenanteil)	m²
b_D	Breite des Tageslichtbereichs	m
b_{Fe}	Breite des Fensters (inkl. Rahmen)	
h_{Li}	Fensterstürzhöhe über dem Fußboden	m
h_R	Lichte Raumhöhe des Berechnungsbereichs mit Dachoberlichtee	
b_{links}	Abstand vom Fenster zur linken raumabschließenden Wand	m
b_{rechts}	Abstand vom Fenster zur rechten raumabschließenden Wand	m
h_{Ta}	Höhe des Bereichs der Sehaufgaben	m
NGF	Netto-Grundfläche des Gebäudes	
R	Reflexionsgrad der jeweiligen umschließende Fläche	-
θ	Winkel des sichtbaren Himmels, gemessen vom Zentrum der Fensteröffnung in der Ebene der Innenseite der Außenwand	°
τ_{D65}	Lichttransmissionsgrad der Verglasung bei Normlichtart D65	-



Daylighting

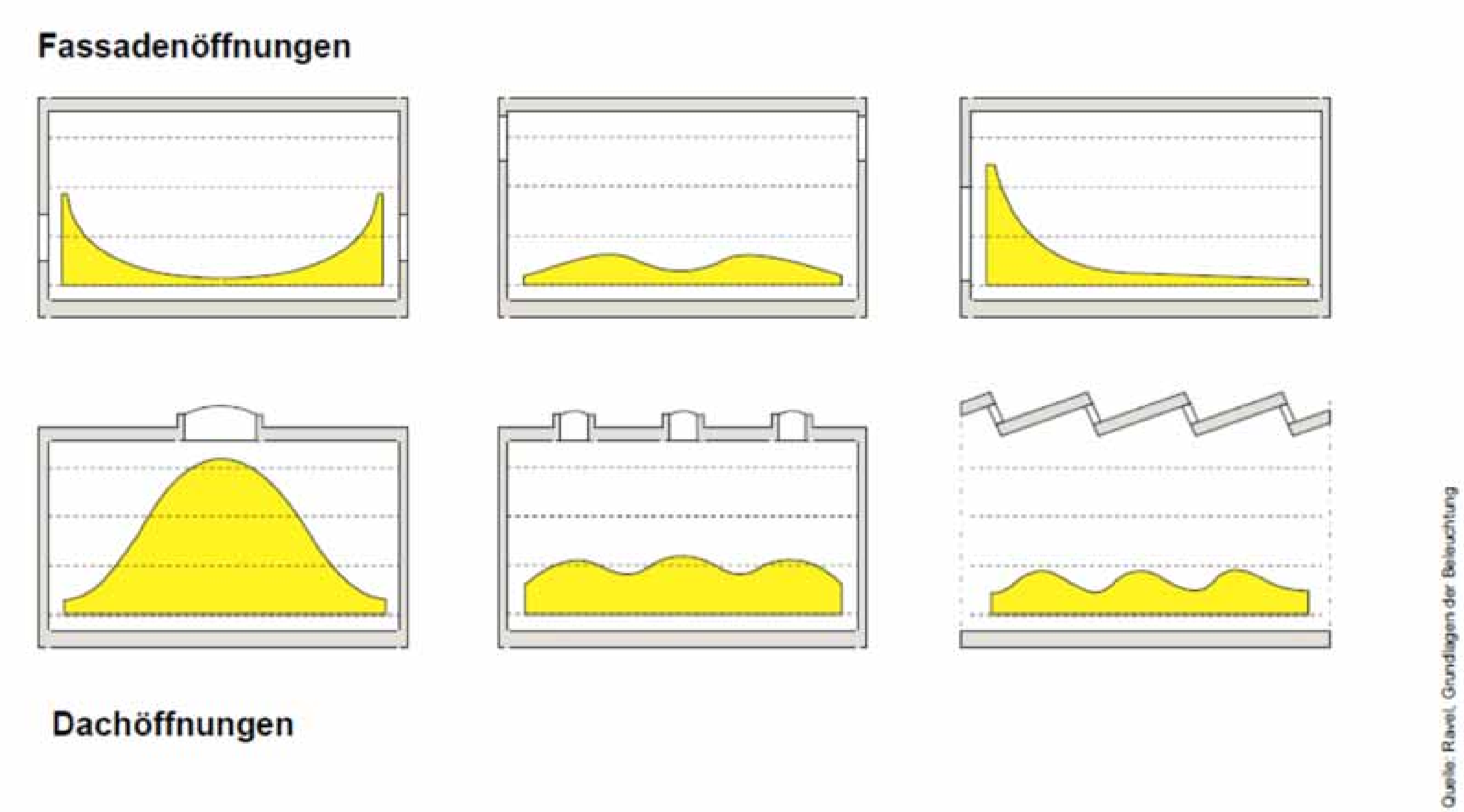
- .



[source: TU Braunschweig]

Daylighting

- .

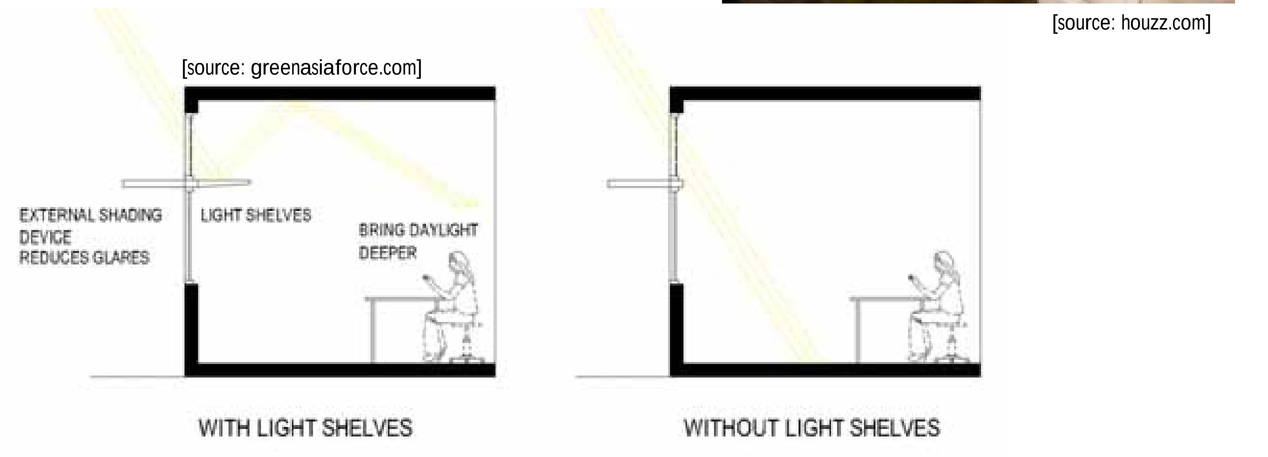


Daylighting components

- Windows
- Skylights
- Clerestory windows
- Light reflectors
- Light shelves

[source: my.whirlwindsteel.com]

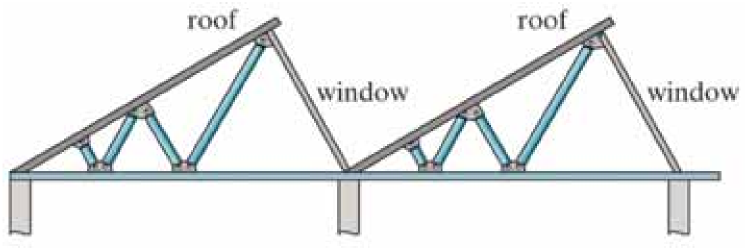
[source: houzz.com]



[source: greenasiaforce.com]

Daylighting components

- Sawtooth roof



[source: classes.mst.edu]

- Heliostats

[source: wikipedia]

- Smart glass

[source: www.prote.in]

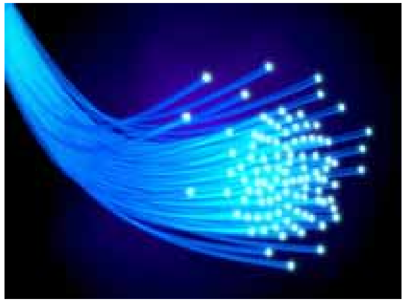
- Fiber-optic concrete wall

[source: litracon.hu]

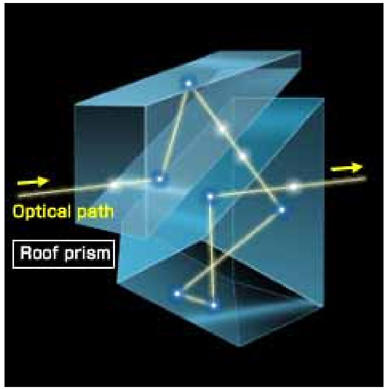
Light tubes

- Light tube with reflective material
- Optical fiber
- Transparent hollow light guides
- Fluorescence based systems
- IR Light Tube

[source: velux.at]

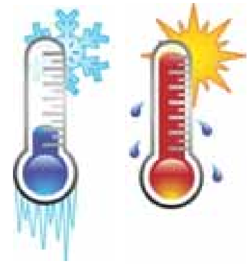


[source: sites.psu..edu]



[source: nikon.com]

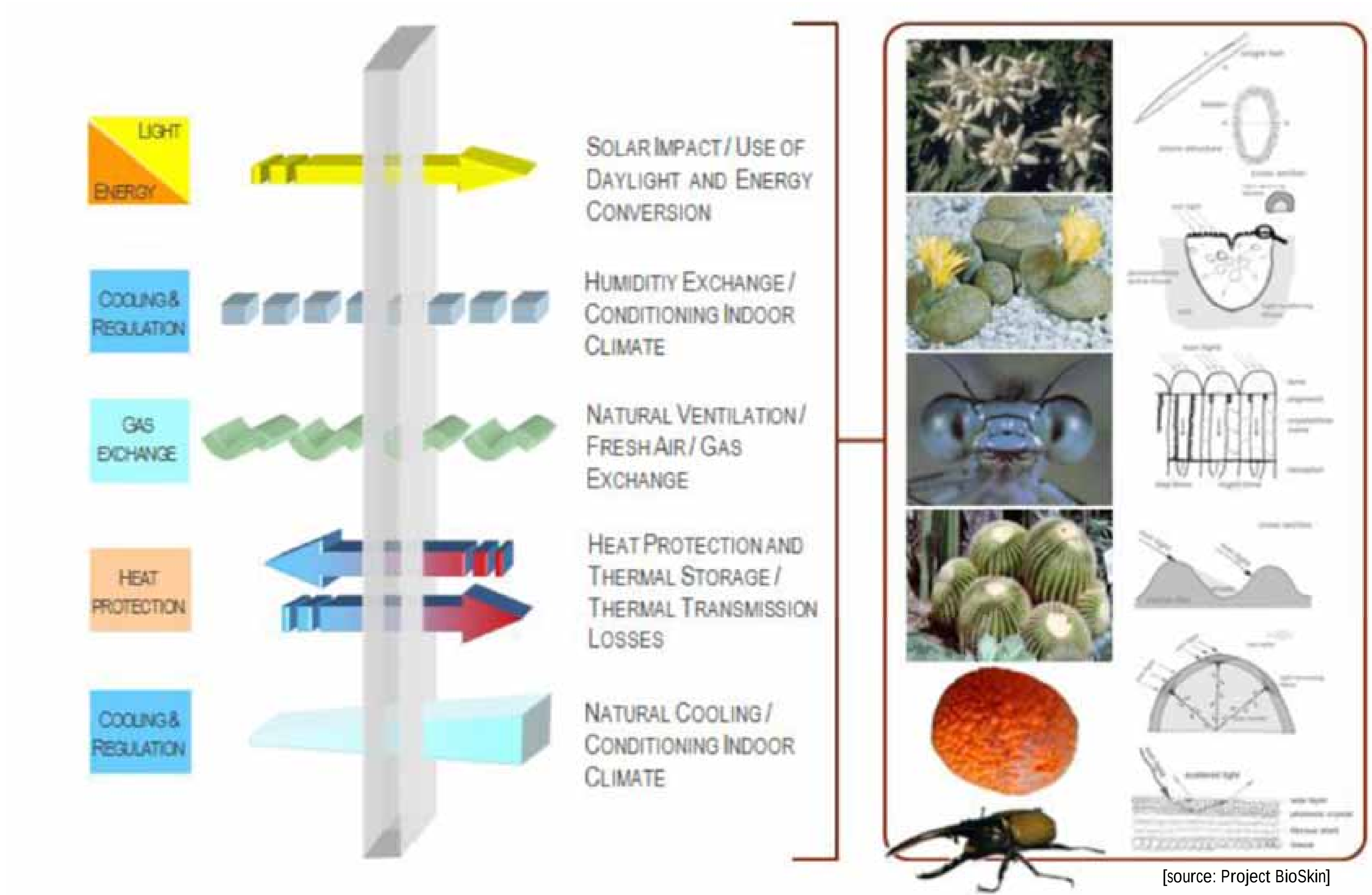
Biomimetics



- Nature – Technology
- Top Down or Bottom Up approach
- Research project: BioSkin

[source: Project BioSkin]

BioSkin - Functionality



[source: Project BioSkin]

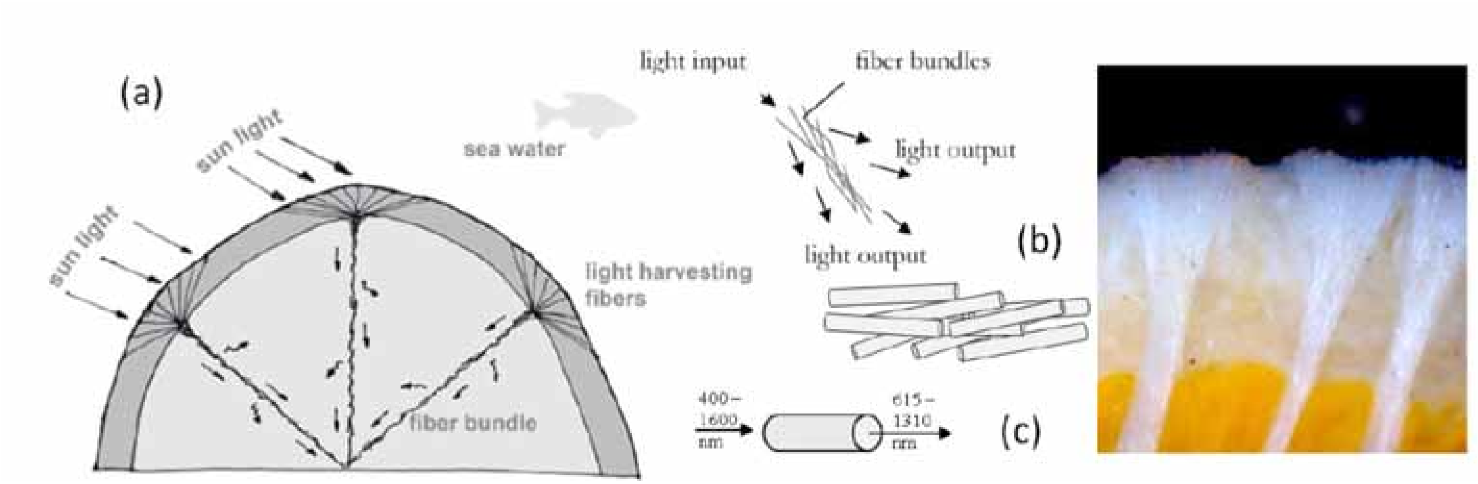
BioSkin – Daylight evaluation

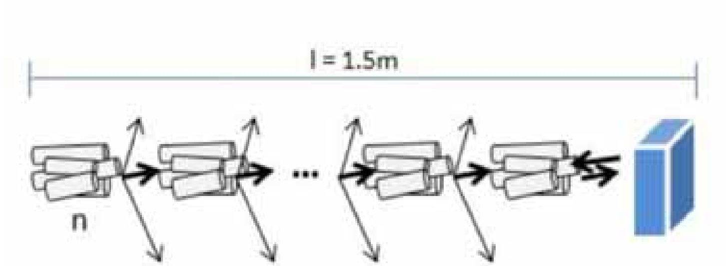
TAGESLICHT *Auszug biologischer Prinzipien*

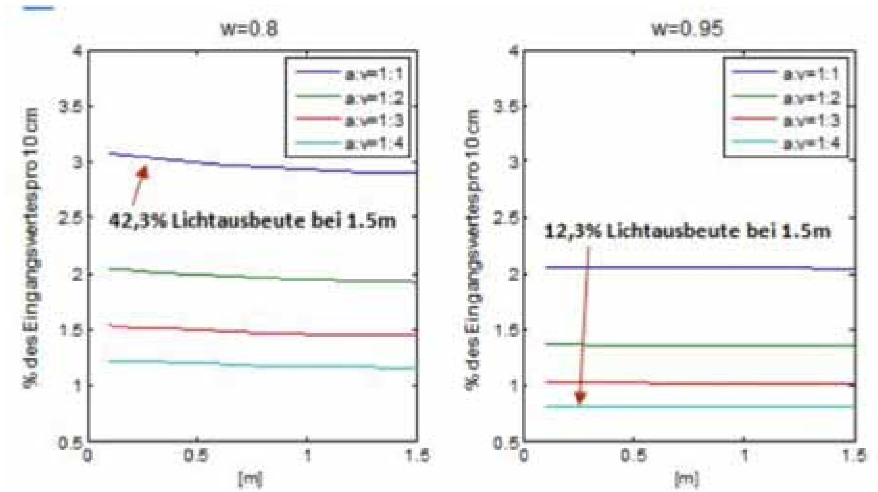
technisches Funktionsziel	Strukturfarben	antireflektive Beschichtung	Licht-transmission durch Linsen und Facetten	Licht-transmission durch Fasern und Kristalle	selektive Lichtkontrolle durch Pigmente	Statische Verschattungs-strukturen	reversible Aktuator-systeme
Maximale Licht-transmission	x	x	x	x	x		
Selektive Licht-transmission	x	x			x	x	x
Lichtleitung	x	x		x			
Beispiel potenzieller biologische Vorbilder	Cyphochilus, Herkuleskäfer (*Scarabaeidae*) 	Mottenaugen (*Deilephila elpenor*) 	Gießkannen-schwamm (*Euplectella aspergillum*) 	Meerorange (*Thethya aurantia*) 	Facettenaugen von Insekten (*Oculi compositi*) 	Kakteen-gewächse (*Cactaceae*) 	Blattbewegung, Orientierung der Heliconia 

[source: Project BioSkin]

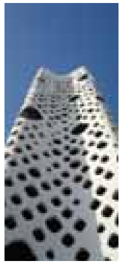
Daylight guiding example







[source: Project BioSkin]

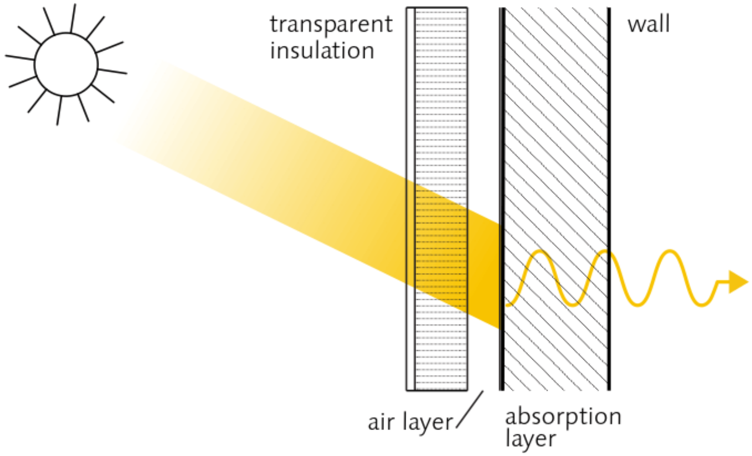


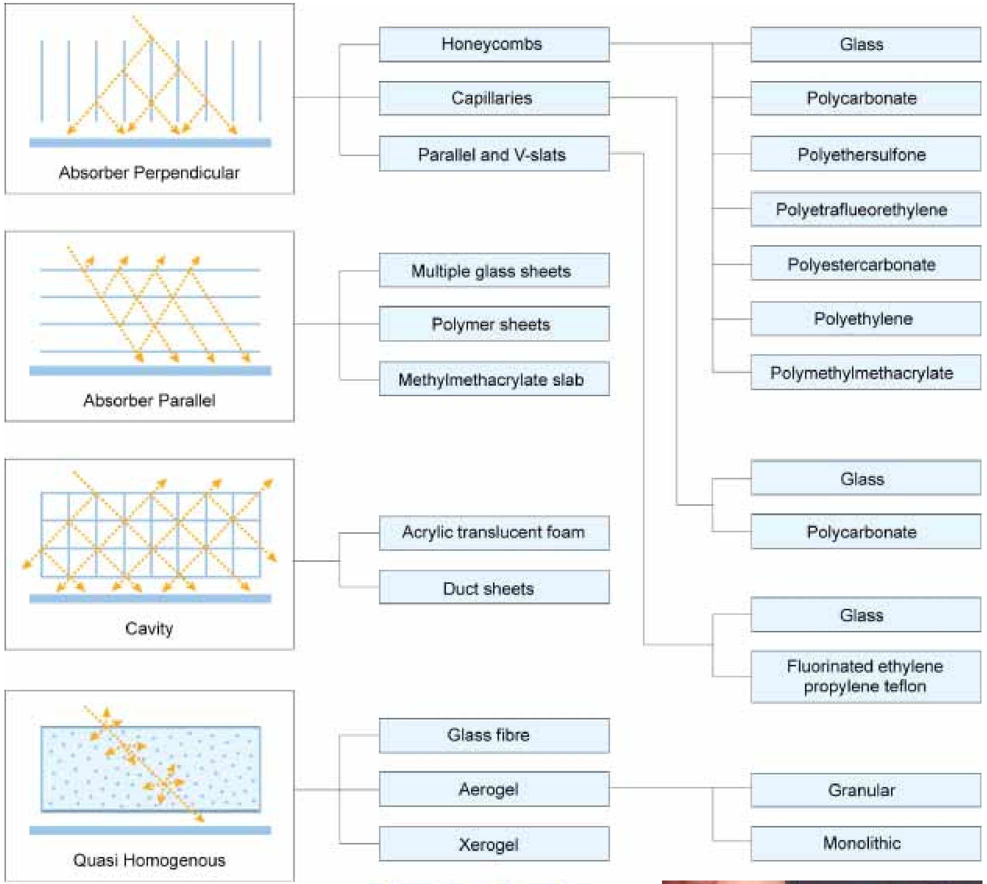
Transparent insulation

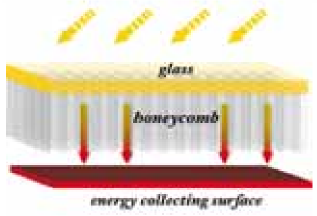
- Application: windows, walls

Benefits

- Additional solar heat gain
- Improvement of insulation
- Increased thermal comfort
- Decreased condensation and mold growth
- Delay of solar heat gains (complements solar gain through windows)



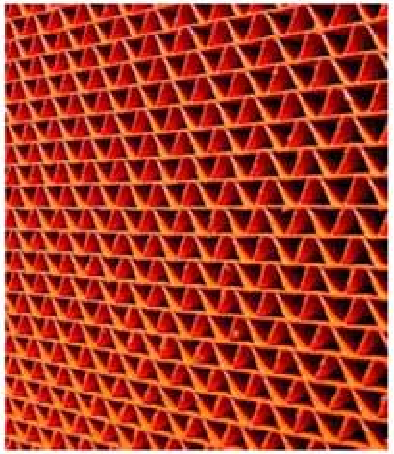


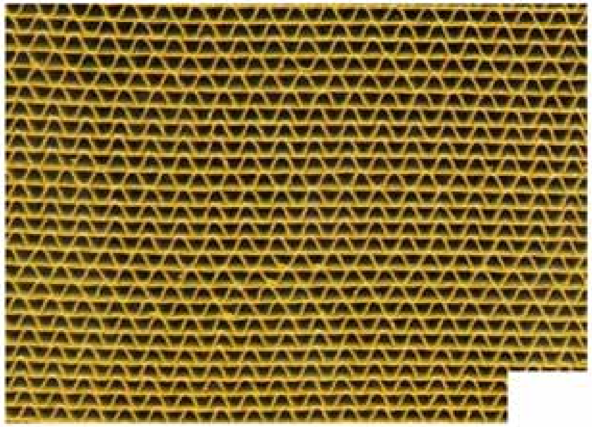


Transparent insulation - Examples

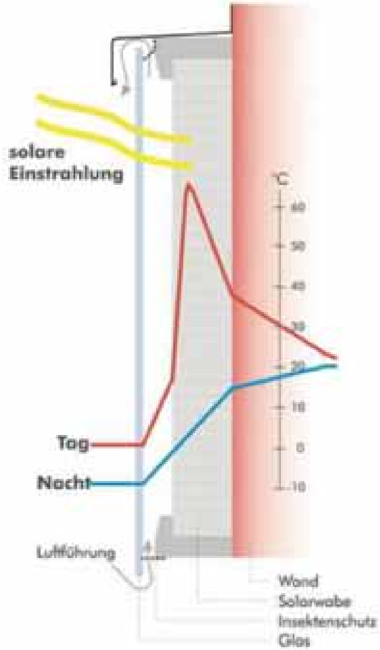
Transparent insulation - Study

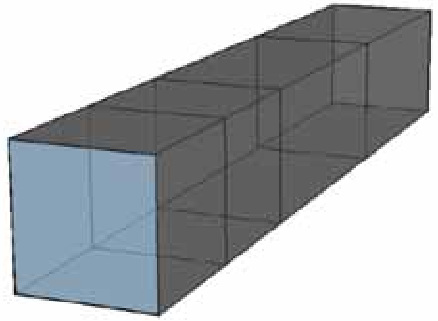
- Simulation study
- Refurbishment of residential building with transparent insulation
- Master thesis M. Wallner (FHTW, 2014)





[source: Master thesis M. Wallner]



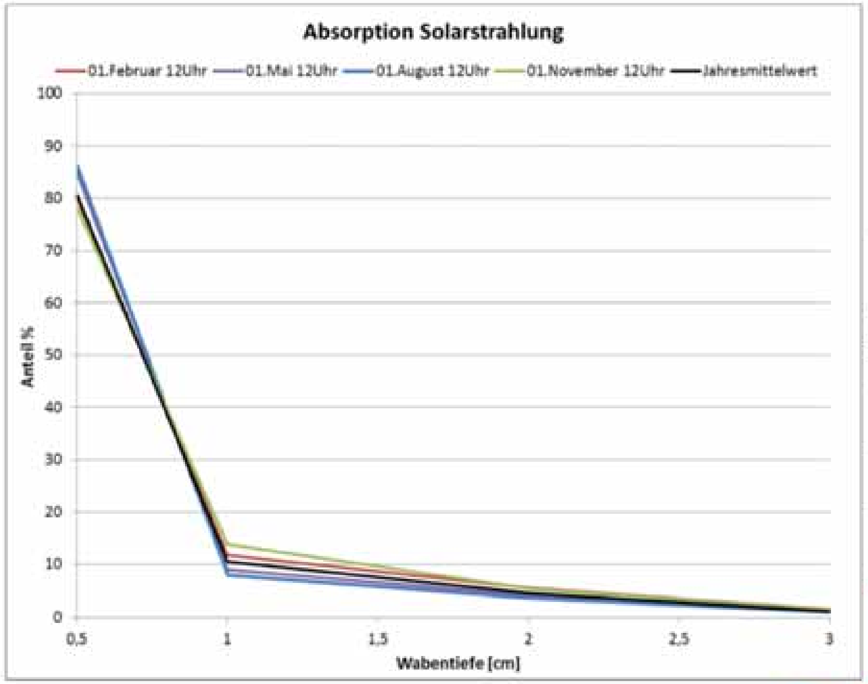


[source: Master thesis M. Wallner]

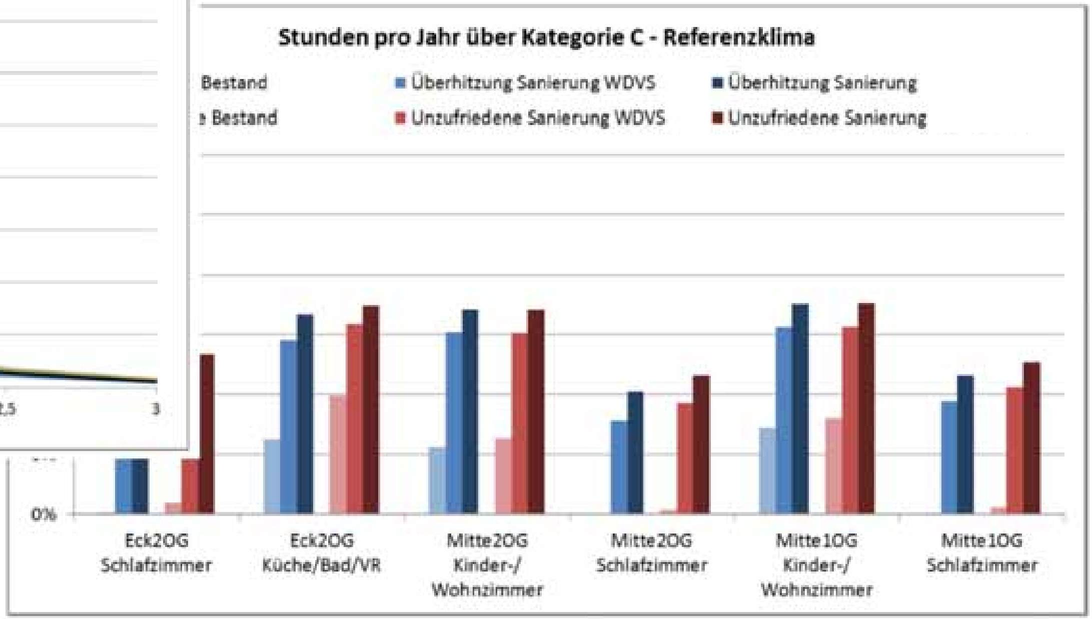
Transparent insulation - Study

Some results…

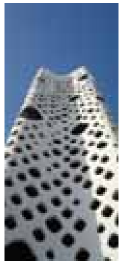
- 90 % of radiation absorbed within first 1 cm
- Increased overheating during summer



[source: Master thesis M. Wallner]



[source: Master thesis M. Wallner]

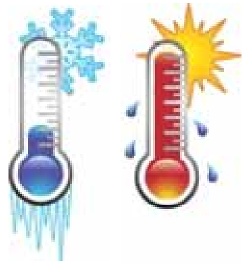


Transparent insulation

- http://inhabitat.com/lets-talk-about-insulation-baby/

- Solar transparent insulation materials: a review. N.D. Kaushikaa, K. Sumathy

Building structure

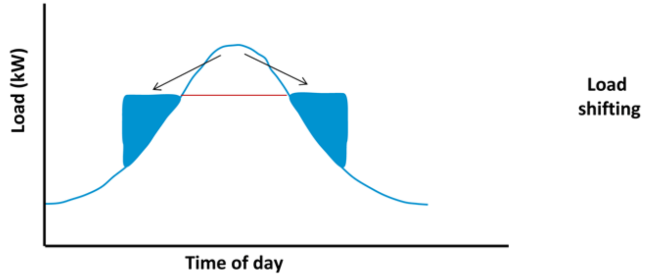


- Building structure holds thermal inertia

  Heat: $Q = m \cdot c_p \cdot \Delta\vartheta$ (kJ, Wh,…)

  Thermal diffusivity: $a = \frac{\lambda}{\rho c}$ (m^2/s)

- Enables load shift due to storage effects
- Pre-Heating or Pre-Cooling



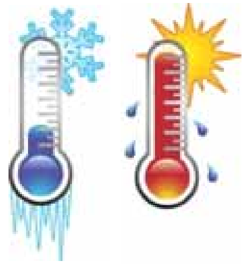
- Basic principle:
  Shift thermal loads to times when production or regeneration is more efficient!

Building structure

Please do a ranking: High thermal mass → Low thermal mass

C – D – A – B

Building structure - Basics



- EN ISO 13786 „Wärmetechnisches Verhalten von Bauteilen – Dynamisch thermische Kenngrößen

  $\rightarrow Q = m \cdot c_p \cdot \Delta\vartheta = C_{eff} \cdot \Delta\vartheta$

- Periodical penetration depth

  $$\delta_{pe} = \sqrt{\frac{\lambda \cdot T}{\pi \cdot \rho \cdot c}}$$

- Effective heat capacity – „Verfahren der wirksamen Dicke“

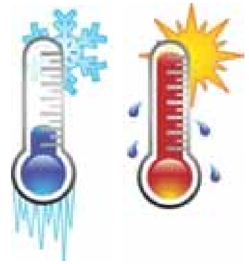
  $\chi_m = \sum_i \rho_i \cdot d_i \cdot c_i$ und $\sum_i d_i = \delta_{eff}$, δ_{eff} = Maximum effective thickness

  - $\delta_{per,\ const}$ = 20 mm (1 hour) | 100 mm (1 day) | 250 mm (1 week)
  - δ_{ins} = Thickness till first insulation layer
  - δ_{constr} = Thickness of entire construction / 2

  Find minimum!

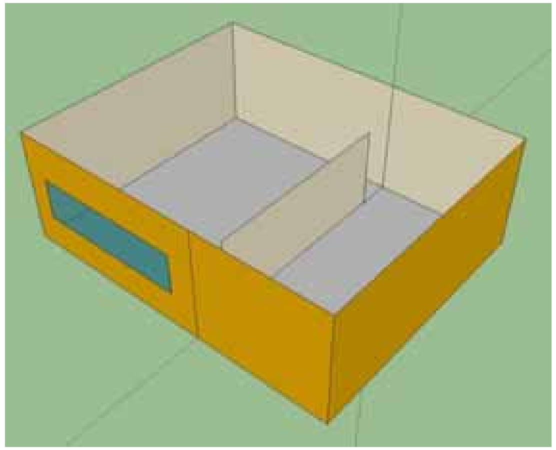
$\rightarrow \delta_{eff}$ = Maximum effective thickness = min ($\delta_{per}, \delta_{ins}, \delta_{constr}$)

Effective thermal capacity

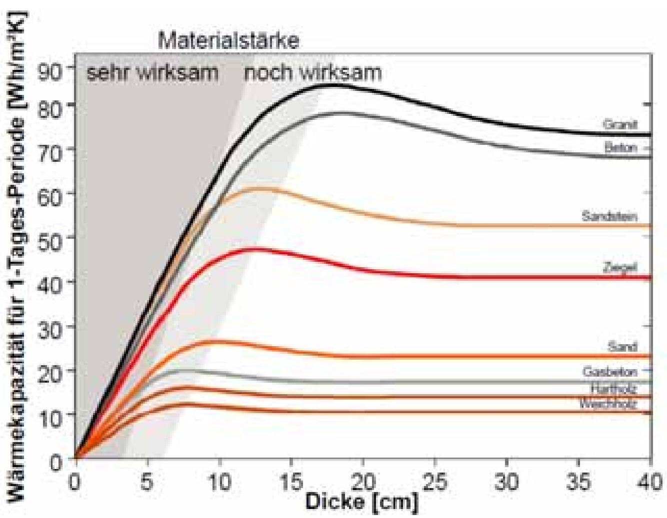


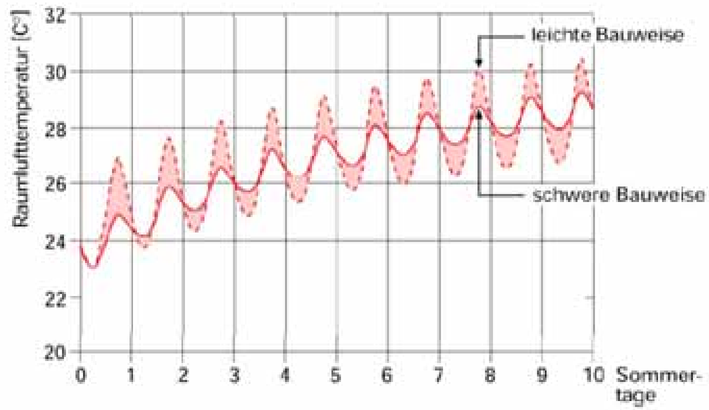
- C_{eff} (Internal walls):
  if both sides in 1 room, consider both sides

- C_{eff} (Windows) = 0



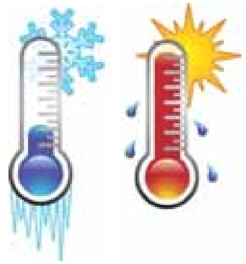
→ C_{eff} (Room) = C_{eff} (Walls + roof + floor + internal walls)





[TU Braunschweig]

Example residential



External wall — EXT_RES45

Material	d	ρ	λ	c
INSIDE	m	kg/m³	W/m.K	J/kg.K
Plaster in	0,015	1.200	0,600	1.000
Brick	0,210	1.380	0,700	1.000
EPS	0,120	17	0,040	700
Plaster out	0,003	1.800	0,700	1.000

Ground floor — GRD_RES45

Material	d	ρ	λ	c
	m	kg/m³	W/m.K	J/kg.K
Wood	0,015	600	0,150	2.500
Plaster floor	0,120	2.000	1,400	1.000
Sound ins.	0,040	80	0,040	1.500
Concrete	0,180	2.400	1,330	1.080
XPS	0,160	38	0,037	1.450

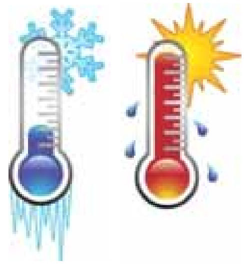
Roof — RC_RES45

Material	d	ρ	λ	c
	m	kg/m³	W/m.K	J/kg.K
Gypsum boarc	0,025	900	0,211	1.000
Plywood	0,015	300	0,081	2.500
Rockwool	0,160	60	0,036	1.030
Plywood	0,015	300	0,081	2.500

Ceiling — CEI_RES45

Material	d	ρ	λ	c
	m	kg/m³	W/m.K	J/kg.K
Concrete	0,180	2.400	1,330	1.080
EPS	0,100	17	0,040	700

Specific thermal capacity



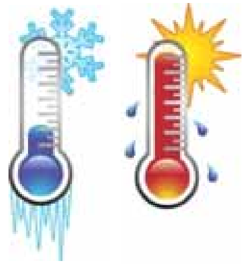
External wall				EXT_RES45
Material	**d**	**ρ**	**λ**	**c**
INSIDE	**m**	**kg/m³**	**W/m.K**	**J/kg.K**
Plaster in	0,015	1.200	0,600	1.000
Brick	0,210	1.380	0,700	1.000
EPS	0,120	17	0,040	700
Plaster out	0,003	1.800	0,700	1.000
d (1/2)	0,174		*U*	*0,286*
d (Dämmung)	0,225			**cwirk, spez**
d (Periode)	0,100			**Wh/m².K**
d (MIN)	0,100		*87,4*	37,6

Roof				RC_RES45
Material	**d**	**ρ**	**λ**	**c**
	m	**kg/m³**	**W/m.K**	**J/kg.K**
Gypsum boarc	0,025	900	0,211	1.000
Plywood	0,015	300	0,081	2.500
Rockwool	0,160	60	0,036	1.030
Plywood	0,015	300	0,081	2.500
d (1/2)	0,108		*U*	*0,197*
d (Dämmung)	0,040			**cwirk, spez**
d (Periode)	0,100			**Wh/m².K**
d (MIN)	0,040		*15,2*	9,4

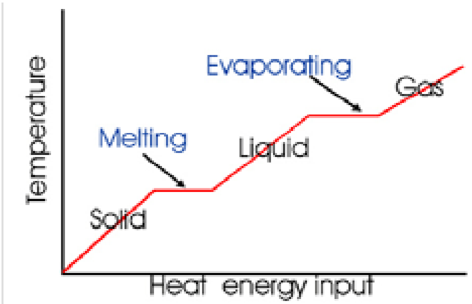
Ground floor				GRD_RES45
Material	**d**	**ρ**	**λ**	**c**
	m	**kg/m³**	**W/m.K**	**J/kg.K**
Wood	0,015	600	0,150	2.500
Plaster floor	0,120	2.000	1,400	1.000
Sound ins.	0,040	80	0,040	1.500
Concrete	0,180	2.400	1,330	1.080
XPS	0,160	38	0,037	1.450
(Aktivierung: "Plaster floor", 50% - aktiv - 50%)				
d (1/2)	0,258		*U*	*0,172*
d (Dämmung)	0,135			**cwirk, spez**
d (Periode)	0,100			**Wh/m².K**
d (MIN)	0,100		*206,3*	53,5

Ceiling				CEI_RES45
Material	**d**	**ρ**	**λ**	**c**
	m	**kg/m³**	**W/m.K**	**J/kg.K**
Concrete	0,180	2.400	1,330	1.080
EPS	0,100	17	0,040	700
d (1/2)	0,140		*U*	*0,360*
d (Dämmung)	0,180			**cwirk, spez**
d (Periode)	0,100			**Wh/m².K**
d (MIN)	0,100		*129,9*	72,0

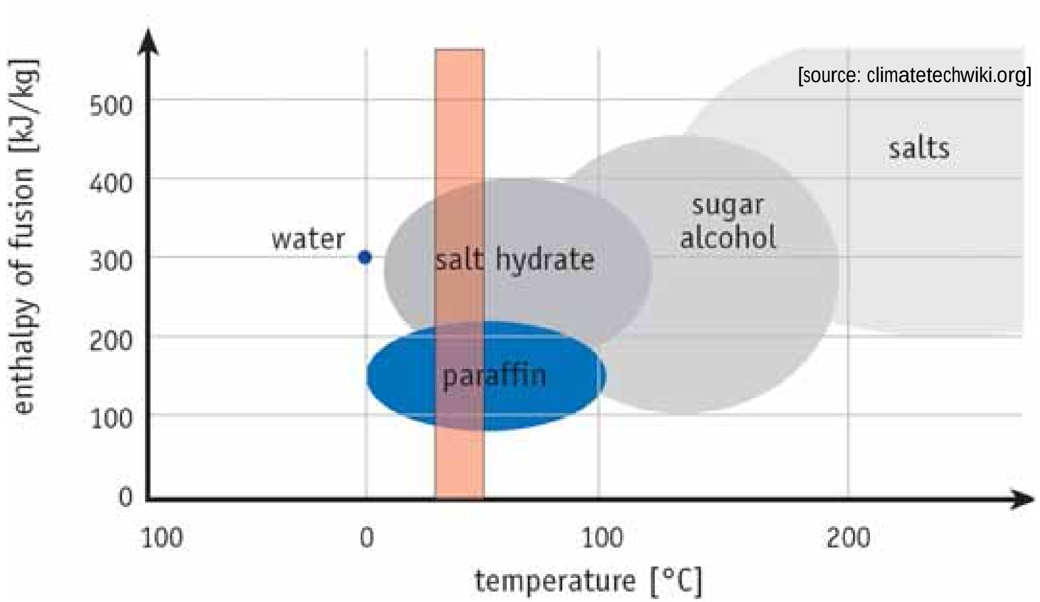
PCM



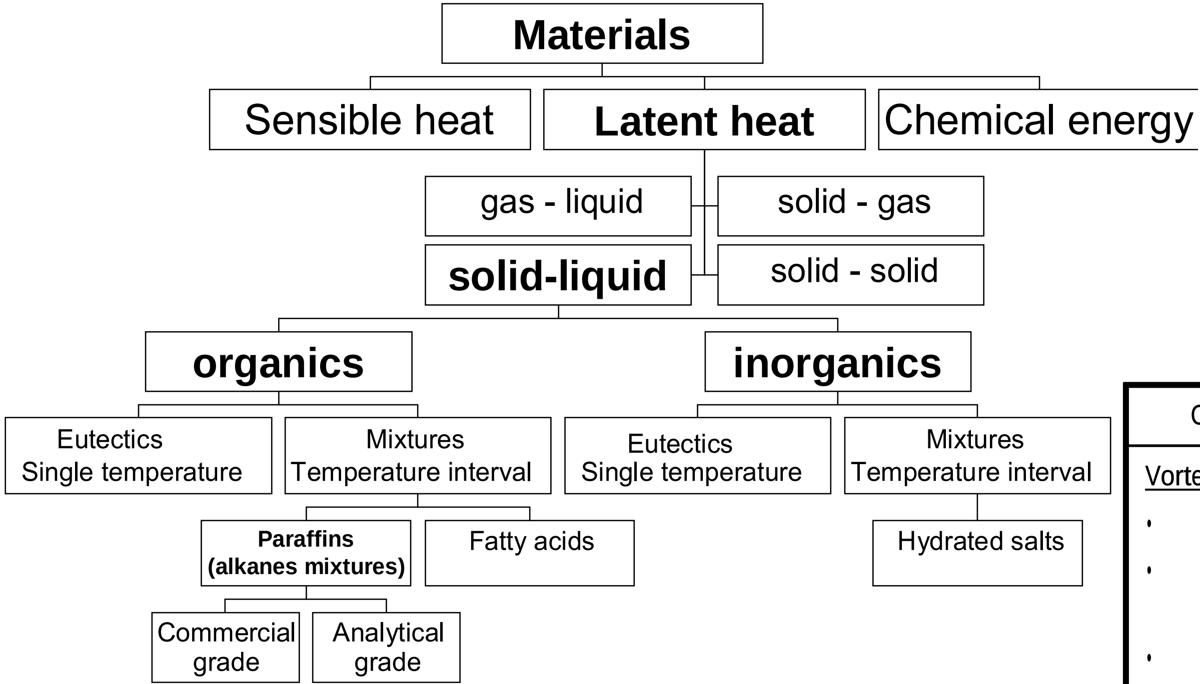
- Increasing thermal inertia
- „Isotherm“ phase change



- Building application
  - Walls
  - Roof
  - Floor
  - HVAC



PCM classification

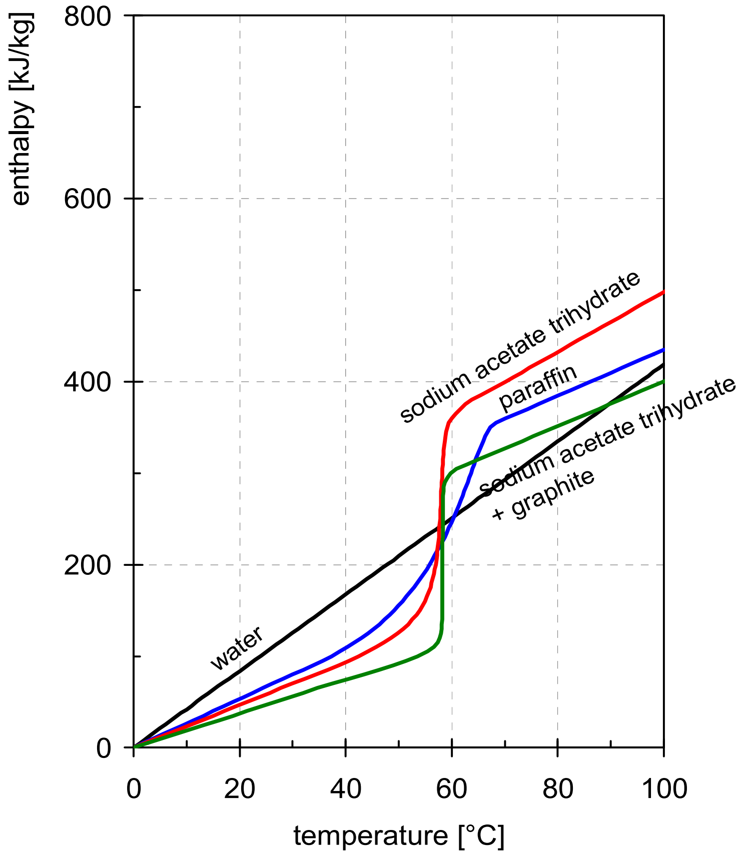


[source: A. Abhat, Low temperature latent heat thermal energy storage: heat storage materials, Solar Energy 30 (1983), 313–332.]

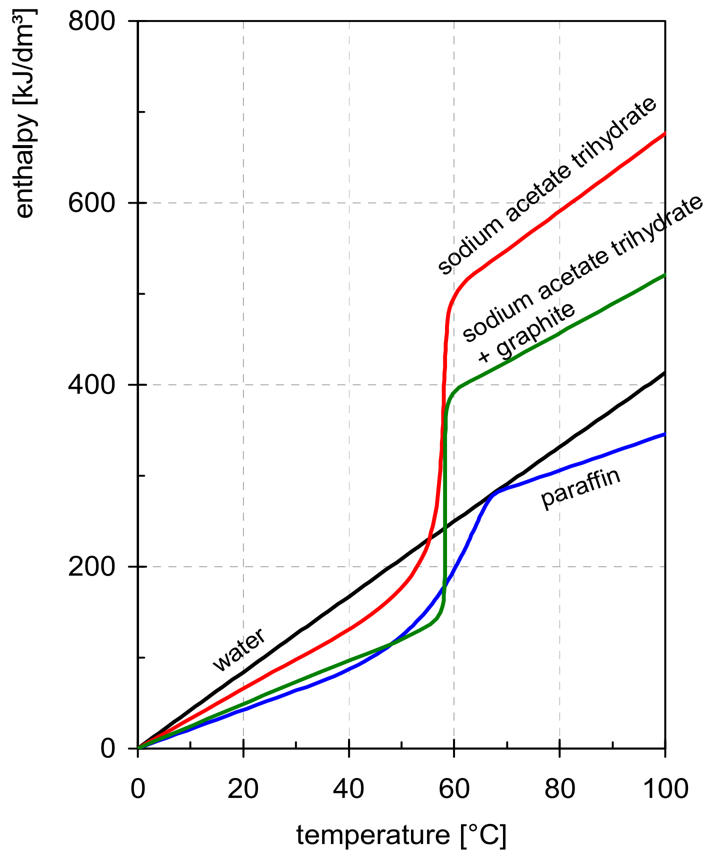
Organische (Paraffine)	Anorganische (Salzhydrate)
Vorteile • Nicht Korrosiv • Chemisch and thermisch stabil • Keine oder geringe Unterkühlung	Vorteile • Höhere Phasenwechselenthalpie • Größere Dichte
Nachteile • Niedrige Phasenwechselenthalpie • Geringere Dichte • Geringe Wärmeleitfähigkeit • Brennbar	Nachteile • Unterkühlung • Korrosiv • Phasenentmischung • Zyklenstabilität ?

PCM – Specific enthalpy

Per mass



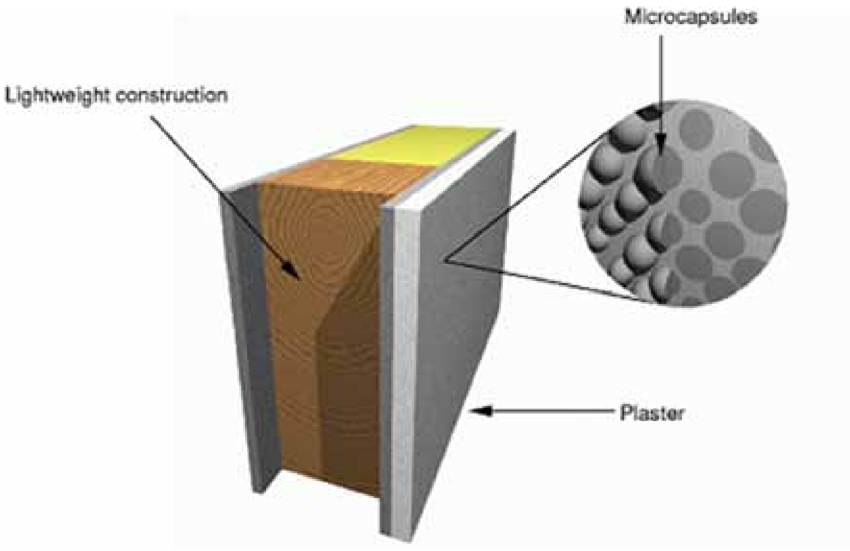
Per volume



[source: W. Streicher]

PCM in building structure

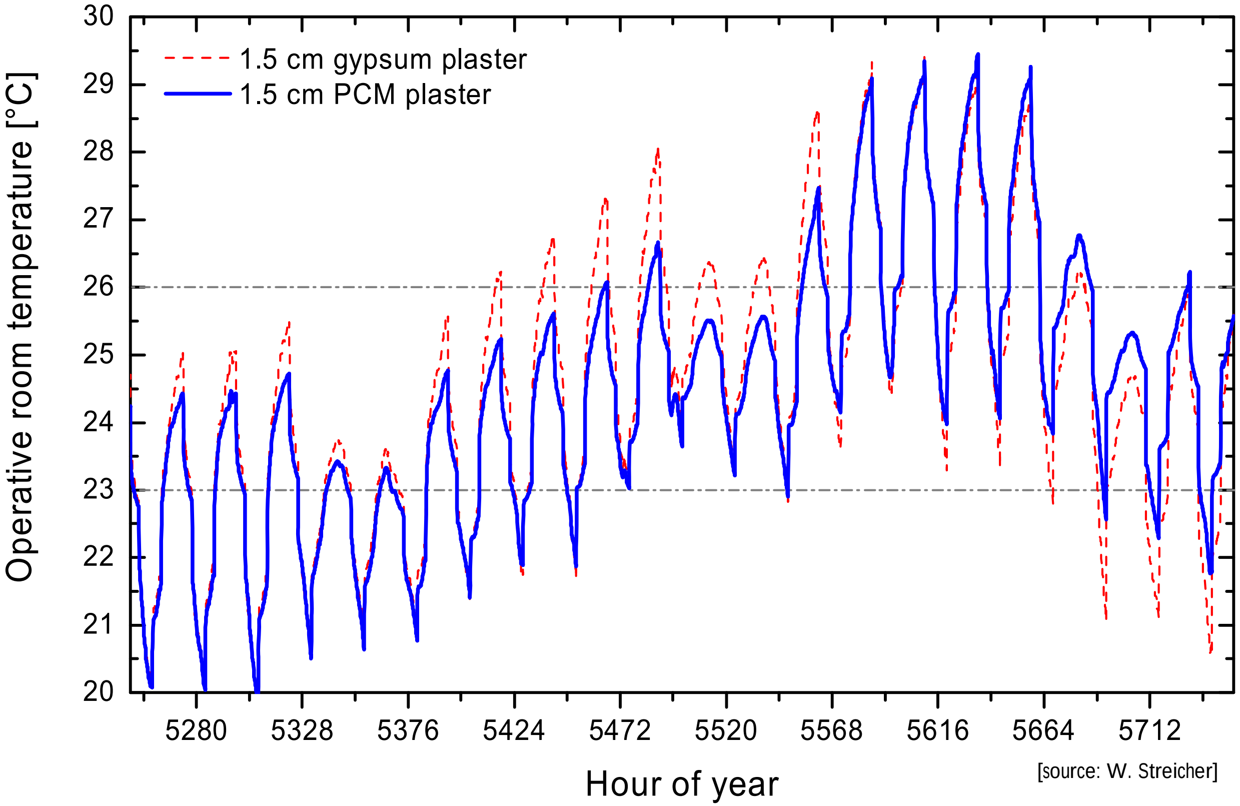
- Micro-encapsulated paraffines in plaster
- 1 cm plaster (thermally) equal to 10 cm concrete
- Application in leight weight constructions (Wood,…)
- Increased thermal inertia only available at switching point
- Higher costs



[source: W. Streicher]

PCM – Example

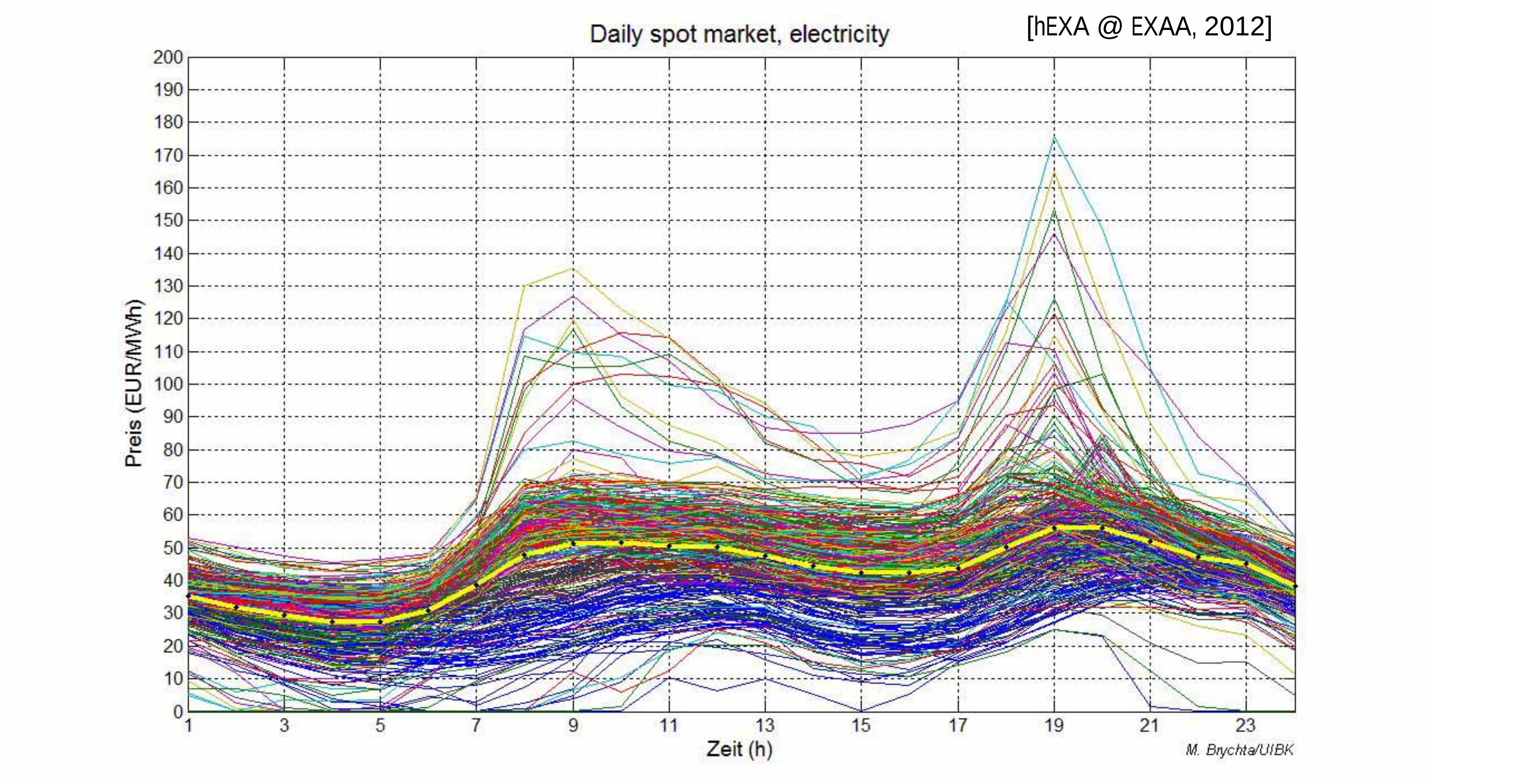
- Application in building
- Plaster
- Lleida / Spain



[source: W. Streicher]

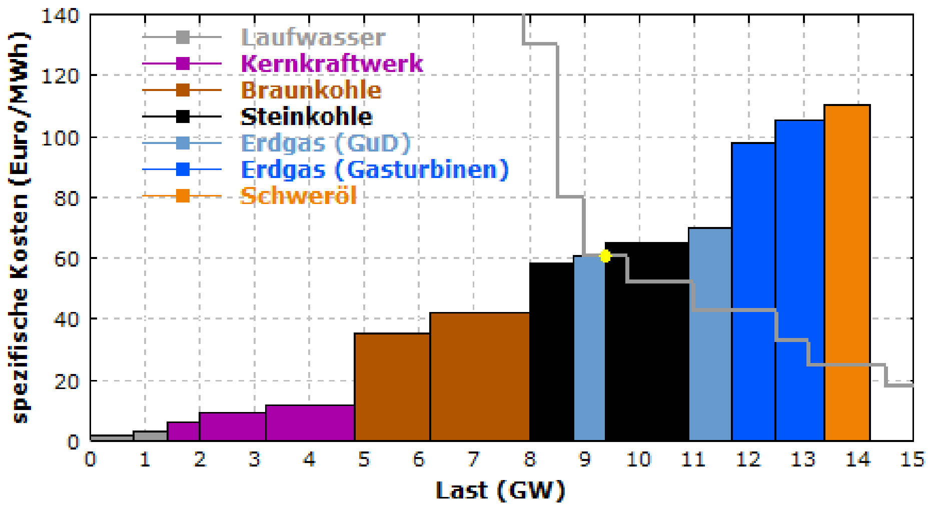
Energy markets

- Electrictiy prices…?
- Stock market places: EEX, EXAA

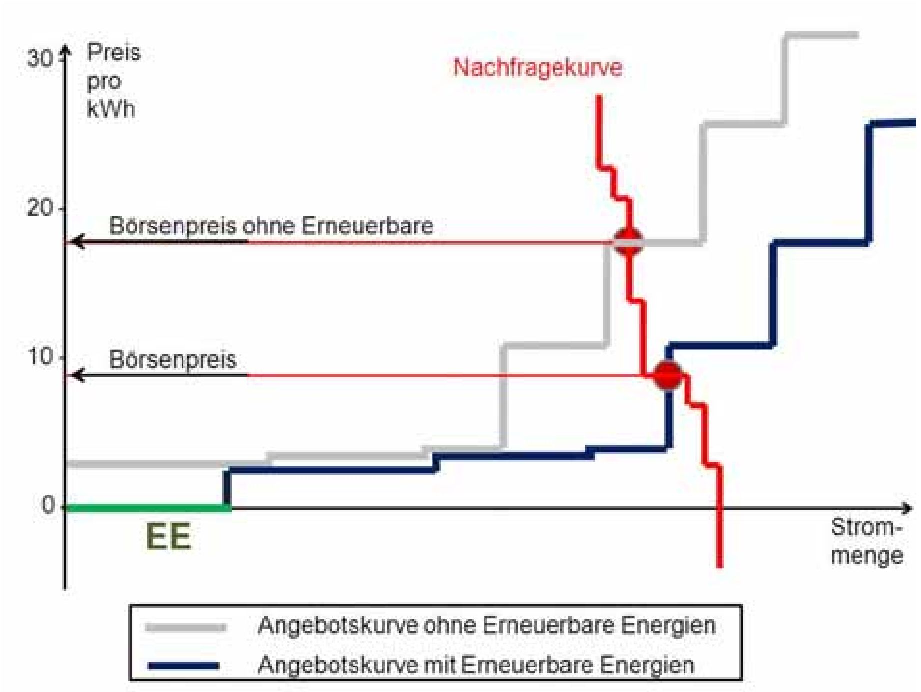


Electricity price - Merit order

- Demand vs. Production
- Impact of RES on electricity price sfv.de

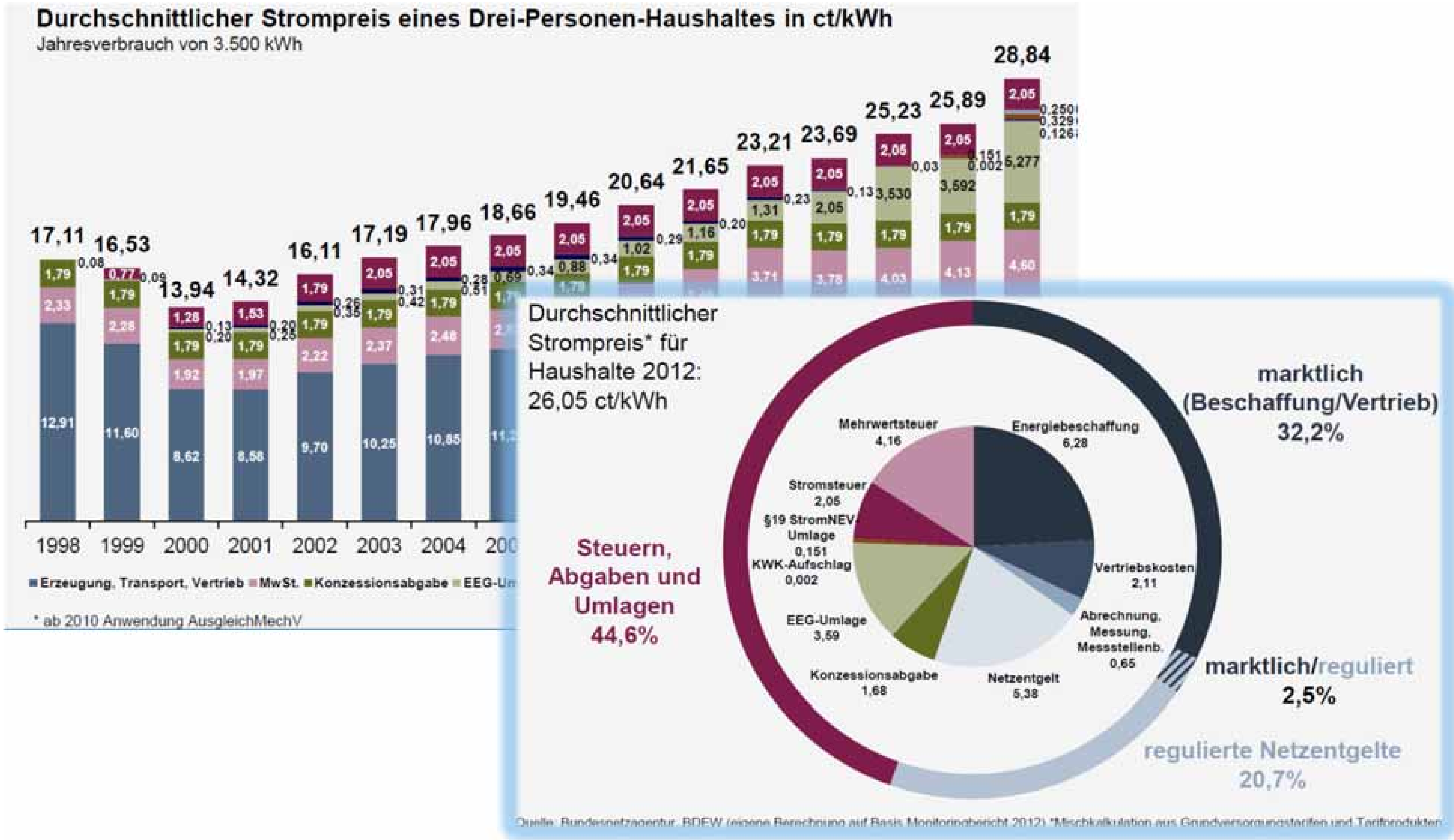


[source: energie-lexikon.info]



[source: sfv.de]

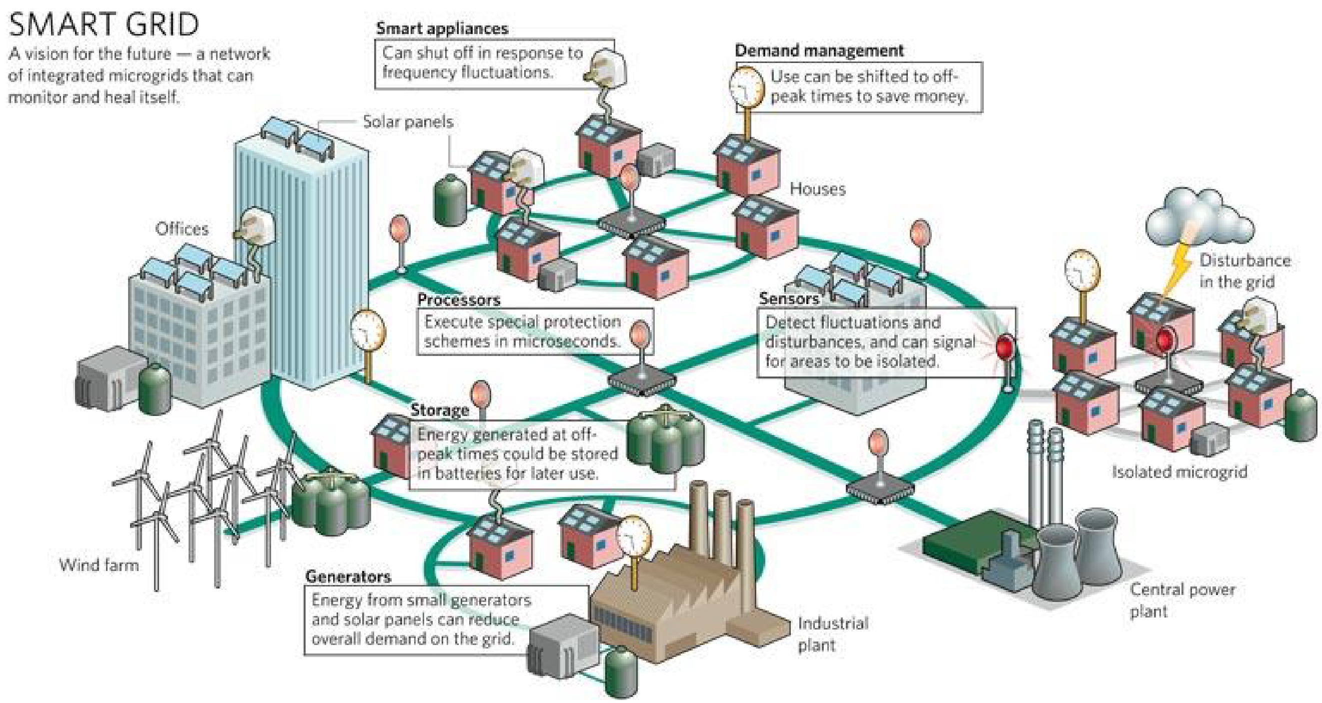
Electricity price – Germany



Demand Side Management

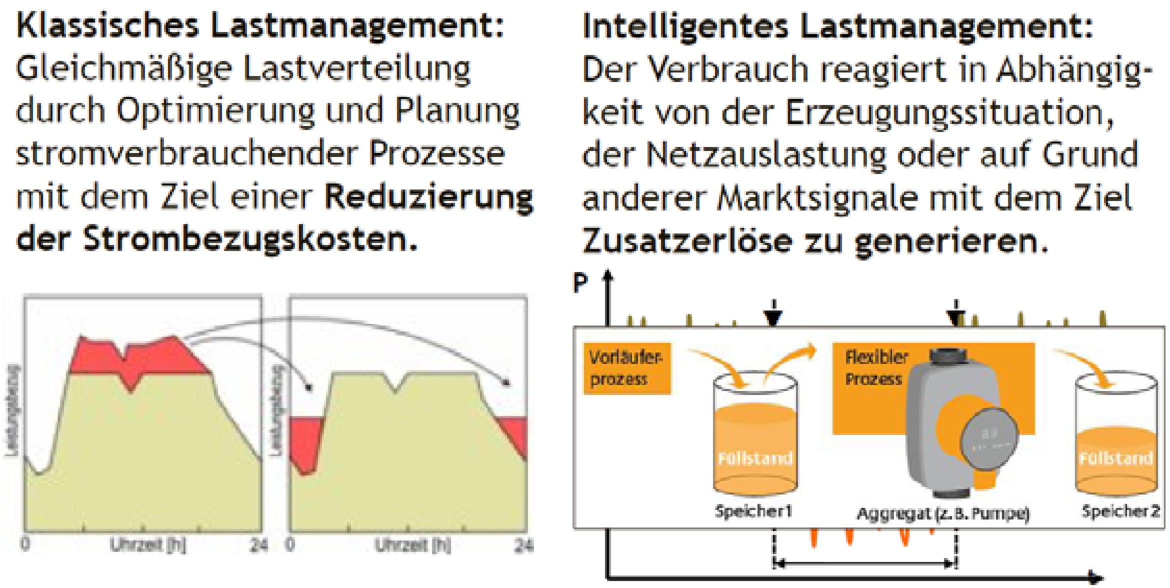
- *Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. (DoE)*

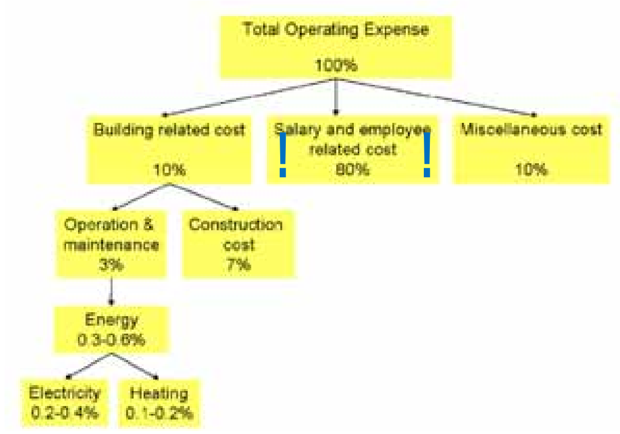
- One aspect of „Smart Grids“



DSM concepts

- Cost benefits due to dynamic prices
- Optimization of self consumption („Entsolidarisierung“)
- Providing (selling) operating reserve
- Pooling to coordinate e.g. private households





[source: REHVA Guidebook] – Solar Shading

Project example: The BAT

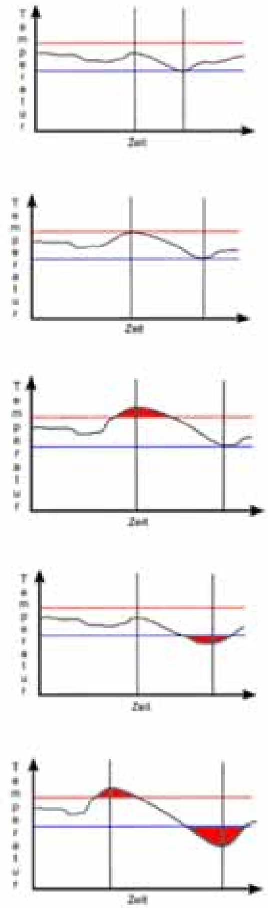
Objectives

- Development of strategies to optimize interaction:
  Heat pump, PV, Thermal Energy Storages (building structure, HVAC)
- Development and implementation of **Model Predictive Control** (MPC)
- Optimization of the **heat pump design** with respect to Demand Side Management
- Experimental investigation of a test system in a **Hardware In the Loop** (HiL) environment
- **Modeling and simulation** of the above mentioned systems and domains

DSM concepts 1/2

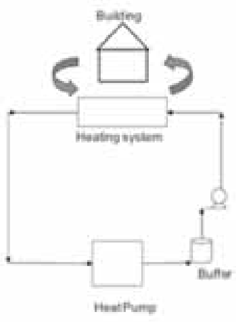
Controls

- (Broadcasted ON/OFF control: household appliances, electrical heating)
- Building management system:
  - Interface: grid status and shiftable loads
  - Forecast of demand and production
  - Evaluation of load shifting potential (Preheating, rebound)
  - Optimization of selfconsumption
  - External data: Weather, prices, grid status, user behaviour
- Flexible comfort criteria

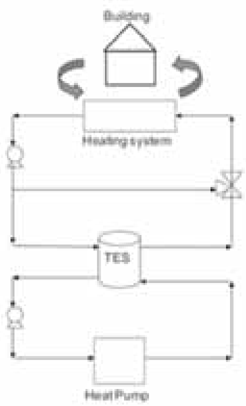


HVAC

- Space heating/cooling, DHW, (de)humidification, ventilation
- Heat pump, chiller, CHP
- Concrete core activation, DHW storage



[Arteconi et. al., 2013]

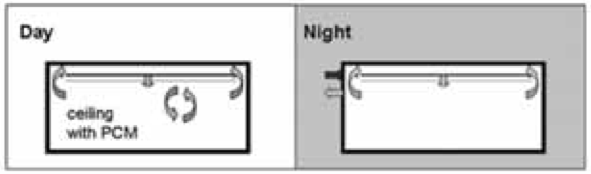


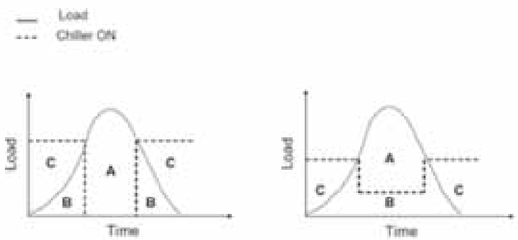
TheBAT

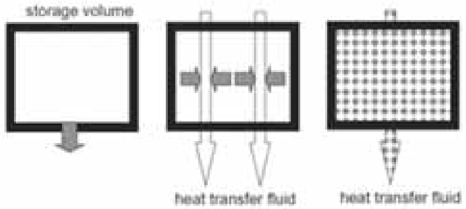
DSM concepts 2/2

Thermal storage

- **Sensible**: Concrete, stone, brick, water,…
- **Latent**: Water/ice, salt hydrates, polymeres
  - Space heating (SH): T* >25°C
  - Cooling: T* 5-15°C
  - DHW: T* 55-70°C
- **Thermal-chemical**:
  - ADsorption
  - Liquid - Sorption
  - Other chemical reactions
- **Building structure**:
  - Active
  - Passive
- **Full / Partial** storage strategy
- **Interface space – storage**: passive (a), active (b,c)

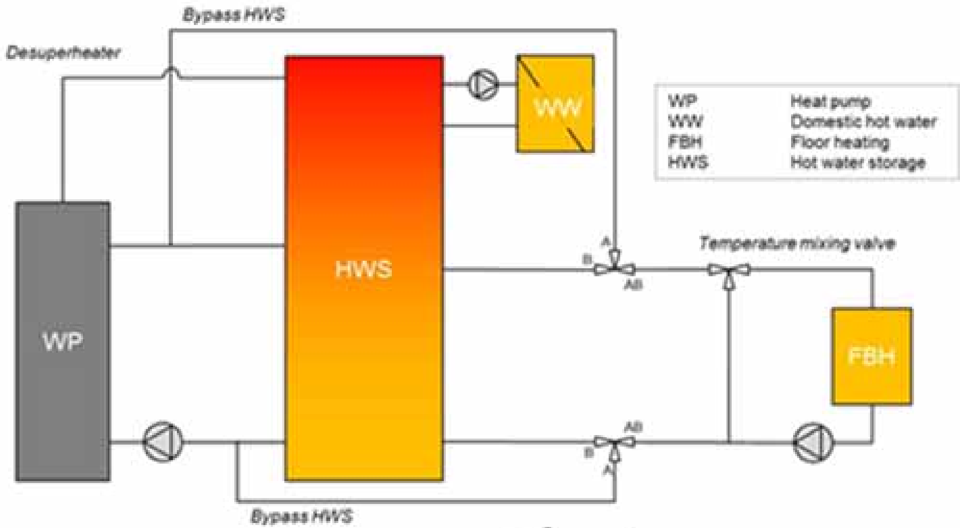


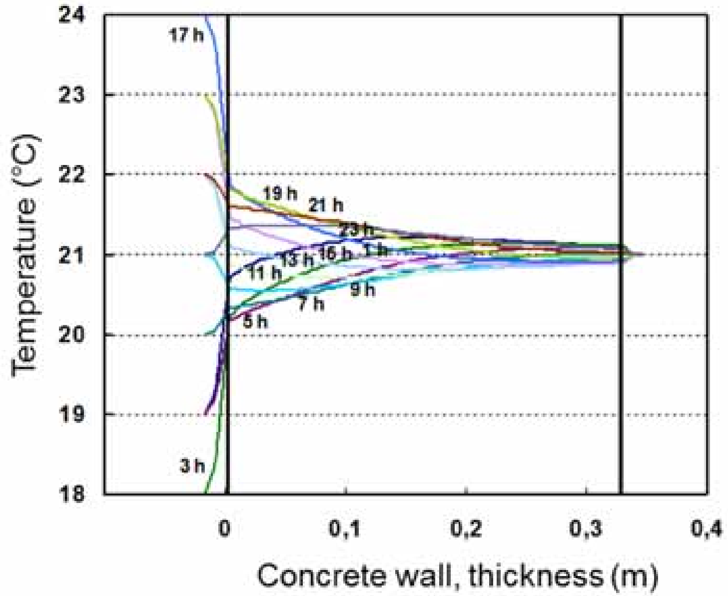




System design

- Building: Reference building ex Task 44
- HVAC system: HP, HWS (incl. bypass) -> DHW, floor heating



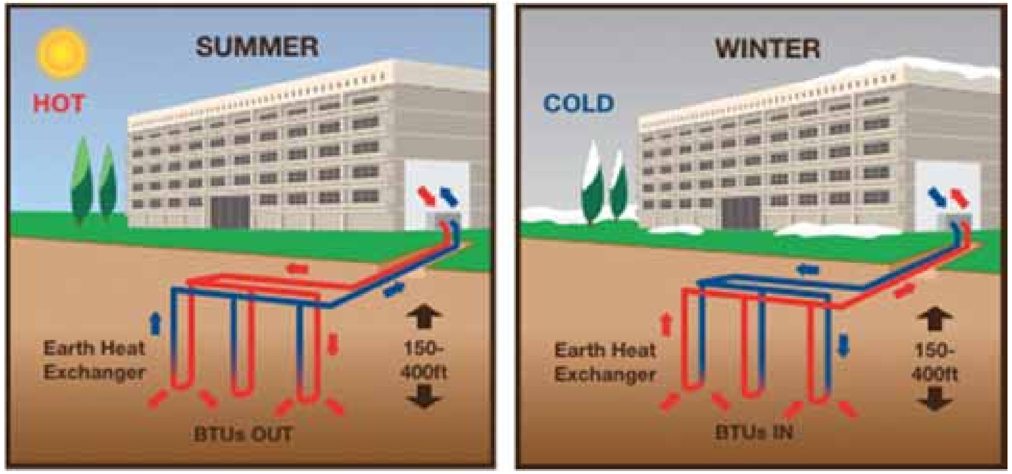


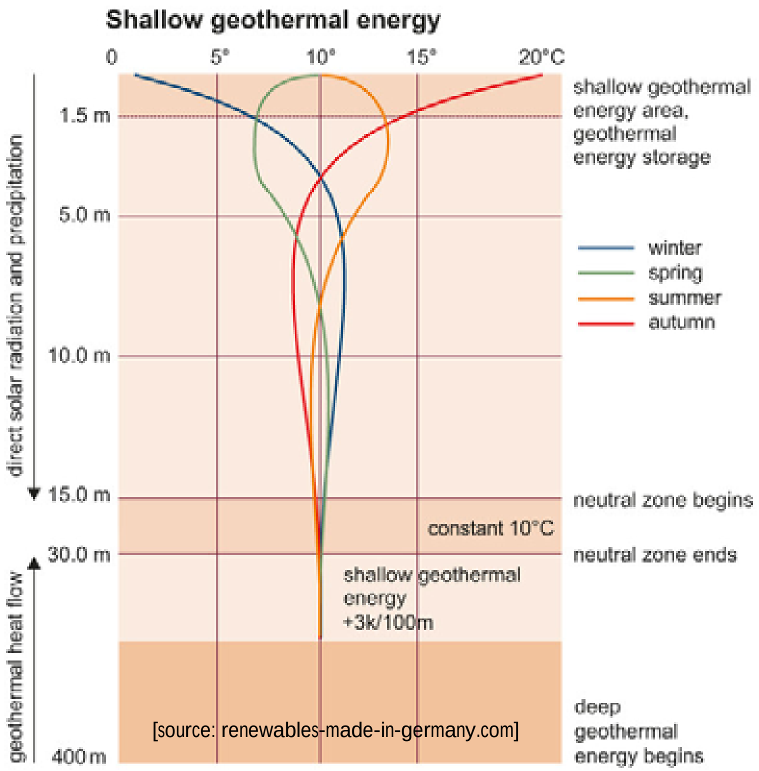
Different storage characteristics, e.g. wall:

- Impact of temperature changes typically <= 10cm
- Small changes in wall temperature
- Delayed reaction

Soil-air heat exchanger

- Air system
- Tubes buried in the ground
- Using geothermal heat
- Pre-heating / Pre-cooling

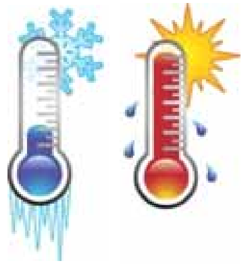




[source: renewables-made-in-germany.com]

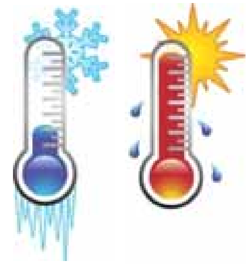
Total thermal heat flux out of earth:
approx. 23 TW (r=6.371.000 m)
→ approx. < 0,1 W/m²

Soil-air heat exchanger



[source: rehau.com]

Soil-air heat exchanger

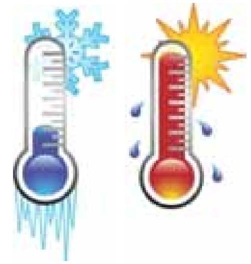


- **Closed loop system**: Air from inside the home or structure is blown through a U-shaped loop of typically 30 to 150 m of tube(s) where it is moderated to near earth temperature. The closed loop system can be more effective (during air temperature extremes) than an open system, since it cools and recools the same air.

- **Open system**: Outside air is drawn from a filtered air intake. The cooling tubes are typically 30 m long straight tubes into the home. An open system combined with energy recovery ventilation can be nearly as efficient (80-95%) as a closed loop.

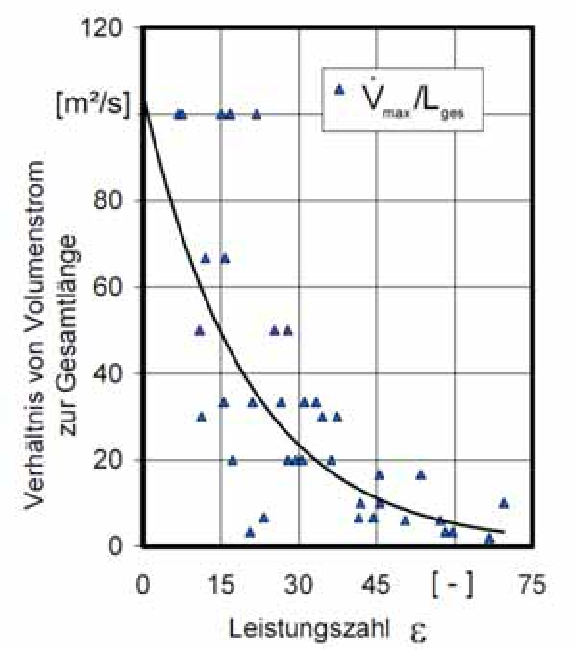
- **Combination system**: This can be constructed with dampers that allow either closed or open operation, depending on fresh air ventilation requirements.

Design approach (simplified)



- Performance parameter: $\varepsilon = Q_{useful} / E_{el}$

- „Metervolumenstrom“: $VL = \dot{V}/L_{ges}$

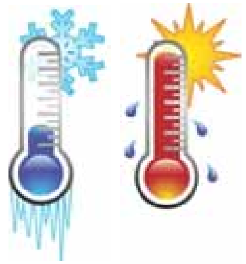


[source: LEWT Planungsleitfaden]

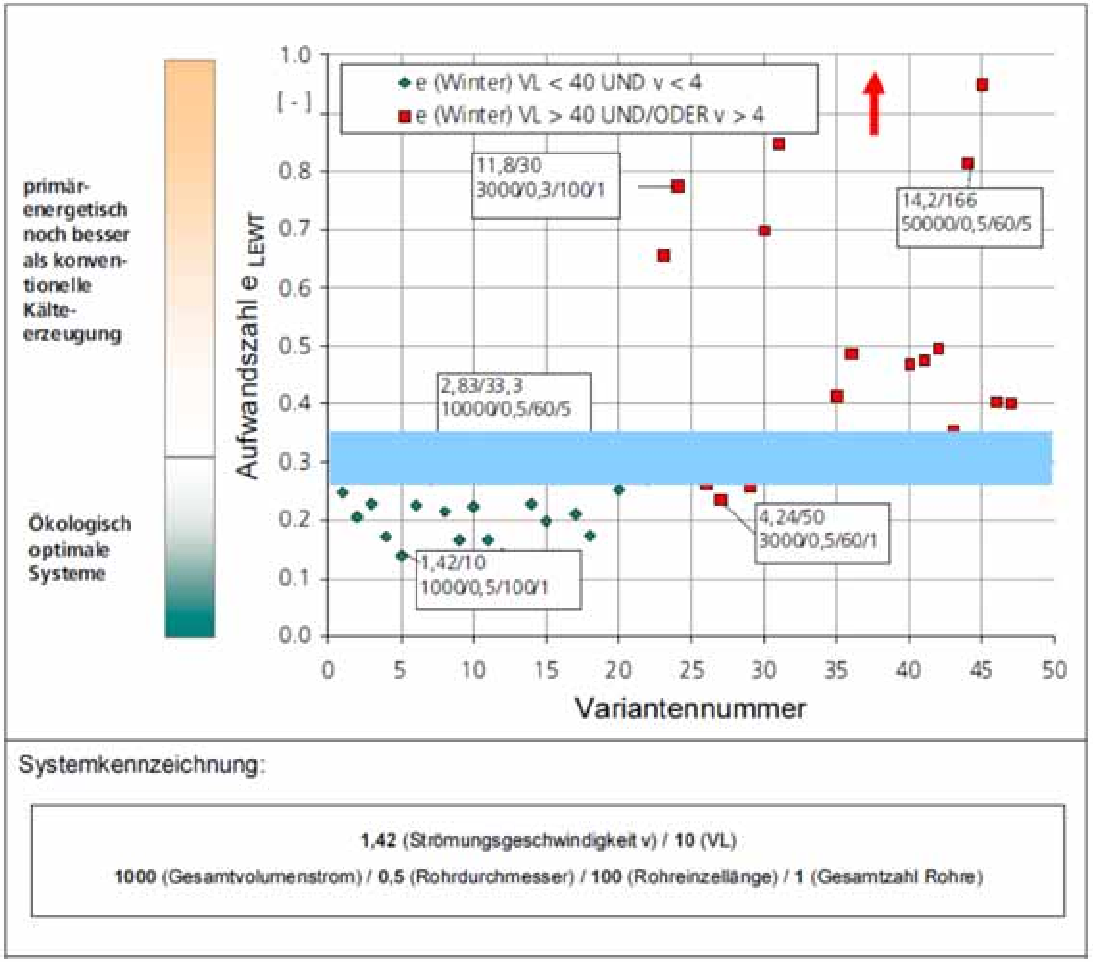
Bedingung 1	Bedingung 2
Geschwindigkeitsprüfung [m/s]	Metervolumenstrom [m³/(hm)]
$1 \leq v_L \leq 4$	$\dot{V}_{LEWT}^{max} / L_{ges} \leq 40$

[source: LEWT Planungsleitfaden]

Design approach (simplified)

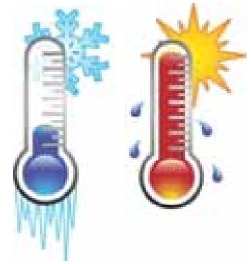


- Evaluation of design approach



[source: LEWT Planungsleitfaden]

Soil-air heat exchanger



- **Example**:
  - Vdot = 50.000 m³/h
  - Multiple pipe system
  - r_{max} = 0,25 m

Bedingung 1	Bedingung 2
Geschwindigkeitsprüfung [m/s]	Metervolumenstrom [$m^3/(hm)$]
$1 \leq v_L \leq 4$	$\dot{V}^{max}_{LEWT} / L_{ges} \leq 40$

- **Results**

Vdot	d	r	n	v
m³/h	m	m		m/s
50.000	0,50	0,25	20,00	3,54

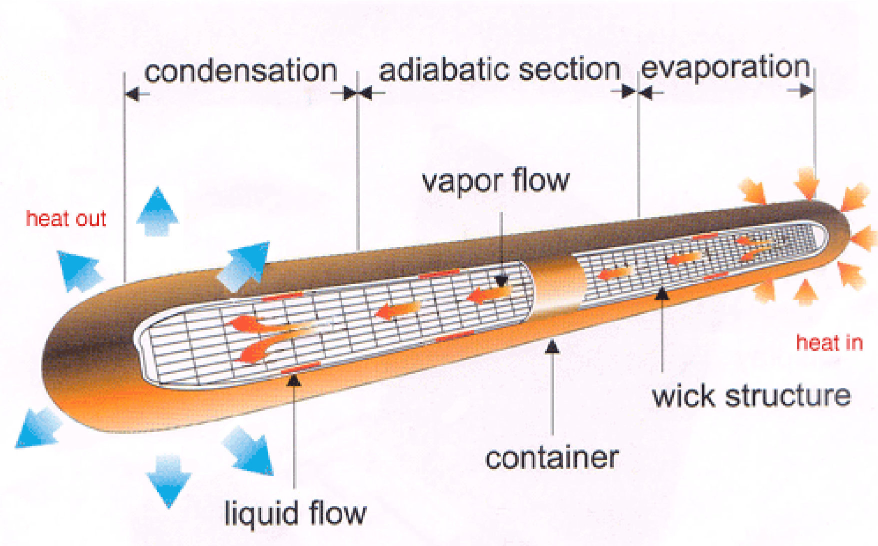
L	Lges	V/L
m	m	m³/h.m
65,0	1.300,0	38,5

- **Outlook** → Detailed simulation

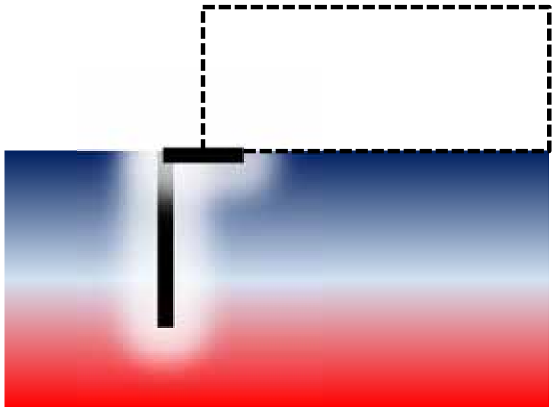
	von - bis	
Wärmeleitfähigkeit λ	**0,3 - 2,9**	W/(mK)
Dichte ρ	**1100 - 2000**	kg/m³
Wärmekapazität c	**840 - 1600**	J/(kgK)
Temperaturleitfähigkeit a	**0,5 - 1,4 *10⁶**	m²/s

Buried heat pipes

- Evaporation at higher temperature
- Condensation at lower temperature
- Phase change → High heat flux possible
- No auxilliary energy needed!

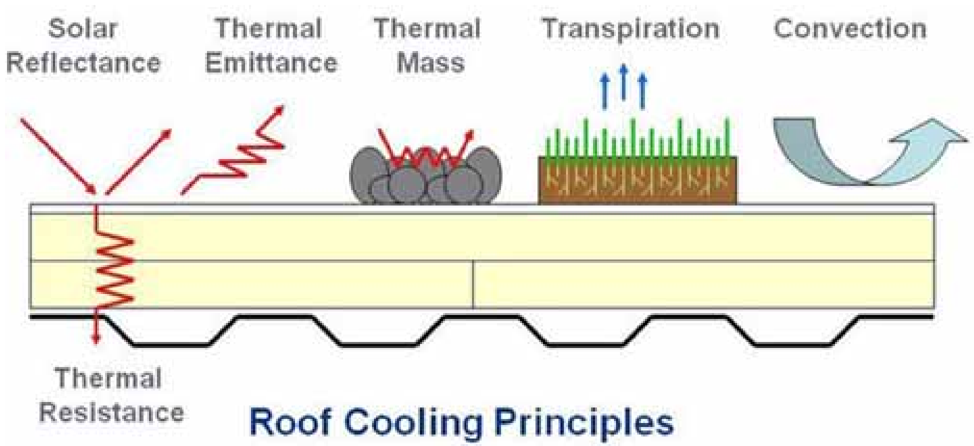


- Application in buildings

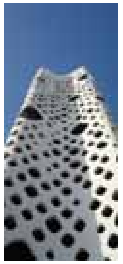


Cooling optimization

- Control of solar radiation, shading
- Adiabatic cooling
- Natural ventilation
- Soil as heat sink
- Radiative cooling
- Thermal mass



& (self-) shading



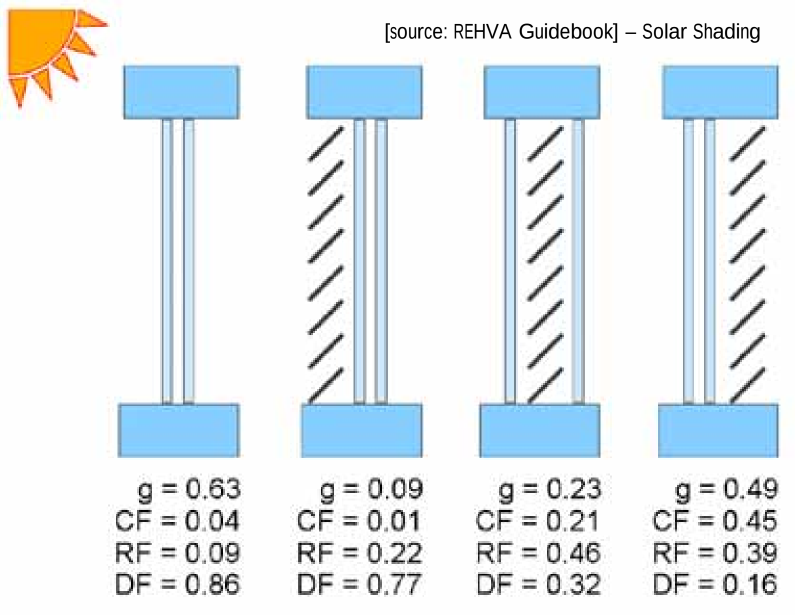
Shading

Basic functions

- Reduction of solar radiation
- Further features possible:
  RES, guiding light, aesthetics,…

To be considered…

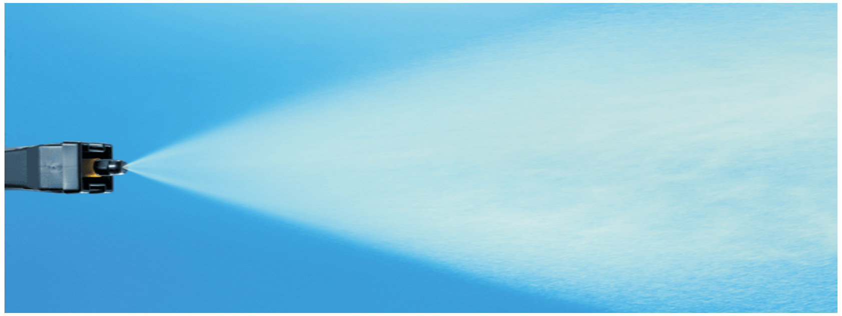
- Climate
- Orientation
- Wind
- Heigth
- Regional preferences
- Building character
- Construction details
- User expectations and behaviour



CF: convection fraction
RF: radiation fraction
DF: direct fraction

Type	Cooling	Heating	Visual comfort
External	+++	+	+
Intermediate	++	+	++
Internal	+	-	++

Adiabatic cooling



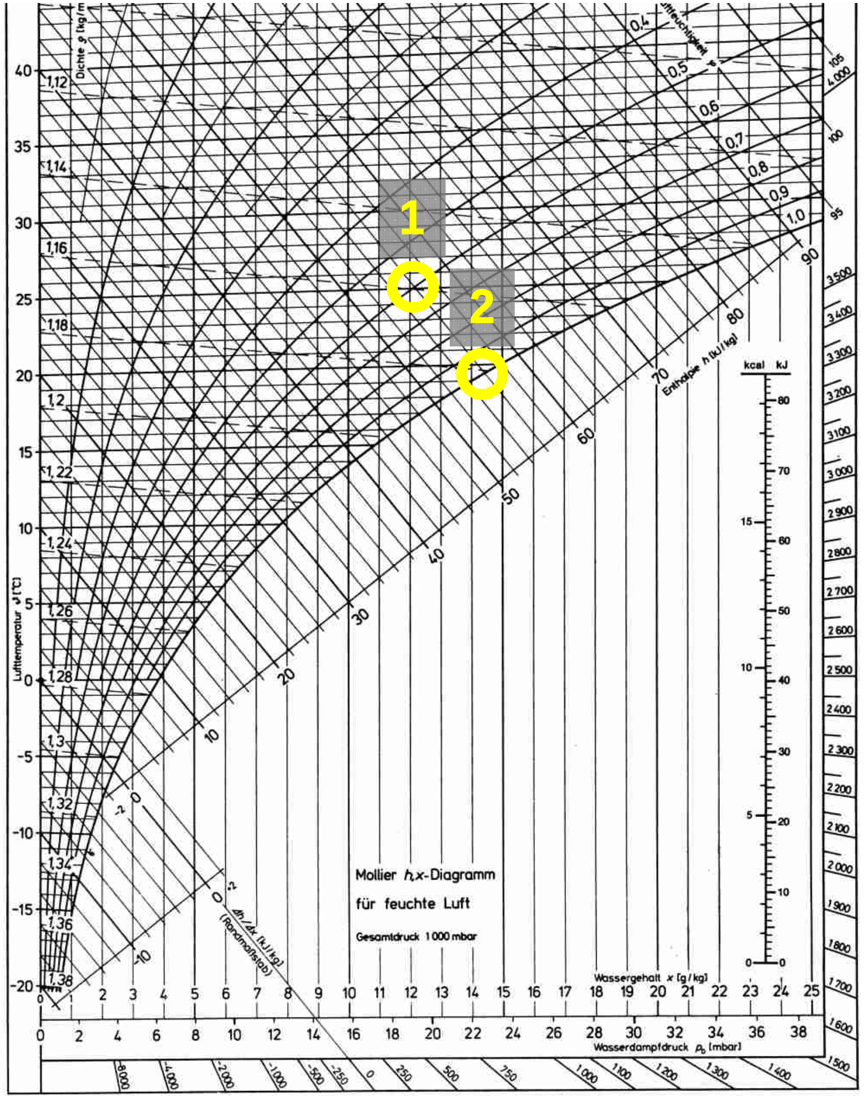
- How much water has to be evaporated to get 1 kW of cooling power?
  (Typical summer conditions: 25°C, 60%)

→ Approx. 0,6 kW cooling per kg/h water

t1	x1	h1
°C	kg/kg	kJ/kg
25,0	0,012	55,1

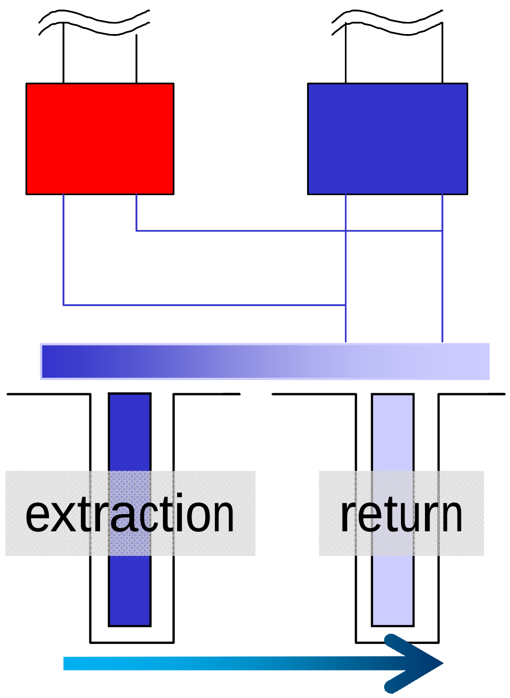
t2	x2	h2
°C	kg/kg	kJ/kg
19,0	0,015	56,6

Qdot	Cp Luft	dT	mdot, air	mdot, water
kJ/h	kJ/kg.K	K	kg/h	kg/h
3.600	1,0	6,0	600,0	1,8



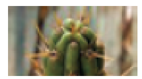
Ground water

- Direct use of ground water as thermal source (no heat pump)
- Soil temepráture: approx. 7-12 °C
- 2 wells: Extraction and return well
- Ground water flow from extraction to return
- Experimental testing (Pumping)
- Estimation of performance: 1 kW per >150l/h

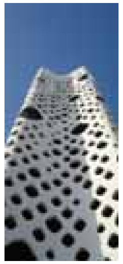


- Hydrochemical parameters to be considered:
  T, pH, O2, conductivity, redox potential, calcium, iron, manganese
- Riscs:
  Corrosion, iron hydroxide deposition, Risc of lime sediment when dT > +-

BioSkin – Passive cooling

(Passive) KÜHLUNG	*Auszug biologischer Prinzipien*						
technisches Funktionsziel	Evaporation, Evapo-transpiration	Strukturelle Eigenschaft - Kristalle	Reflektive Beschichtungen, Selektive Pigmente	Adaption/ Bewegung	Kontrolle des Feuchtegehalts, Metabolismus	Vermeidung von Überhitzung	Thermische Grenzschicht-effekte
Kühlung durch Verdunstung	**x**				**x**		
Luftbewegung				**x**			**x**
Temperatur-änderung	**x**	**x**	**x**	**x**	**x**	**x**	x
Beispiel potenzieller biologische Vorbilder	Stomata Blätter, Bromelie (*Bromeliaceae*) 	Herkuleskäfer (*Scara-baeidae*) 	Glas-schnecke (*Zonitidae*) 	Flügelschlag; Mimose (*Mimosa pudica*) 	Gefäßanatomie Hasenohr (*Leporidae*) 	Termitenbauten (*Isoptera*) 	Konvektionskühle ffekte bei Kakteen (*Cactaceae*) 

[source: Project BioSkin]



Cool roof

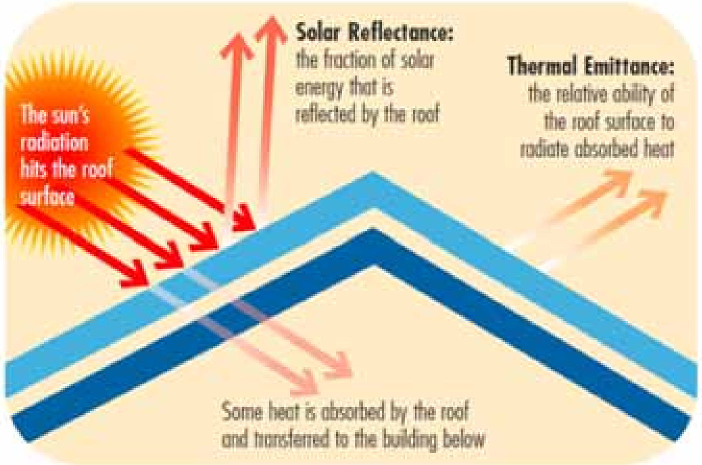
- Roof acts as
  - Thermal insulation barrier
  - Radiative heat exchanger

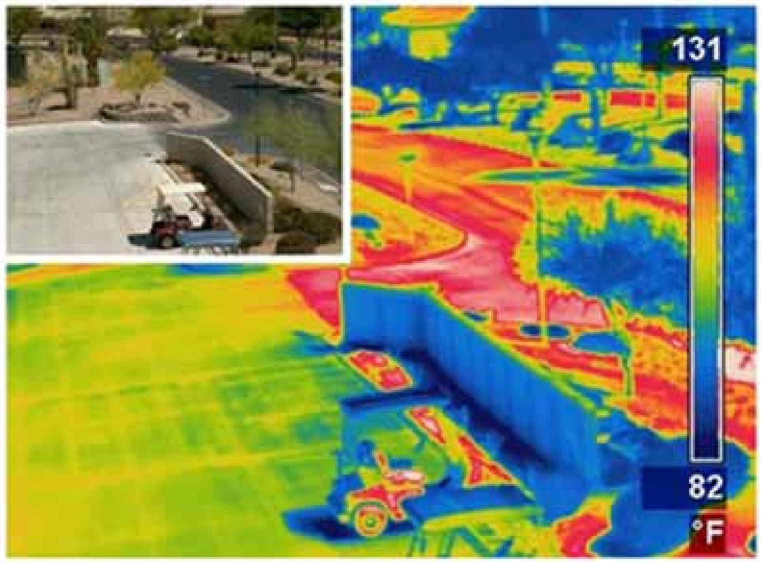
- Important parameters
  - High solar reflectance
  - High thermal emittance

What is a Cool Roof?

A cool roof reflects and emits the sun's heat back to the sky instead of transferring it to the building below.

"Coolness" is measured by two properties, solar reflectance and thermal emittance. Both properties are measured from 0 to 1 and the higher the value, the "cooler" the roof.





Radiative heat exchange

- Maximum heat flux („Black body“) $\dot{q} = \sigma T^4$
- Radiation hits a surface $r + \alpha + \tau = 1$
- Emitted heat flux $\dot{q}_{em} = \varepsilon(T) \cdot \sigma T^4$
- Absorbed heat flux $\dot{q}_{ab} = a(T) \cdot \sigma {T_{env}}^4$
- Total radiative exchange $\dot{q}_{rad} = \sigma(\varepsilon T^4 - a {T_{env}}^4)$
- Assumption „Grey body“: a=ε

Convective & radiative exchange

- Convective & Radiative:

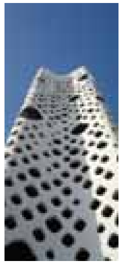
$$\dot{q} = \dot{q}_{conv} + \dot{q}_{rad}$$

$$\dot{q} = \alpha(T - T_{air}) + \varepsilon\sigma(T^4 - {T_s}^4)$$

- Assumption: $T_s \approx T_{air}$

$$\dot{q} = (\alpha + \alpha_{rad})(T - T_{air})$$

$$\alpha_{rad} = \varepsilon\sigma\frac{(T^4 - {T_{air}}^4)}{(T - T_{air})}$$



Cool roof

- Sky emitts radiation

  → **Sky temperature** can be assigned:

  T_{sky} = f (T_{amb} , X_{amb} , p_{amb} , cloudiness factor)

- The "**solar reflectance index**" (SRI)

  "0" → reference black roof
  (solar reflectance R = 0.05, thermal emittance E = 0.90)

  "100" → reference white roof
  (R = 0.80, E = 0.90)

- http://coolroofs.org

Outside surface	solar absorptance coefficient
Roof tile, colored ceramic, slate, concrete	
• rough surface, dark red	0.75 ... 0.80
• smooth surface, dark color	0.70 ... 0.75
• asbestos concrete	0.60 ... 0.65
Roof coating	
• green	0.60 ... 0.65
• aluminum color	0.60 ... 0.65
• light grey, bright	0.30 ... 0.40
• white, smooth	0.20 ... 0.25
Exterior wall	
• smooth surface, dark color	0.70 ... 0.75
• rough surface, medium bright color yellow and yellow red clinker, brick)	0.65 ... 0.70
• smooth surface, medium bright color (chalky sandstone, asbestos concrete)	0.60 ... 0.65
• rough surface and white color	0.30 ... 0.35
• smooth surface and white color	0.25 ... 0.30
Metallic surface	
• zinc sheet, aged and dirty	0.75 ... 0.80
• aluminum, matted surface	0.50 ... 0.55
• aluminum color	0.35 ... 0.40
• bright and polished surface	0.20 ... 0.25

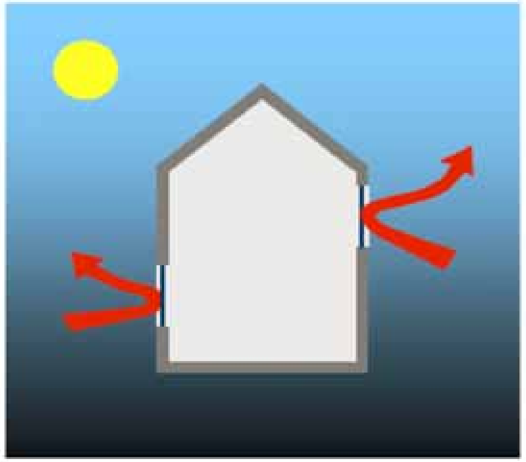
Green facades

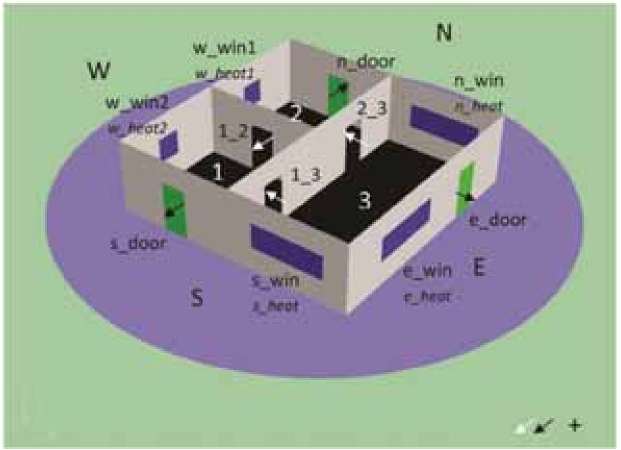
- Vegetation integrated in the facade
- Basic functions:
  - Evaporation
  - Shading
  - CO2 capture
  - Aesthetics
- Application
  - Loose
  - Mat
  - Structure
- Typically in tropical climates

Natural ventilation

- Day-Night ΔT approx. 10 K (Typically, in our climate)
- In combination with sufficient thermal inertia (walls,…)

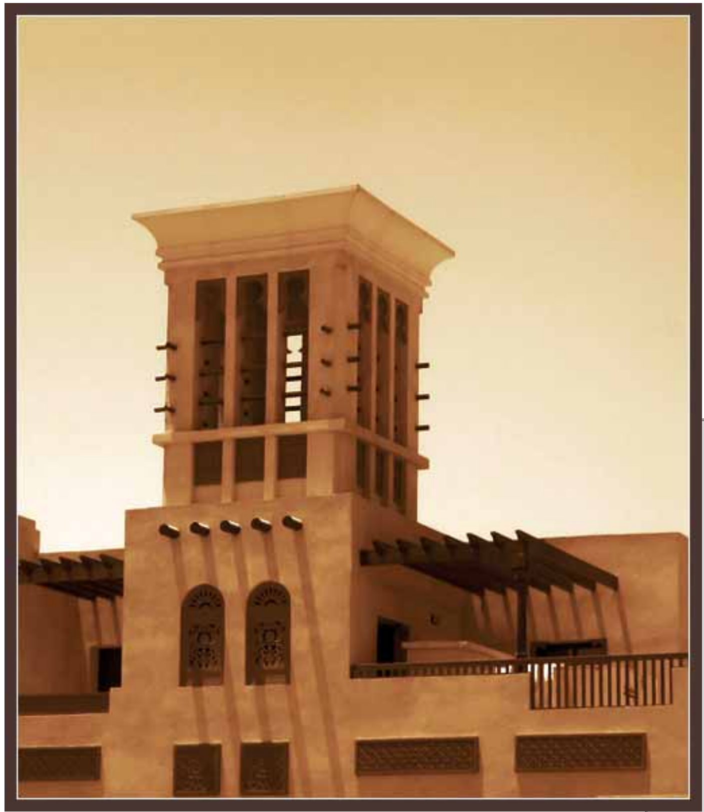
- Simplified models available
- Detailed analysis → Computational Fluid Dynamics CFD



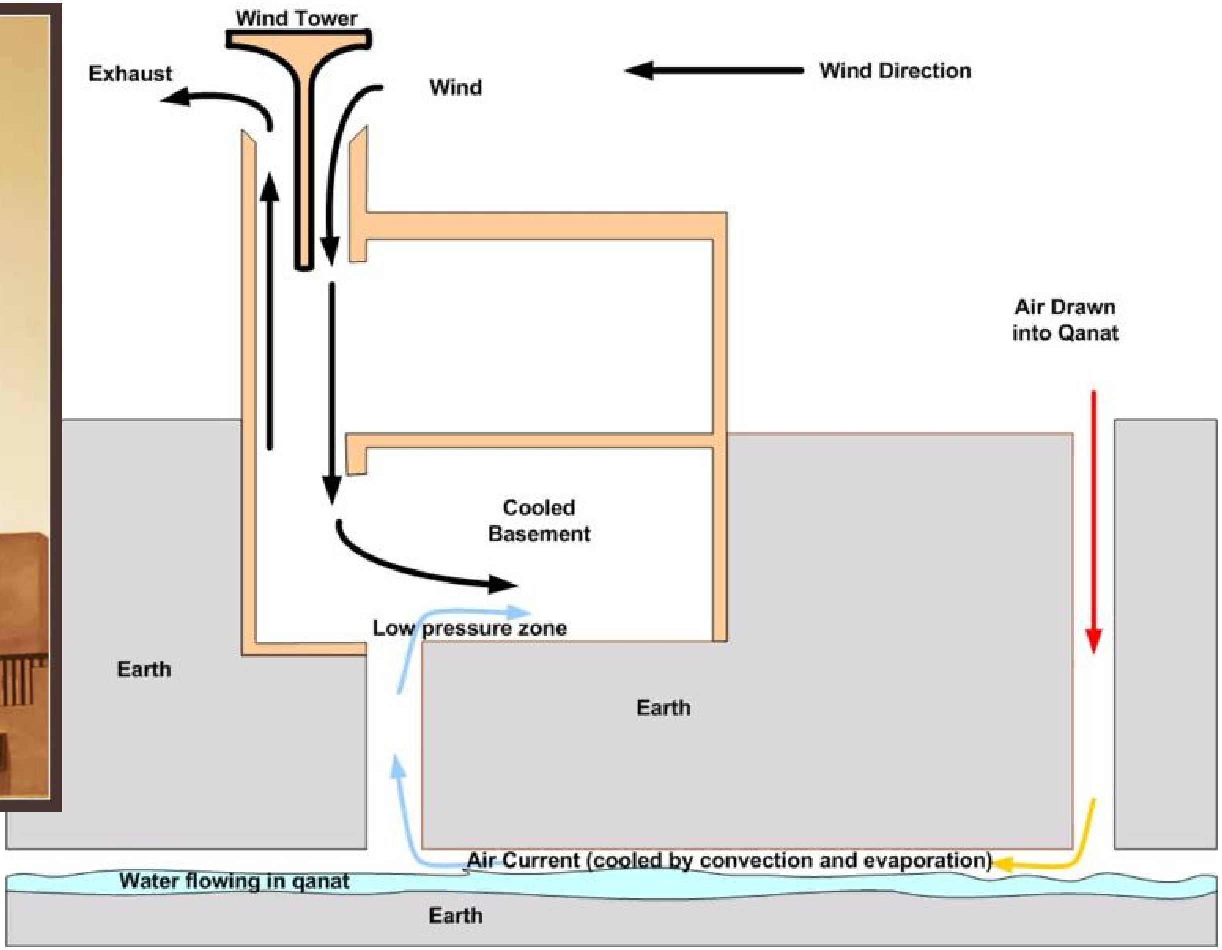


[TU Braunschweig]

Wind tower



[source: www.dpchallenge.com]



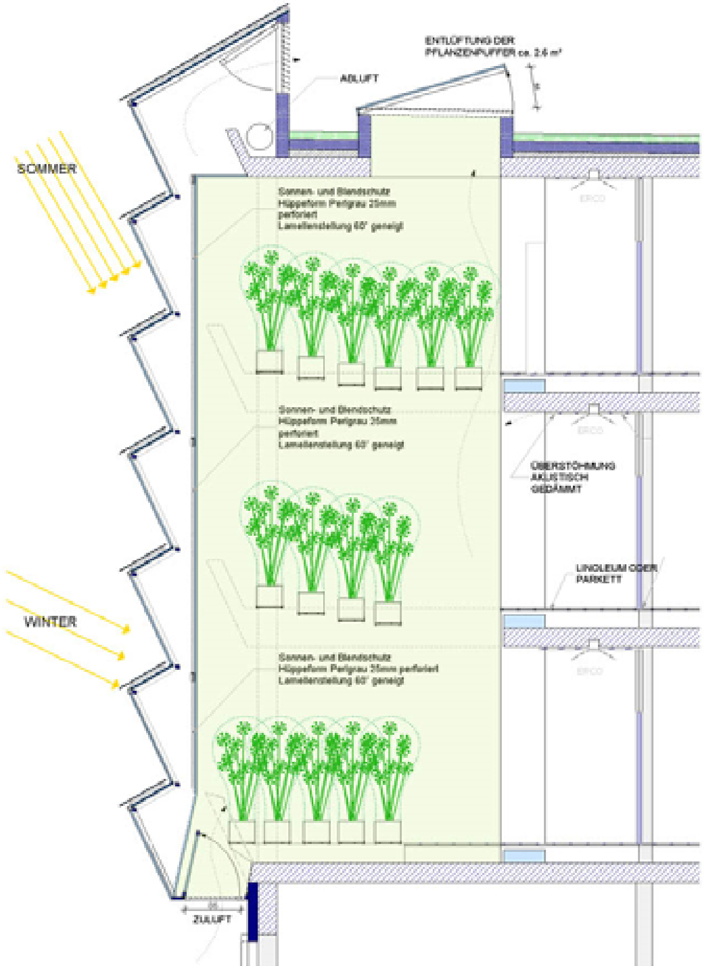
[source: proudlyemirati.wikidot.com]

Green plants for ventilation

Green plants combined with ventilation

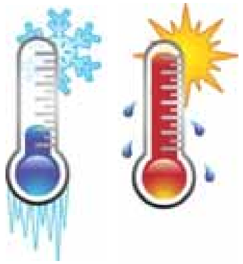
- Humidification
- Improvement of air quality
- “Green islands” in the building
- E.g. cypress grass

- Efficiency?
- Costs?



Schnitt

Green materials



Straw

- Insulation, wall or bearing wall
- Threshed grain (Wheat, rye, barley,…)
- Fibrous plants (Flax, hemp, rice)
- Low PE, CO2 neutral material, renewable
- Certified products available

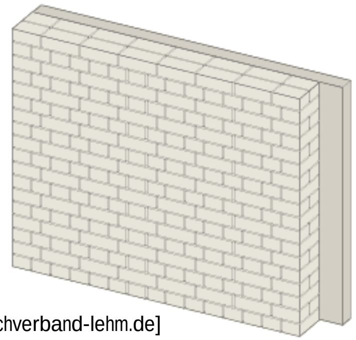
[source: strohundlehm.at]

Green materials

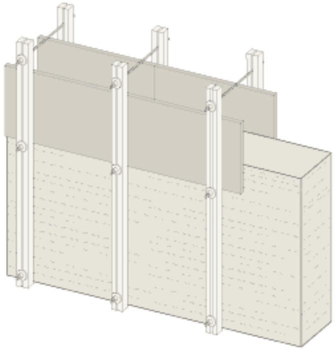
Clay

- Application: wall or bearing wall, in/outdoor plaster
- Ton, Schluff (Feinstsand) und Sand
- Low PE, low related CO2 emissions
- Not only thermal, but also humidity inertia
- Improves indoor climate
- Reduces smells
- 100 % recycling

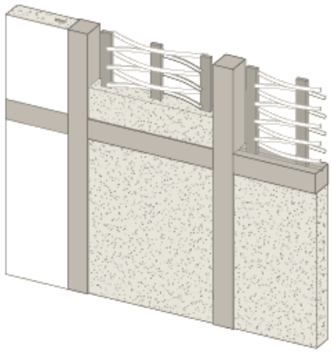
bricks



compressed clay wall



composite



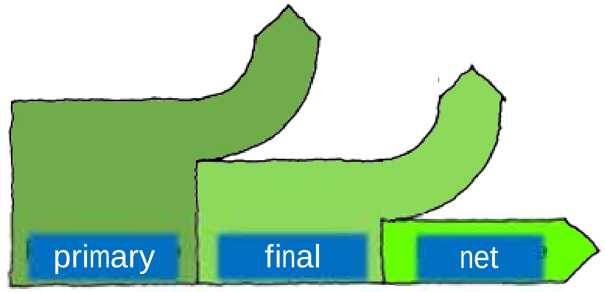
[source: dachverband-lehm.de]

Green materials

- Old jeans → insulation material

Performance and benchmarking

- Charateristic parameters to describe the energetic, thermal,… performance
- Categories of demand
  - Heating
  - DHW
  - Cooling
  - Plug loads
  - …

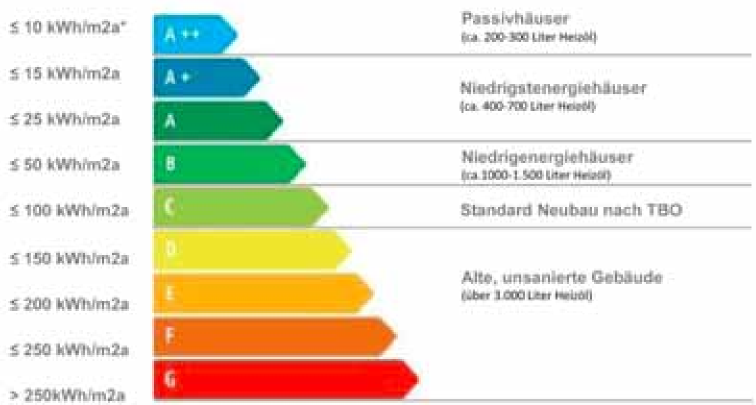


→ Money: invest, operation, LCC

→ Comfort: PPD, PMV,…

→ Energy: Primary, final, net

→ Ecological aspects



[source: isotec-daemmen.at]

- Discussion building certification: LEED, BREAM, Energieausweis,…

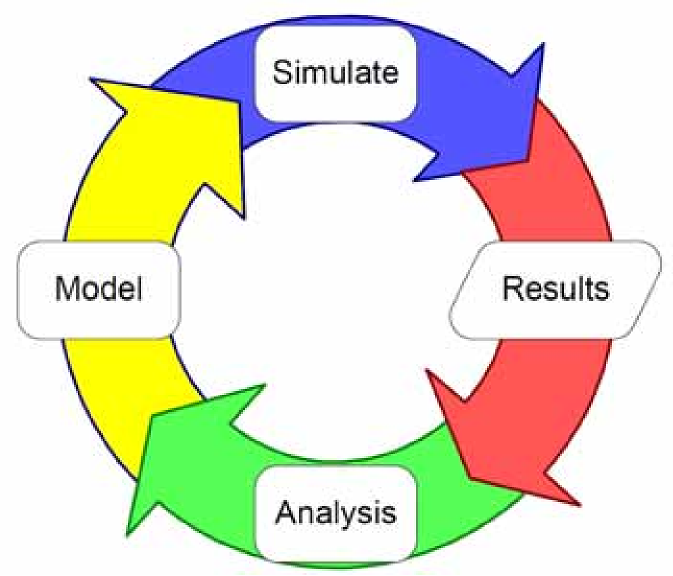
Simulation in the design process

- Design questions <> simulation questions

  → Transformation needed

  → Iterative process

  → Re-Transformation to design questions



Methods to support the process

- Dynamic thermal simulation
- Computational Fluid Dynamics
- Daylighting modelling

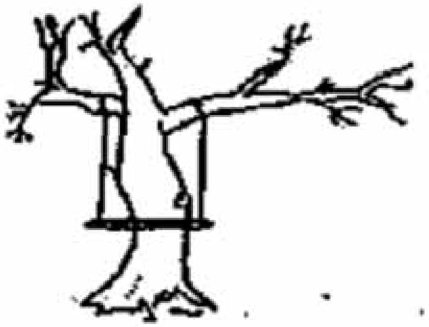
Finally…

What the client wants

Concept by architect

Concept after structural analysis

Approved by authorities



Built by construction company

After refurbishment