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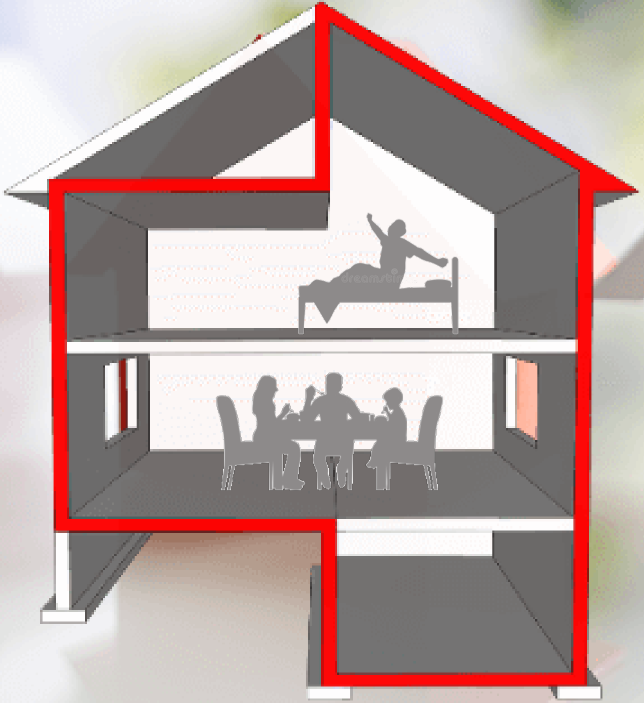

ENG-445 Building Energetics

Heating & Cooling Demand in Buildings

Assist. Professor
Dolaana Khovalyg

14 November 2024

Course Information

Week	Date	Topic	Timing	Teacher	Project (AS, MF)
9	07/11	Building envelope, thermal performance of building elements	45' x 2	DK	Tutorial building envelope
		Exercises	45'		
10	14/11	Heating and cooling demand in buildings	45' x 2	DK	Free work
		Exercises	45'		
11	21/11	Thermal systems for heating and their effect of human comfort	45' x 2	JY	Free work
		Exercises	45'		
12	28/11	Thermal systems for cooling and their effect of human comfort	45' x 2	DK	Tutorial heating systems (emission systems)
		Exercises	45'		

JY – Jaafar Younes, a postdoc from the ICE lab

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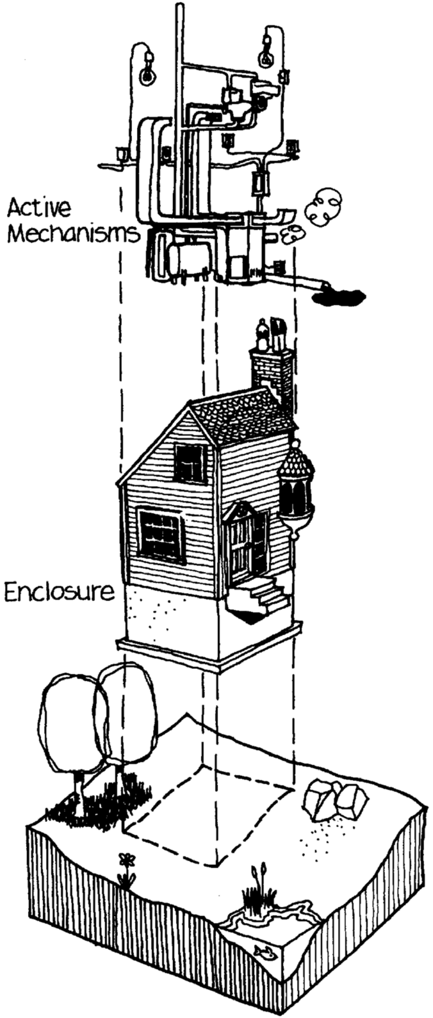

Source: Edward Allen «How Buildings Work» (2005)

CONTENT:

- **Introduction**
- **Space heating/cooling demand:**
  - **Heat gains and heat losses**
  - **Dynamic behavior of building envelope** (thermal mass effect, time lag, decrement factor)
  - **Internal heat gains** (appliances, lights, people)
  - **Methods to determine the thermal load**
  - **Strategies to minimize the energy demand**
- **Sanitary hot water demand:**
  - **Sanitary requirements**
  - **Hot water demand**
- **Summary**

Heating & Cooling Needs in Buildings

Heating Needs:



Cooling Needs:



Which category has the greatest energy share in OLD buildings?

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A. Space cooling

B. Space heating

C. Water heating

D. Need more input to answer

Which category has the greatest energy share in NEW buildings?

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Session ID: **ENG445DK**

A. Space cooling

B. Space heating

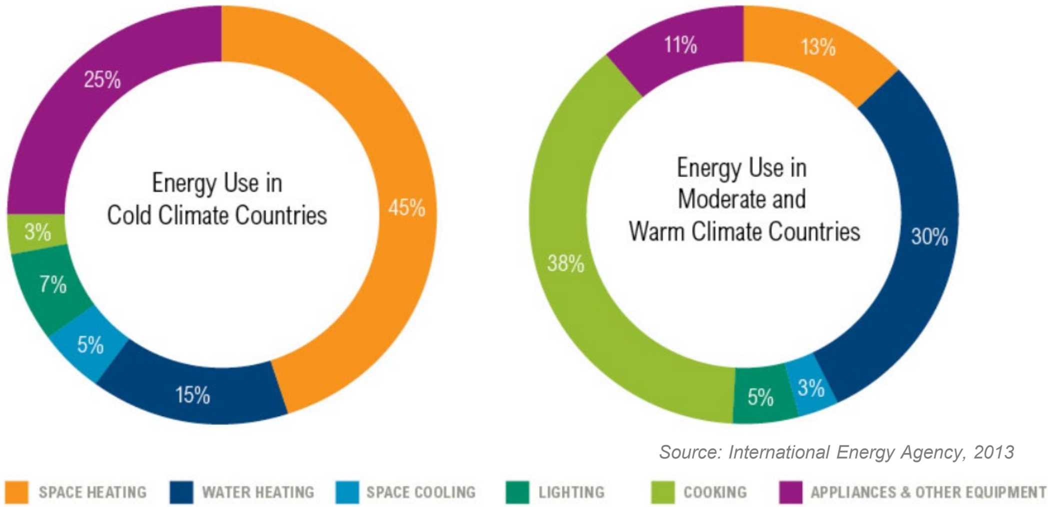
C. Water heating

D. Need more input to answer

Energy Use in Buildings

- **Breakdown of Building Energy Demand in Different Climates**

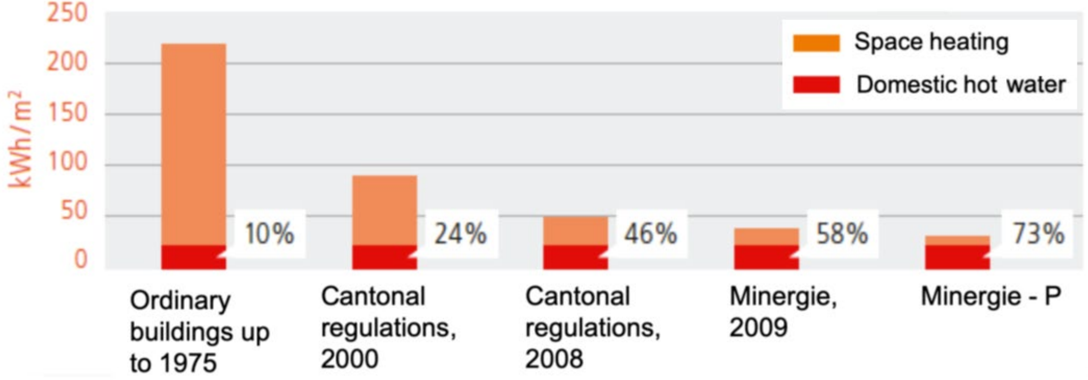
  proportion between space heating & cooling & DHW depends on the climate



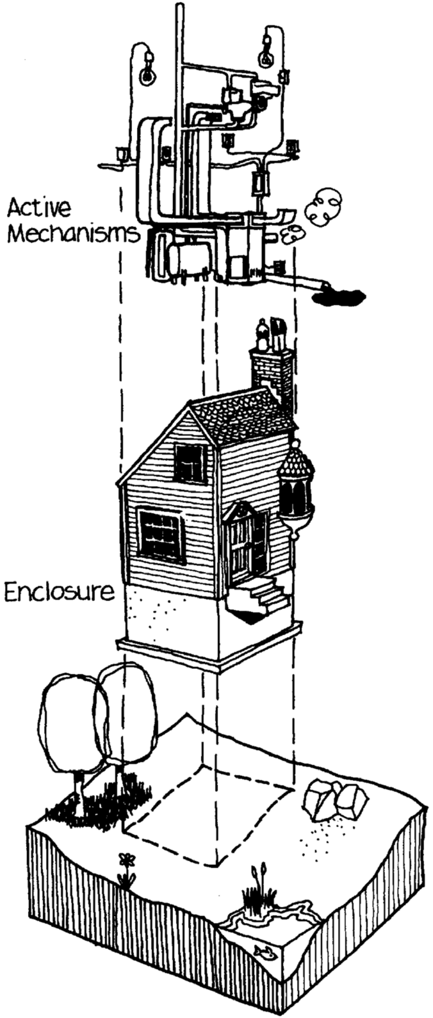
Source: International Energy Agency, 2013

- **Proportion of Energy Use for Heating in Residential Buildings (Switzerland)**

  proportion between space heating & DHW depends on the type of the building (generation, efficiency of insulation)



Source: Office fédéral de l'énergie SuisseEnergie, 2016



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Indoor Climatization (Heating/Cooling)

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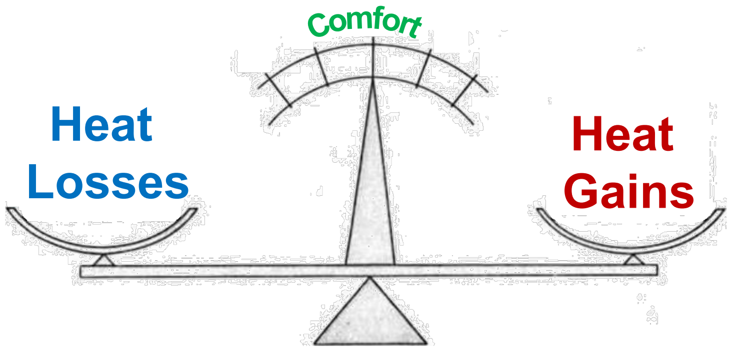
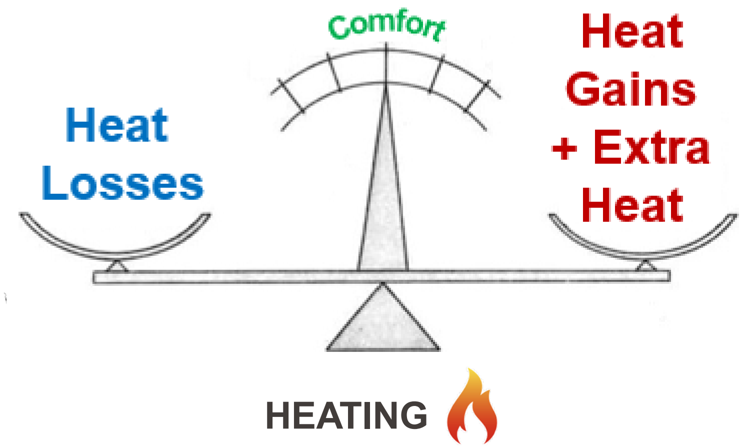
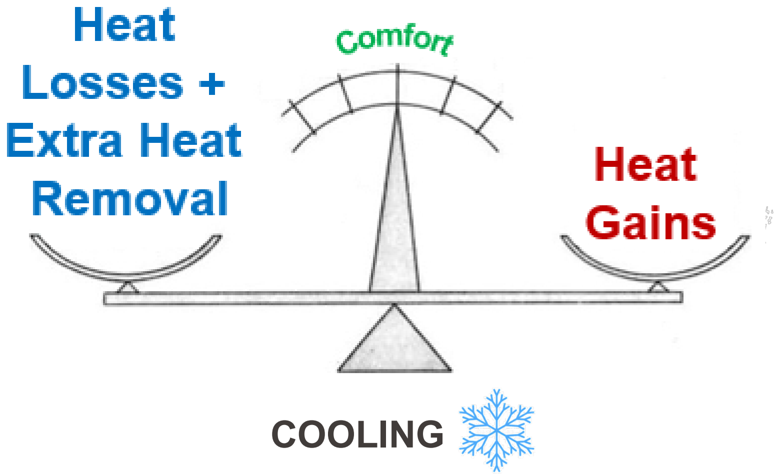
- **Comfortable indoor temperature** is *maintained* by *balanced* **heat losses** and **heat gains**
- **Heating** or **cooling** is needed when *they are imbalanced* and *extra* **heat addition** or **removal** is **necessary**

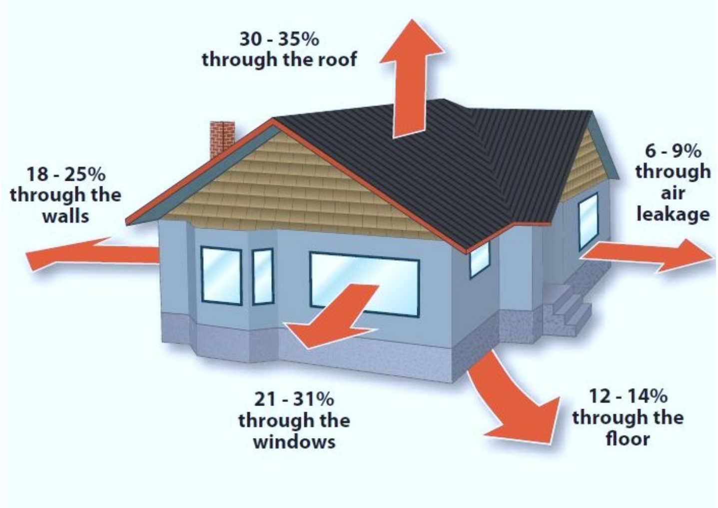




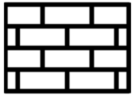


Heat Losses and Space Heating

- **Heat losses** is **the rate** at which **heat leaves** *the indoor space*
- **Heating** (rate of energy *input*) should *compensate* for **heat losses** *to maintain* an indoor environment *at a desired temperature* and *humidity*
- ***A central principle of a Low Energy Building design in heating-dominated regions:*** to **reduce heat losses** by **super-insulating**, creating **airtight building envelopes,** and eliminating **thermal bridges**



Through **opaque** surfaces (walls, floors, ceilings and doors)



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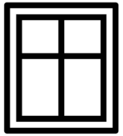
Through **transparent** fenestration surfaces (windows, skylights, and glazed doors)



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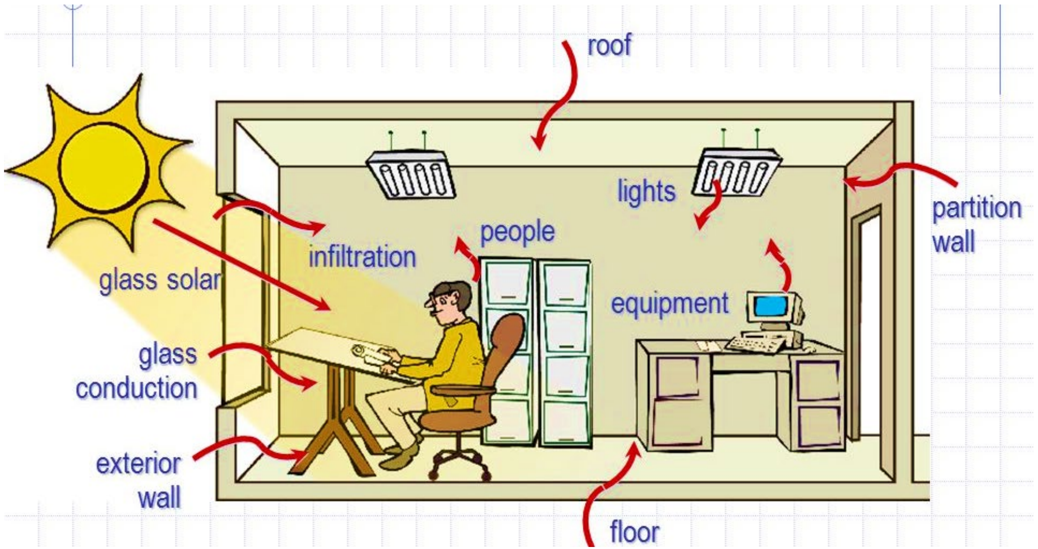
Infiltration and **Ventilation**

Heat Gains and Space Cooling

- **Space heat gain** is **the rate** at which **heat enters into** and/or is **generated within** *a space*
- **Cooling** (rate of sensible and latent energy *removal*) **required *to maintain*** an **indoor environment *at*** a **desired temperature and humidity**



*Can be minimized through **proper architectural design***

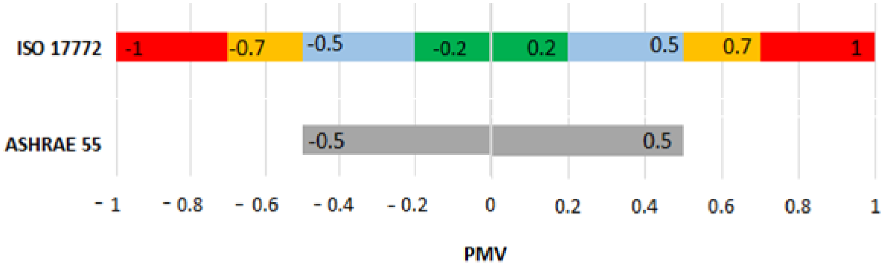
*Can be modulated (shifted in time) through **proper choice of materials***

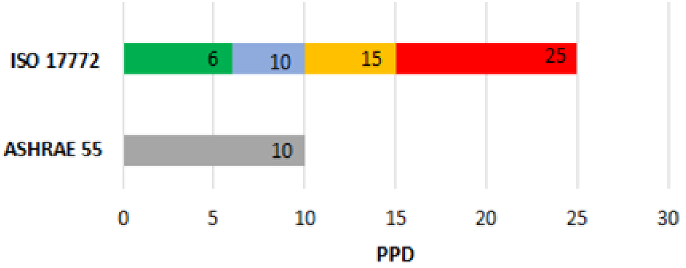
Main modes of heat entry indoors:

1. ***Solar radiation*** through ***transparent*** **surfaces**
2. ***Heat conduction*** through ***exterior*** **walls** and **roofs**
3. ***Heat conduction*** through ***interior*** **ceilings**, **floors**, and **partitions**
4. ***Internal heat*** *generated* by ***occupants***, ***lights***, and ***appliances***
5. **Energy transfer** through ***ventilation*** and ***infiltration*** of outdoor air

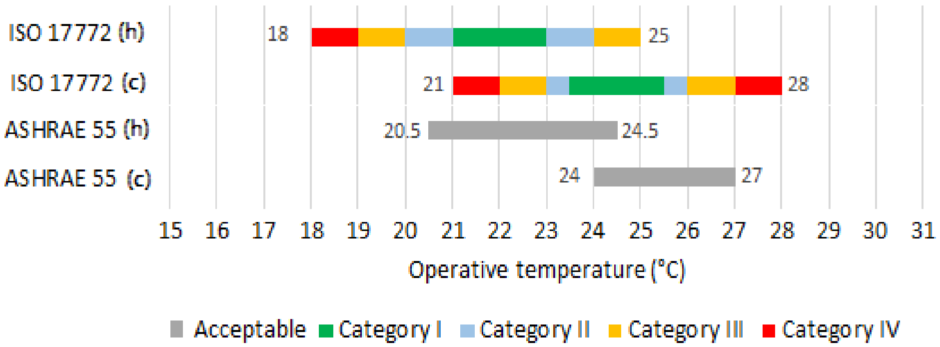
Requirements for Climatization: Thermal Comfort

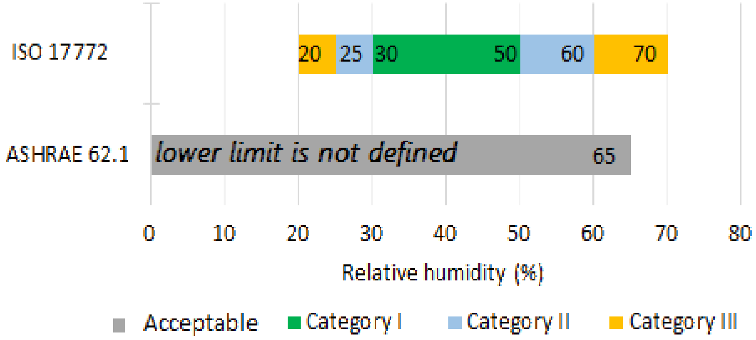
- Limits of **Predicted Mean Vote (PMV)** and **Predicted Percentage Dissatisfied (PPD)**





- Ranges of **operative temperatures** and **relative humidity** in heating and cooling seasons (**offices**)





Source: *Khovalyg et al (2019) Energy and Buildings, DOI: 10.1016/j.enbuild.2020.109819*

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Heating/Cooling Setpoints: Offices

Country	Cooling setpoint [°C]	Heating setpoint [°C]	Cooling setback [°C][a]	Heating setback [°C]
AUS	26.0[b]	18.0	off	off
AUT	26.0	22.0	off	off
BEL	25.0	21.0	28[c]	15[13]
BRA	24.0	–	off	–
CAN	24.0	22.0	off	18.0
CHE	26.0	21.0	off	off
CHN	26.0	20.0	off	off
DEU	24.0	21.0	off	17.0
DNK	25.0	20.0	off	–
ENG	24.0	22.0	off	12.0
FRA	26.0	19.0	30	16, 7[f]
HUN	26.0	20.0	–	–
IND	26.0	18.0	–	12
ITA	26.0	20.0	–	–
KOR	28.0	20.0	–	–
NLD	24.0	20.0	off	18.0
NOR	24.0	21.0	–	19.0
NZL	24.0	20.0	–	–
SGP	23.90, 25.0[h]	–	off	–
SWE	23.0[i]	21.0	–	–
UAE-1	23.9	–	26.7	–
UAE-2	24.0	–	–	–
USA	23.9	21.1	26.7	15.6

a - *Off* indicates that the mechanical cooling system is turned off and the setpoint is effectively ignored.
b - The temperature must be between the heating and cooling setpoint for 98% of operation time.
c - The given value is for low inertia buildings. For high inertia buildings no heating or cooling setback temperature is assumed.
d - This is the minimum desk illuminance prescribed by the French Labour Code.
e - This is the minimum ventilation rate prescribed by the French Labour Code.
f - 16 for off periods less than 48 h, 7 for off periods more than 48 h.
g - Maximum of 0.6 l/(s.m2) and 5.5 l/(s.person).
h - 23 for zones with solar gain, 25 for other zones.
i - 23 and 21 are the minimum setpoints.

Source: O'Brein et al (2020), DOI: https://doi.org/10.1016/j.buildenv.2020.106906

Example: Effect of the Heating Setpoint

- A residential building, Vevey
- 15 apartments
- Built in 1920s

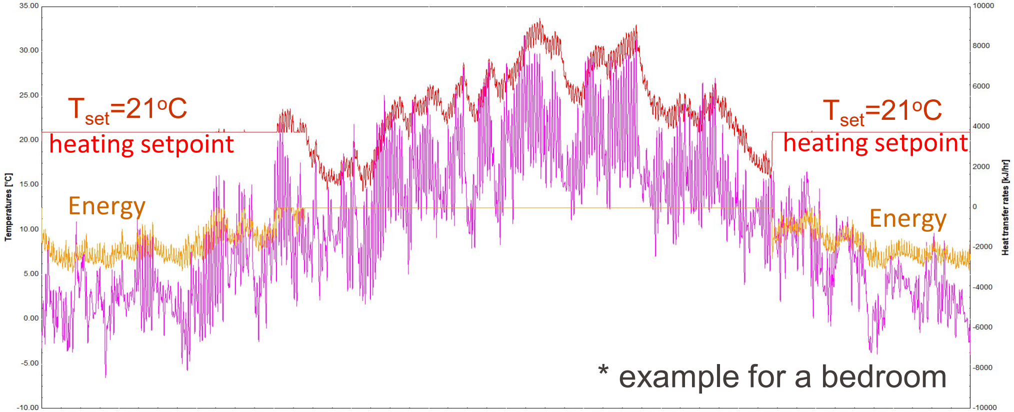
Before renovation:

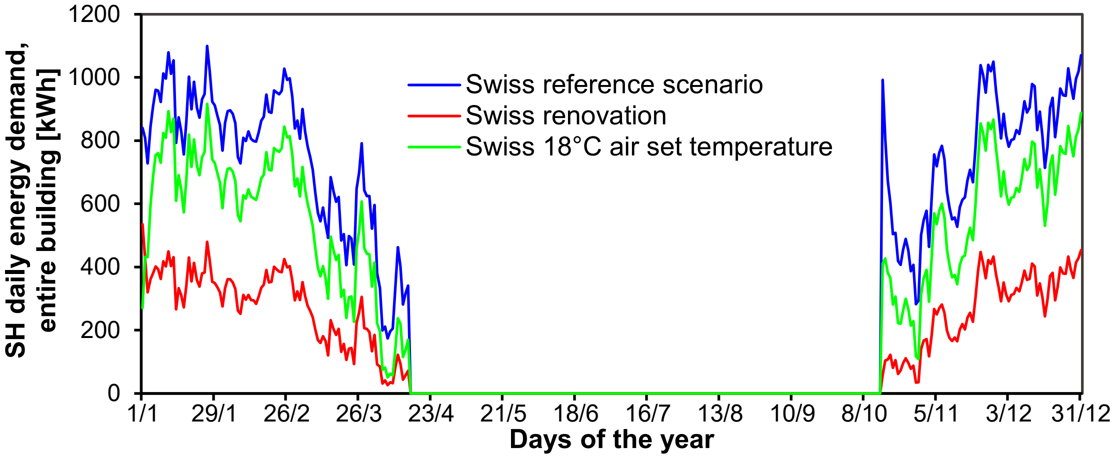
U_{walls} = 0.9 W/(m² K),
$U_{windows}$ = 2.8 W/(m² K)

After renovation:

U_{walls} = 0.17 W/(m² K),
$U_{windows}$ = 1.0 W/(m² K)

Indoor air temperature and heat supply rate variation:





Design Conditions: Outdoor Conditions

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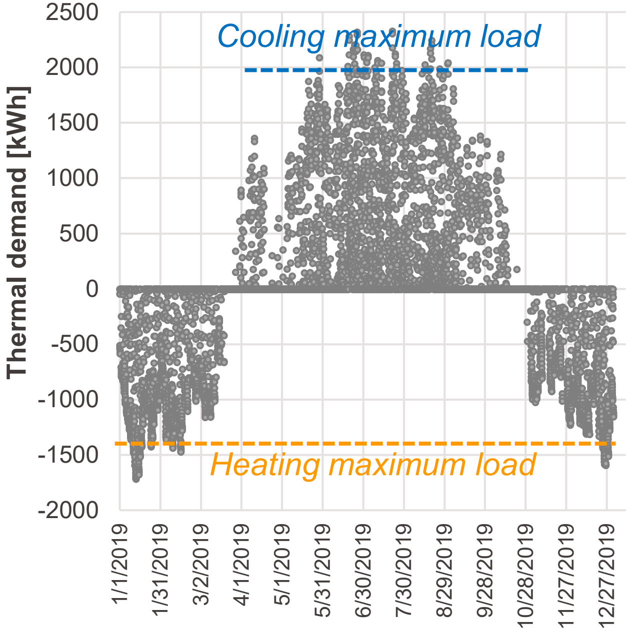
- **Design for typical building use** – design to meet *representative maximum-load conditions*, NOT *extreme conditions*. Normal occupancy should be assumed, NOT the *maximum* that might occur *occasionally*.
- **Outdoor design conditions** can be specified as **0.4**, **1.0**, and **2.0**% for **heating, 99.6** and **99.0**% for **cooling**

Winter

- Coldest month (a month with the *lowest* average DB temperature)
- Dry-bulb temperature corresponding to **99.6%** and **99%** of annual cumulative frequency of occurrence

Summer

- Hottest month (a month with the *highest* average DB temperature)
- Dry-bulb temperature corresponding to **0.4**, **1.0**, and **2.0%** of annual cumulative frequency of occurrence, mean coincident wet-bulb temperature



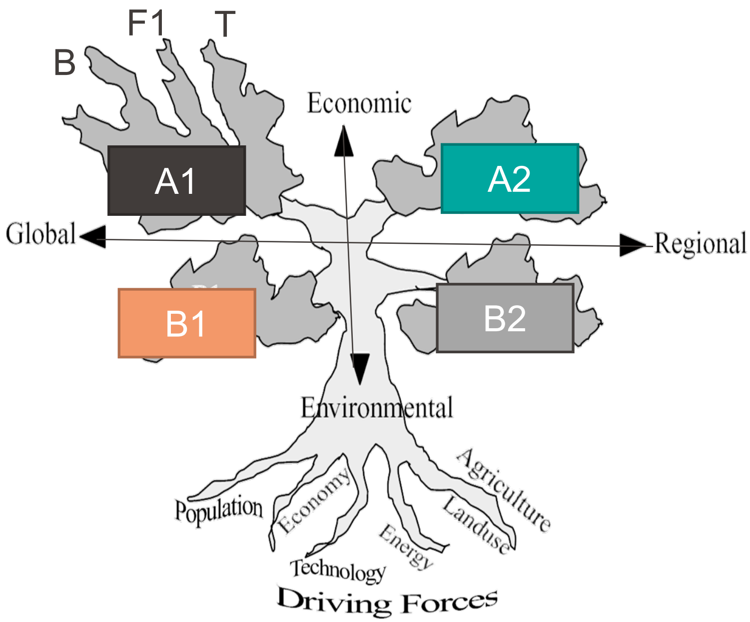
Source: ASHRAE HOF 2017, Chapter 17

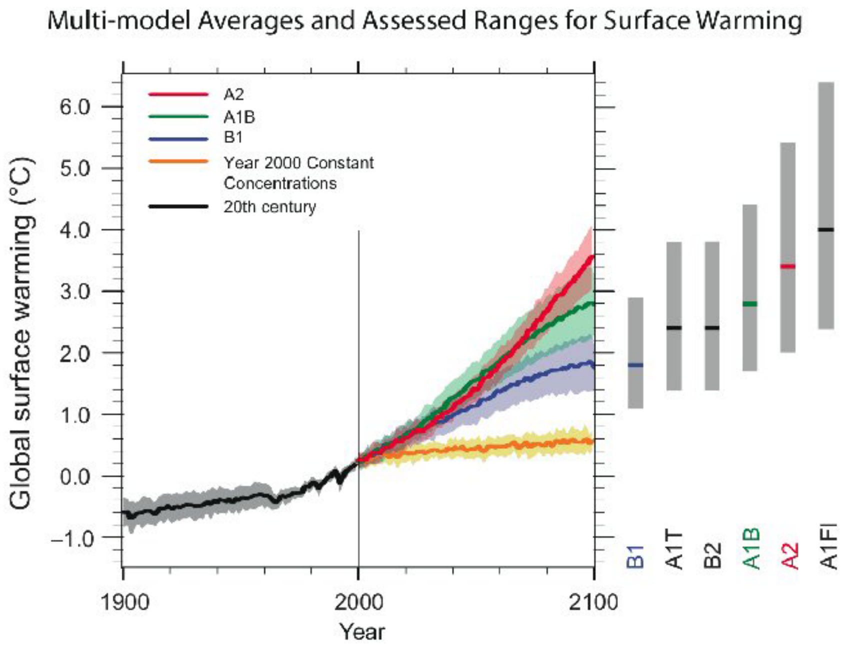
Thermal Demand: Minimization vs. Maximization

- The amount of **heating/cooling** required *at any particular time* **varies dynamically**, depending on *external* (e.g., outdoor conditions) and *internal factors* (e.g., internal heat gains depending on occupancy)

Heating	Cooling
To **minimize** the **demand** (consequently, *minimize operational energy*):	
• Consider dynamics of solar and internal heat gains • Maximize solar heat gains • Consider heat storage capacity of materials • Consider heating modes (radiative vs. convective)	• Minimize solar and conductive heat gains • Consider time lag effect and the heat storage of materials • Minimize infiltration heat gains • Use efficient appliances (minimize internal heat)
To evaluate **maximum demand** for *equipment* ***sizing*** *purposes*:	
• Ignore solar and internal heat gains • Ignore heat storage capacity of materials • Consider heat losses to be *instantaneous* • Consider heat transfer as essentially *conductive*	• Separately treat *convective* and *radiative* portions of heat gains • Consider the time lag effect • Consider the heat storage effect

Climate Change SRES Scenarios





A1B:
- Moderate population growth, sprawling development
- Very high economic growth
- Rapid technological innovation
- Strong biofuels demand
- Reduced regulation

B1:
- Moderate population growth
- Compact urban development
- High economic growth
- Low overall energy use, lower demand for biofuels
- Increased regulation, protection of natural land cover
- Restoration of natural land cover where possible

A2:
- Very high population growth
- Moderate economic growth
- High demand for agricultural products
- Moderate biofuels demand
- Grassland lost to food crops
- Reduced regulation
- Preservation of local identities

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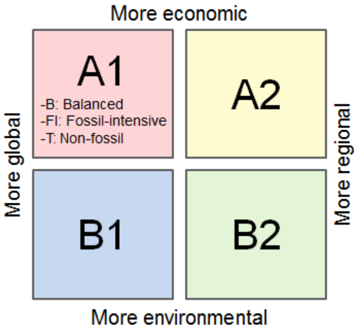
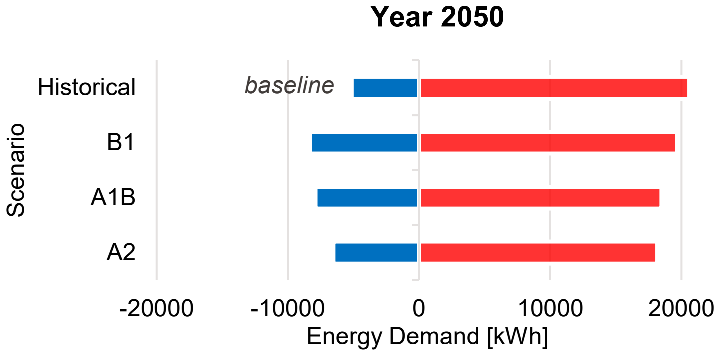
Space Heating & Cooling Demand - Example

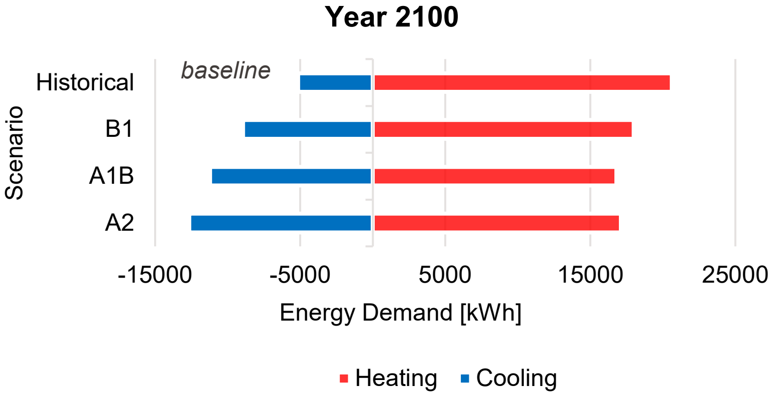
Climate Change Effect on Energy Demand

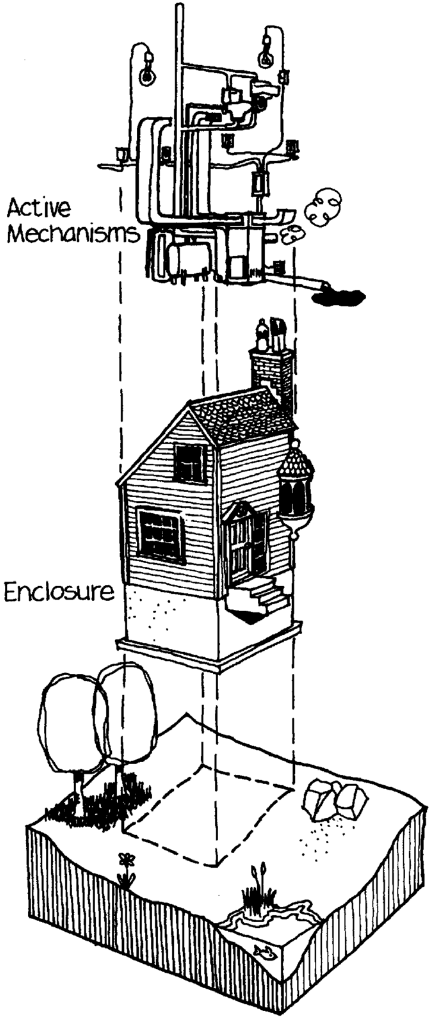




Change in heating/cooling demand (%) compared to the baseline:

scenario	2050 H	2050 C	2100 H	2100 C
A2	-11.9	**26.9**	-17	**146**
A1B	-10.4	**53.2**	-18.5	**117.9**
B1	-4.6	**61.6**	-12.7	**73.8**





Source: Edward Allen «How Buildings Work» (2005)

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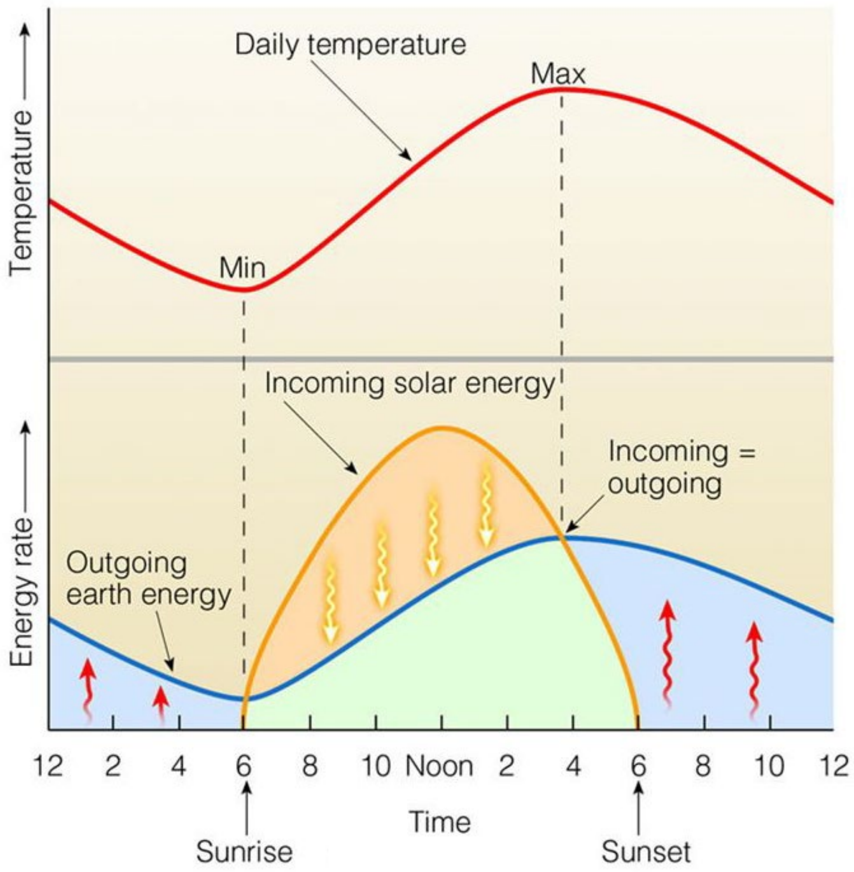
Diurnal Variation of Outdoor Conditions

- **Outside temperature** and **solar radiation intensity** that is *incident upon the surface* varies over a period of **24 hours**
- **Diurnal variations** produce an approx. *repetitive* **24-hour cycle** of *increasing* and *decreasing* **temperatures** that follows nearly a *harmonic variation*
  - The **maximum** air temperature usually occurs *2-3 hours after* solar noon, the **minimum** temperature occur *just before sunrise*
  - The **daily maximum** generally *lags the solar maximum* as the heated surface is warming the surrounding air

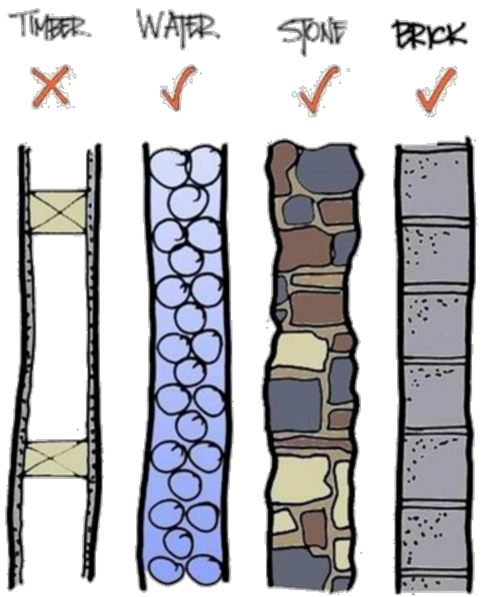


Thermal Mass Effect

- **Thermal mass** - ability of the building material **to store heat** (typically, **dense materials** such as *brick* and *concrete* **have high thermal storage capacity**)

Building with **high thermal mass materials** within the envelope:

- will display a **reduced** and **delayed reaction** to the **change in outdoor temperature** by ***absorbing* heat** during periods of *high solar insolation*, and ***releasing* heat** when the surrounding *air gets cooler*
- can help *reduce* **indoor temperature fluctuations**; thus *reducing* the *heating* and *cooling* demand of the building itself.



Source: https://fairconditioning.org

MATERIAL	THERMAL MASS (volumetric heat capacity, KJ/m³.k)
Water	4186
Concrete	2060
Sandstone	1800
Compressed earth blocks	1740
Rammed earth	1673
FC sheet (compressed)	1530
Brick	1360
Earth wall (adobe)	1300
AAC	550

- **Heat storage q_S (W/m²)** - amount of **thermal energy** required to *change* **internal energy of the material** (determined by specific heat capacity c_p and density ρ of the material)

$$q_S = \rho \cdot c_p \cdot \delta \cdot \frac{dT}{dt}$$

$C_p\ [\frac{kJ}{m^3 \cdot K}]$ thickness

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Dynamic Thermal Inertia Factors

- **Time lag** (phase shift), $\boldsymbol{\varphi}$ [h] –

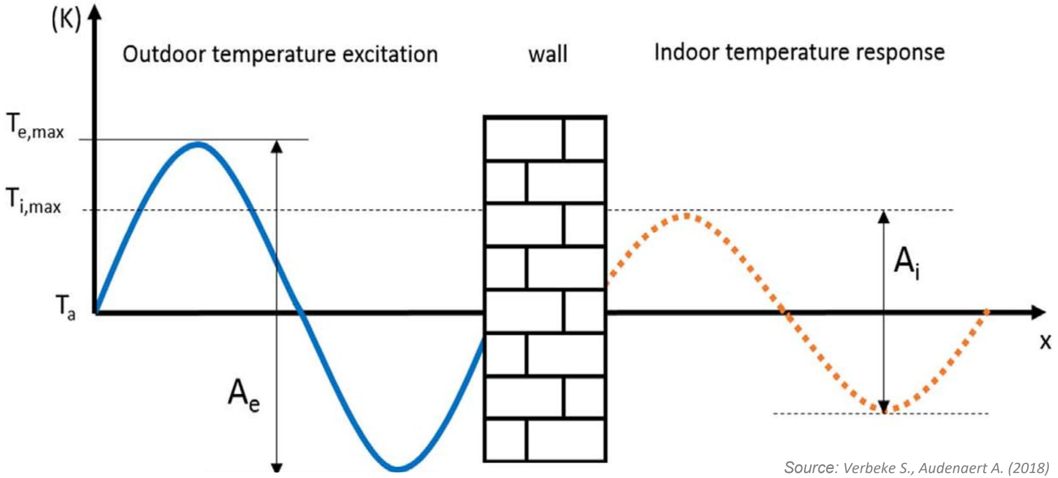
the time required for the heat wave, with period P(=24h), to propagate through a wall from the outer to the inner surface

$$\boldsymbol{\varphi} = \tau(T_{i,max}) - \tau(T_{e,max})$$

- **Decrement factor**, f [-] –

the **ratio** of **decrease** of the **amplitude** of the **thermal wave** during its propagation process from ***outside*** to ***inside*** (the measure of the damping effect)

$$\boldsymbol{f} = \frac{\boldsymbol{A_i}}{\boldsymbol{A_e}} = \frac{T_{i,max} - T_{i,min}}{T_{e,max} - T_{e,min}}$$



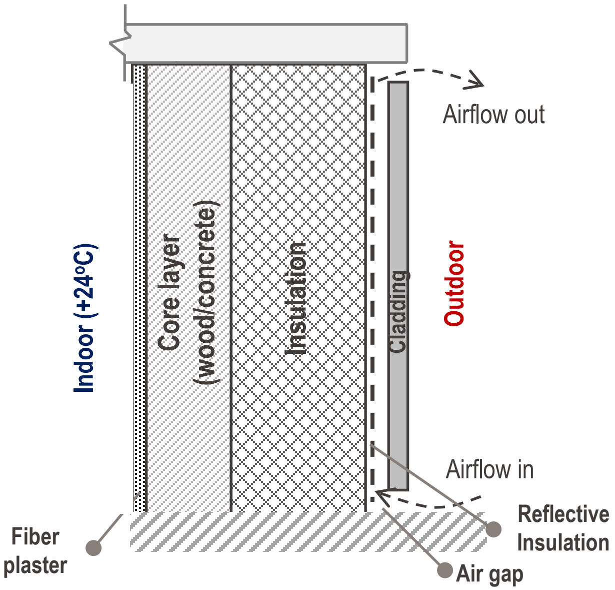
Source: *Verbeke S., Audenaert A. (2018)*

- *Surface temperatures* need to be considered for $\boldsymbol{\varphi}$ and $\boldsymbol{f}$ calculations
- The benefits of decrement delay are only *significant* when outside temperature *fluctuates significantly higher* than the inside temperature

Building Envelope Dynamic Behaviour: Example

- The **smaller the decrement factor *f***, the **more effective the building element** at **suppressing temperature swings** (greater outdoor temperature attenuation)

Which wall structure has the minimum decrement factor *f*?



Parameter	Thickenss	Conductivity	Density	Specific heat capacity	Emissivity
Unit	m	W/m·K	kg/m^3	J/kg·K	[-]
Cladding					
Fiber cement	0.008	0.58	1900	1000	0.9
Heavyweight wall core					
Reflective insulation	0.0002	235	2700	890	0.05
Insulation	0.17	0.03	25	1380	0.9
Concrete	0.15	0.5	1400	1000	-
Fiber plaster	0.01	0.18	837	800	0.9
Lightweight wall core					
Insulation	0.16	0.03	25	1380	0.9
Wood	0.1	0.14	400	1255	-
Fiber plaster	0.01	0.18	837	800	0.9
Air cavity	0.045	varies	varies	varies	-

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Which wall structure has the minimum decrement factor *f*?

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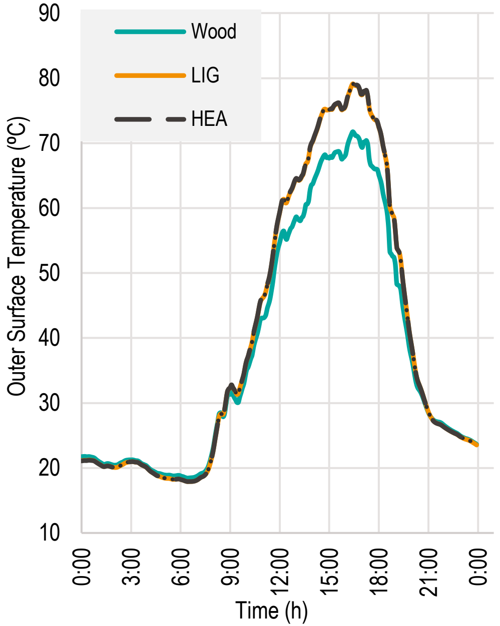
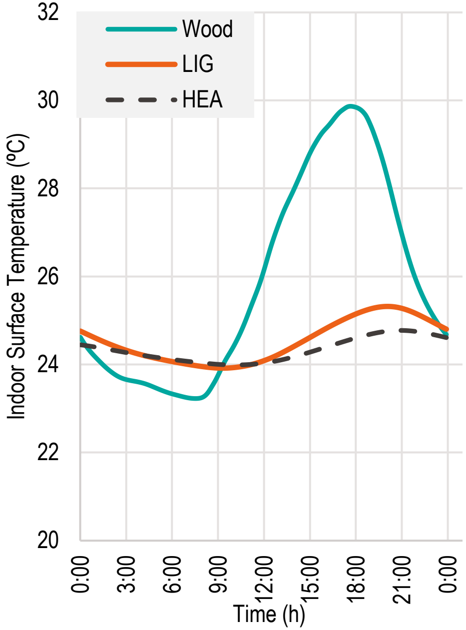
A. LIG: Lightweight wall assembly
B. HEA: Heavyweight wall assembly
C. WOOD: Wooden wall





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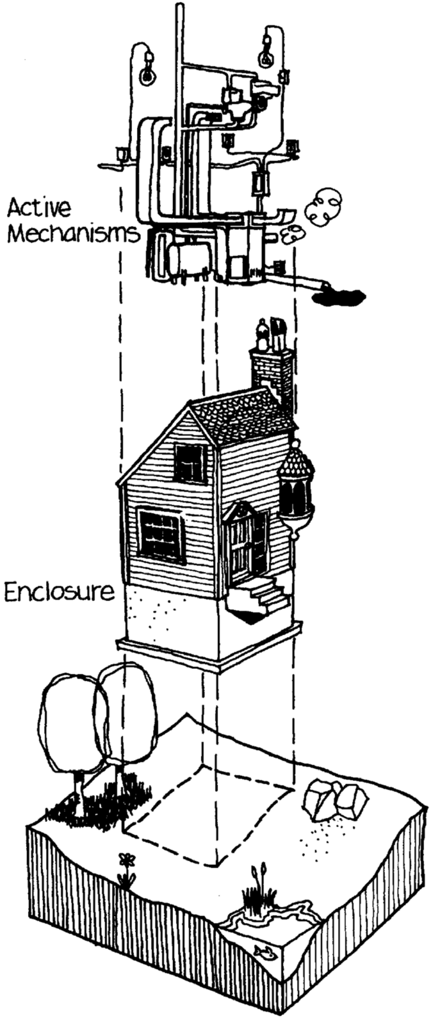

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Indoor Heat Sources

- Lights

- People

- Appliances/ Equipment/ Plug loads

What values to take if the details of the building are not known or you want to design a new building?

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Density of Heat Gains per floor m² (from SIA 2024-2015)

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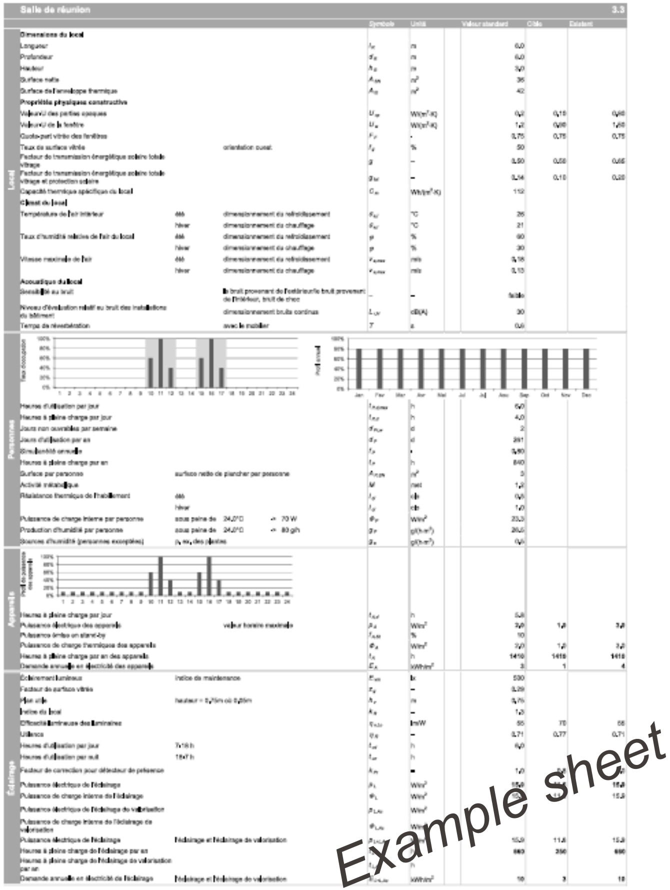
- SIA 2024-2015 provides 3 values for each category: **Actual** / **Standard** / **Target**

Space type	Appliances [W/m²]	Lights [W/m²]	People* [W/m²]
Individual/ shared office	15 / 7 / 3	15.9 / 15.9 / 11.6	5
Open space office	19 / 10 / 4	12.5 / 12.5 / 9.1	7
Meeting room	3 / 2 /1	15.9 / 15.9 / 11.6	23.3
Individual housing	10 / 8 / 4	2.7 / 2.7 / 1.7	1.4
Collective housing	10 /8 / 4	2.7 / 2.7 / 1.7	2.3

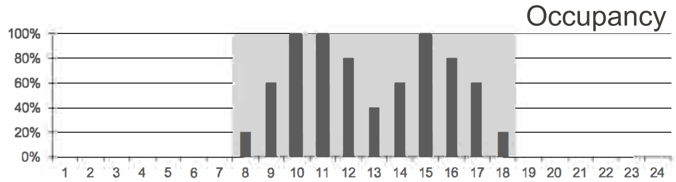


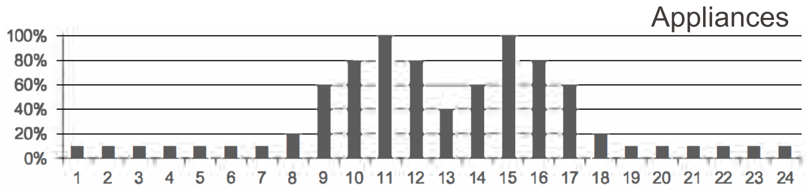
* *The unit of* [**m²**] is the floor surface area, not the body surface area
Heat gains from people are estimated based on the people density, and typical activity type (and corresponding met)

Shedules of Internal Heat Gains

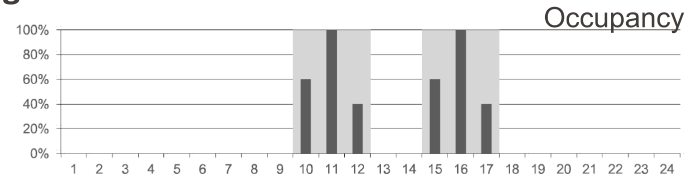
- As internal heat gains primarily depend on the human presence and activity, the **schedules** of appliances/lights usage are **occupant-dependent**. The lecture on “Occupant Behavior” highlights different models.
- SIA 2024-2015 provides **standard schedules** for energy calculations:

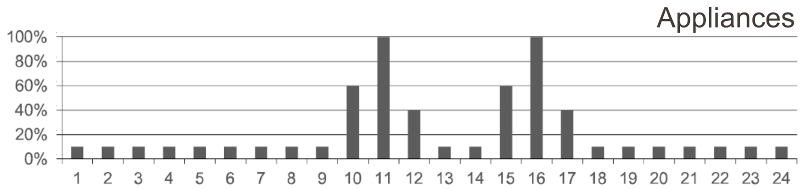
Personal/shared offices



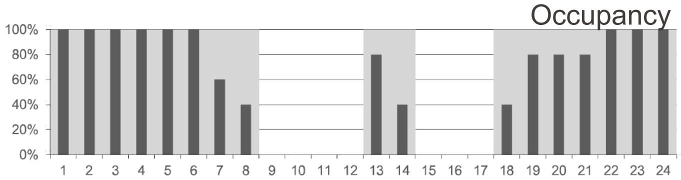


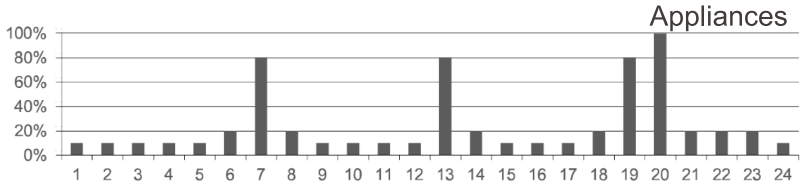
Meeting rooms

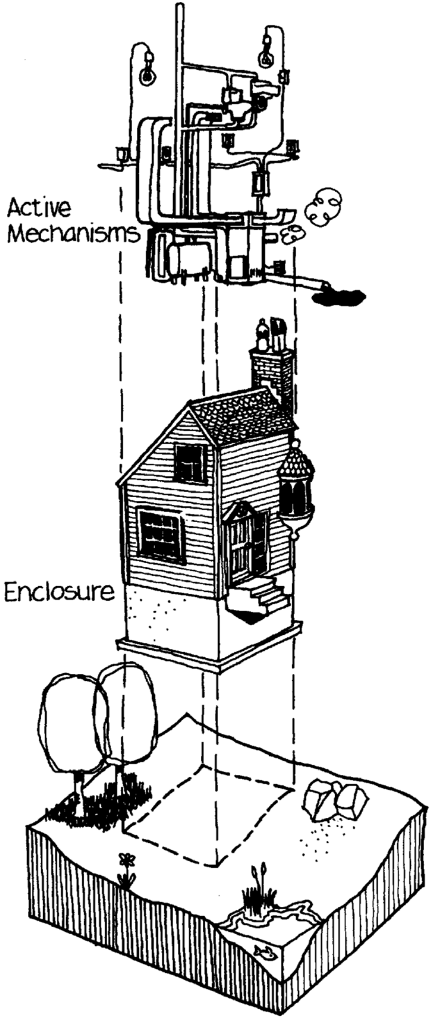




Apartments







Source: Edward Allen «How Buildings Work» (2005)

CONTENT:

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  - Sanitary requirements
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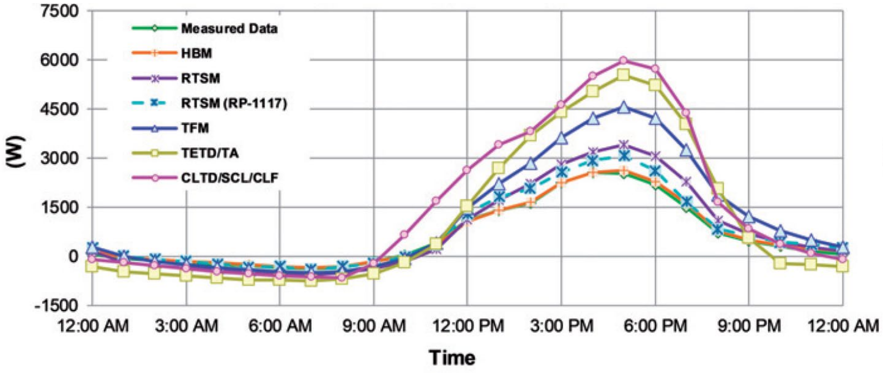
- Summary

Thermal Loads Calculation Methods

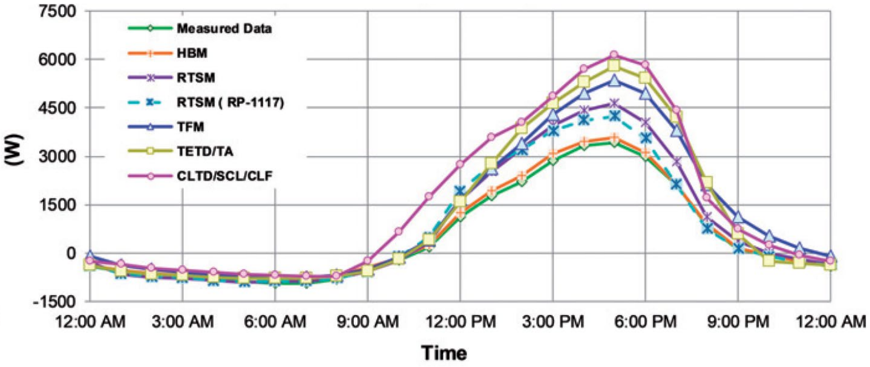
METHODS

1. Total Equivalent Temperature Difference/Time Averaging (**TETD/TA**)
2. Cooling Load Temperature Difference/Solar Cooling Load/ Cooling Load Factor (**CLTD/SCL/CLF**)
3. Transfer Function Method (**TFM**)
4. Radiant Time Series Method (**RTSM**) ← *approximation of HBM*
5. Heat Balance Method (**HBM**) ← *the most accurate, numerical*

(a) Heavyweight building



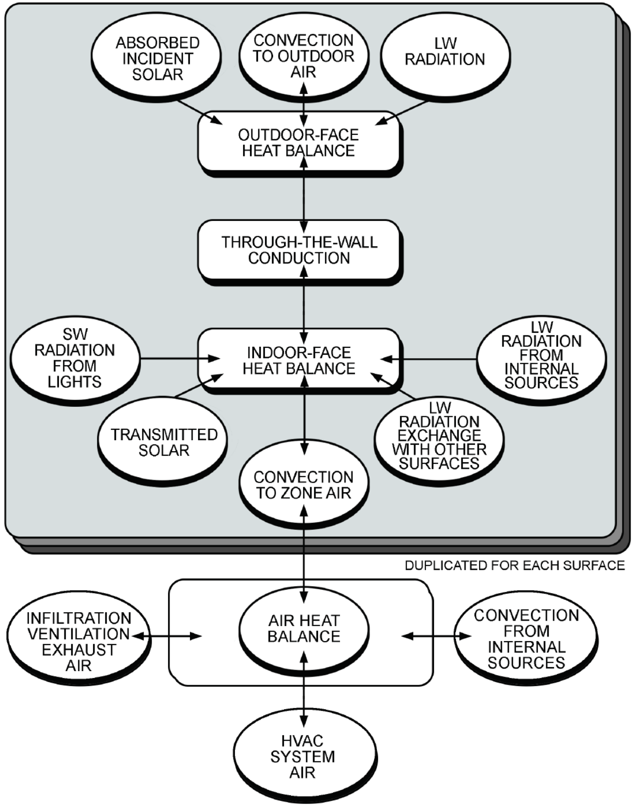
(b) Lightweight building



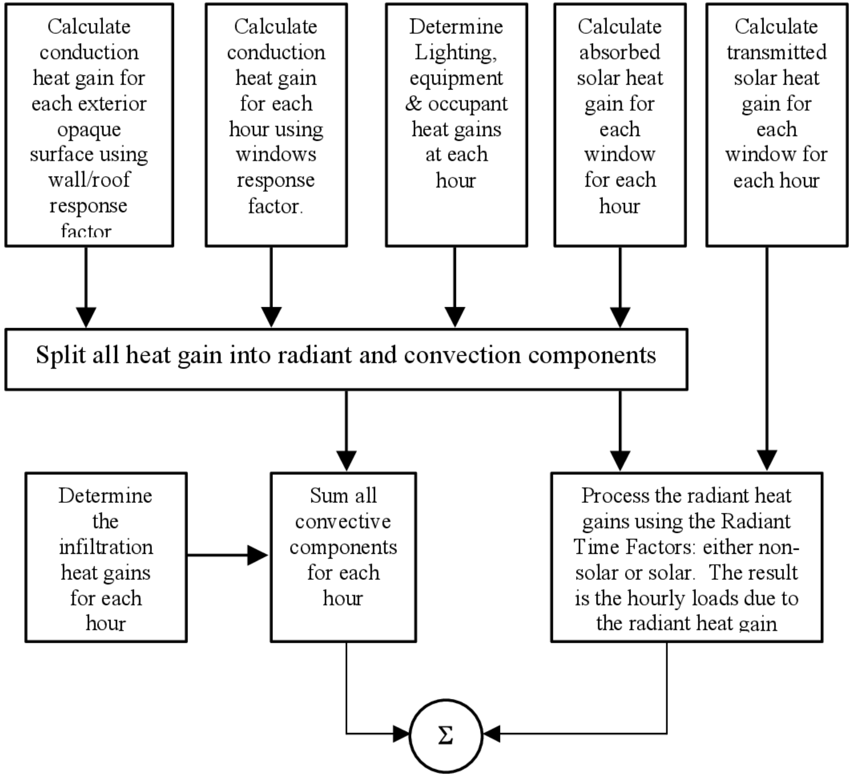
Source: Mao C. et.al. (2018) DOI: 10.1080/23744731.2018.1510240

Thermal Loads Calculation Methods

Heat Balance Method

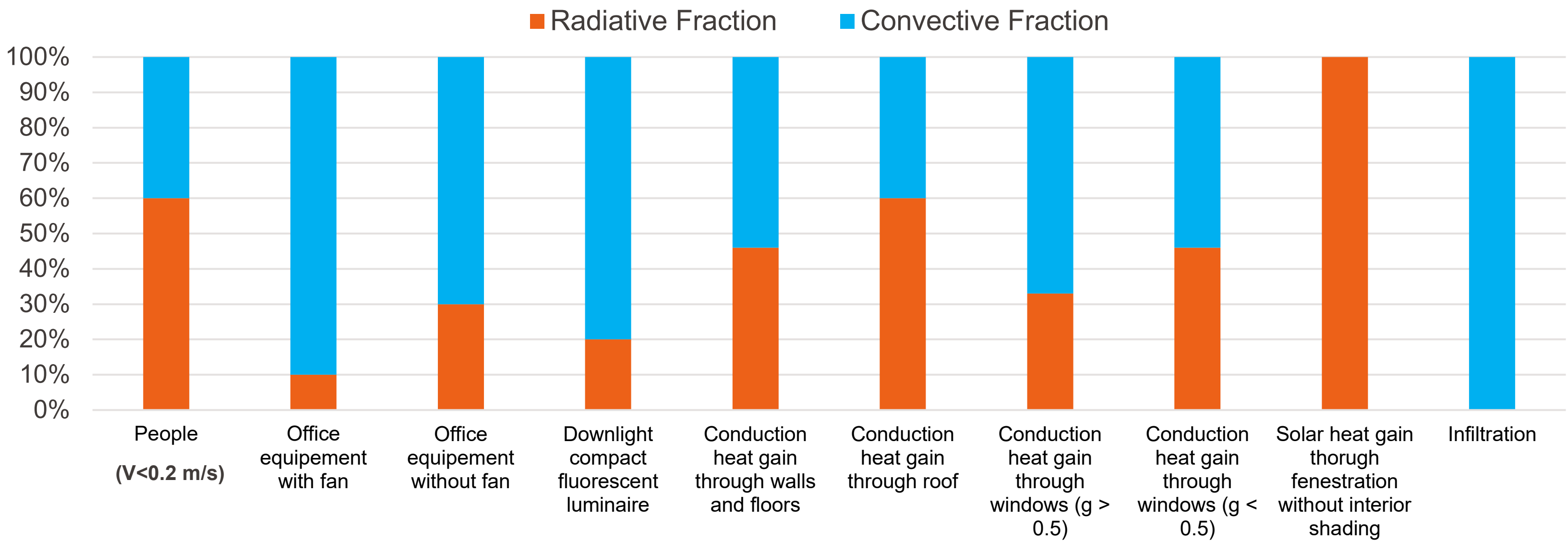


RTS Method



Heat Gains: Radiative/Convective Splits

Each **heat gain** can be split into ***radiative*** and ***convective*** portion

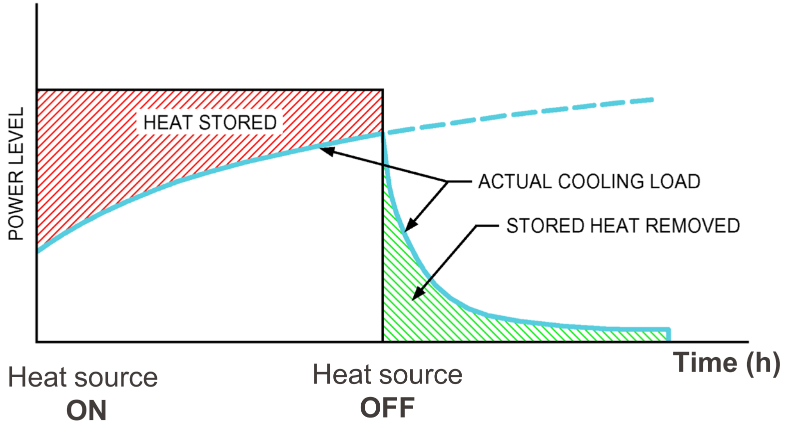


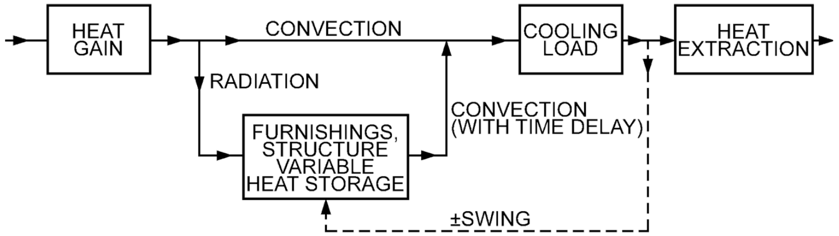
- The **convective portion** *instantly* becomes **a cooling load**
- **Radiant heat gain** must first **be *absorbed*** by **the *surfaces*** that *enclose the zone* and *objects in the zone and **re-radiated** with **certain time lag** (for **non-active surfaces)***

Source: ASHRAE HOF 2017, Chapter 18

Space Cooling Load: Time Lag Effect

- Energy absorbed by *non-active surfaces* such as *walls*, *floor*, *furniture*, etc., contributes to **space cooling load** only after **a time lag**. Some of this energy is ***still present*** and ***re-radiating*** even after the heat sources **have been switched OFF** or **removed**.
    - There can be a *significant delay* between **the time a heat source is activated**, and the **time when re-radiated energy** *equals* that being ***instantaneously*** **stored**.
- This **time lag** must be considered **when calculating cooling load**, because the load required for the space can be **much lower** than the ***instantaneous*** **heat gains being generated**, and ***the peak load of the space*** may be *significantly* affected

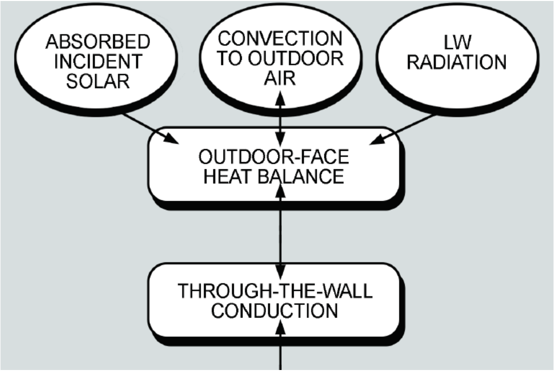




Source: ASHRAE HOF 2017, Chapter 18

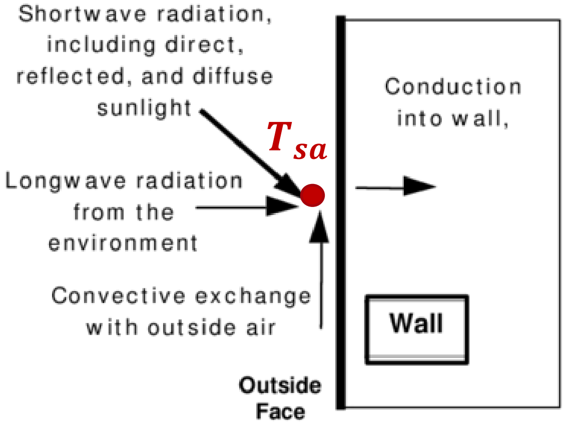
Sol-Air Temperature

- **Sol-air temperature T_{sa}, [K] - a fictitious temperature** of **the outdoor air**, which, in the absence of radiative exchanges on the outer surface of the roof or wall, *would give the same rate of heat transfer* through the *wall or room* as *the actual combined heat transfer mechanism between the Sun,* the *outdoor air* and *the surroundings.*
- The concept *facilitates* **predictions of transient** and **periodic heat flows** *through* building structures.



$$T_{sa} = T_a + \frac{\alpha \cdot I}{h_{se}} - \frac{\varepsilon \cdot \Delta R}{h_{se}}$$

- α [–] – absorptivity of the outer surface material
- ε [–] – hemispherical emissivity of the outer surface material
- I [W/m^2] – global horizontal solar irradiance
- h_{se} [W/m^{2}K] – heat transfer coefficient by long-wave radiation and convection at the outer surface, can be estimated through R_{se}
- ΔR [W/m^2] – difference between *long-wave radiation* incident on surface from sky and surroundings and *radiation emitted by outdoor environment*
  - Horizontal surfaces: ΔR = 63 W/m^2
  - Vertical surfaces: ΔR = 0 W/m^2



Source: *ASHRAE Fundamentals Handbook 2013*

Total Equivalent Temperature Difference (TETD) Method

- When heat transfer **through the external surfaces** is considered, **solar radiative flux** and **infrared exchanges from the sky** need to be accounted for.
- **Heat flux [W/m^2] through the external building structure:**

in [W/m^2] $$q_t = U \cdot (TETD_t)$$ → $$Q_t = U \cdot A \cdot (TETD_t)$$ in [W]

Overall heat transfer coefficient, [W/m²K]

Total equivalent temperature difference, [K]

Cross sectional area, [m²]

- The *combined effect* of the **solar radiation** and **outside air temperature fluctuations** can be accounted using ***a single*** **effective temperature** ***TETD***
- **Total equivalent temperature difference** ***TETD:***

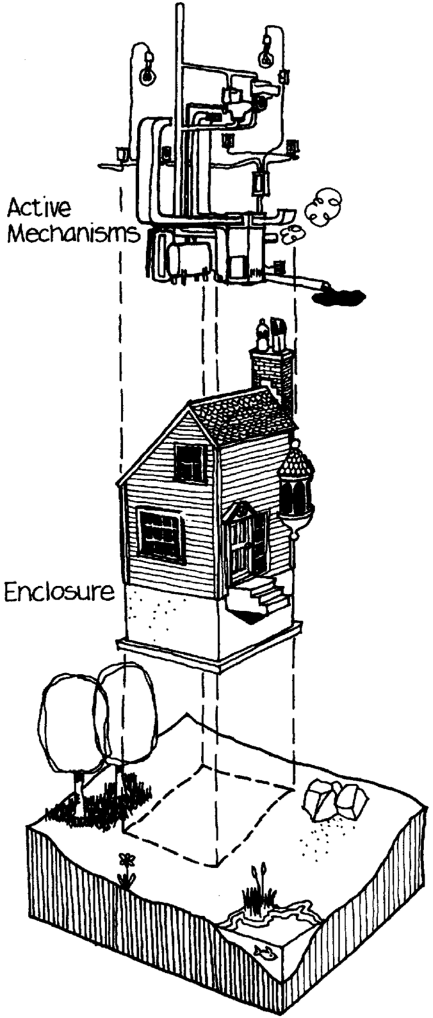
$$TETD_t = T_{sa,t} - T_i + f(T_{sa,t-\varphi} - T_{sa,t})$$

*Outdoor sol-air temperature [K] (at current hour **t**)*

Indoor temperature [K]

Decrement factor

*Outdoor sol-air temperature [K] **φ** hours ago*



Source: Edward Allen «How Buildings Work» (2005)

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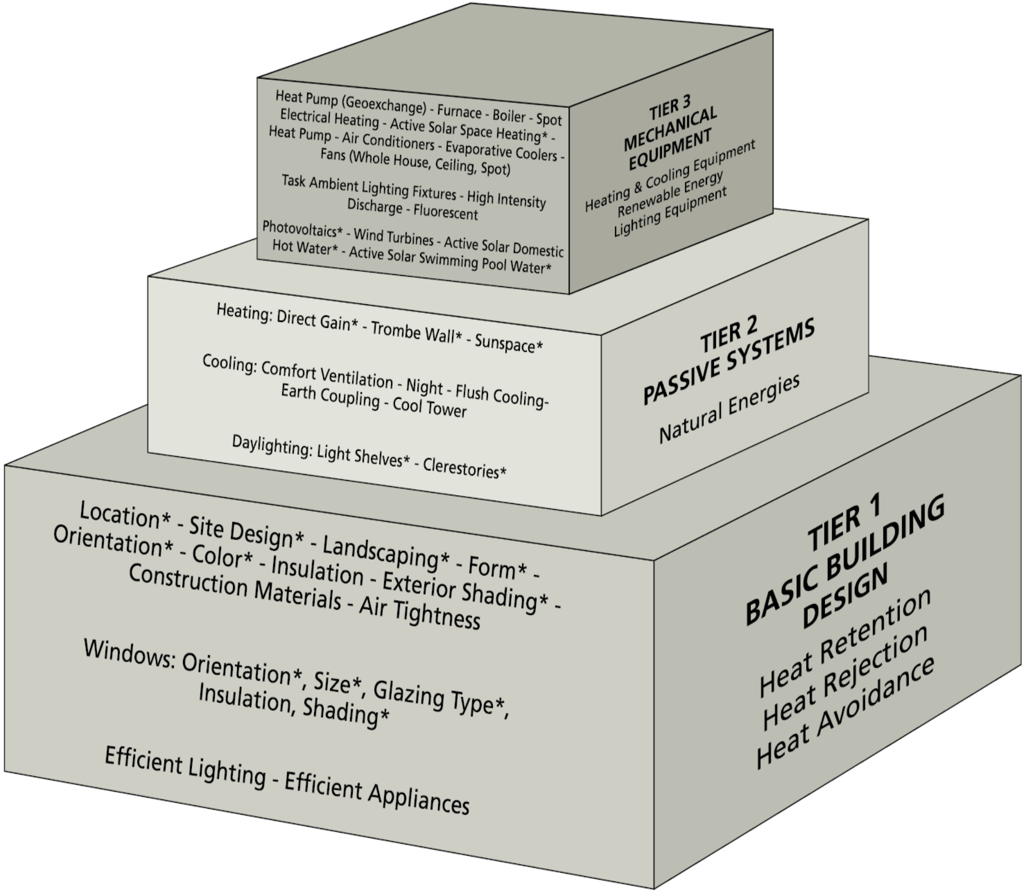
Three-Tier Design Approach

Table 1.4A The Three-Tier Design Approach

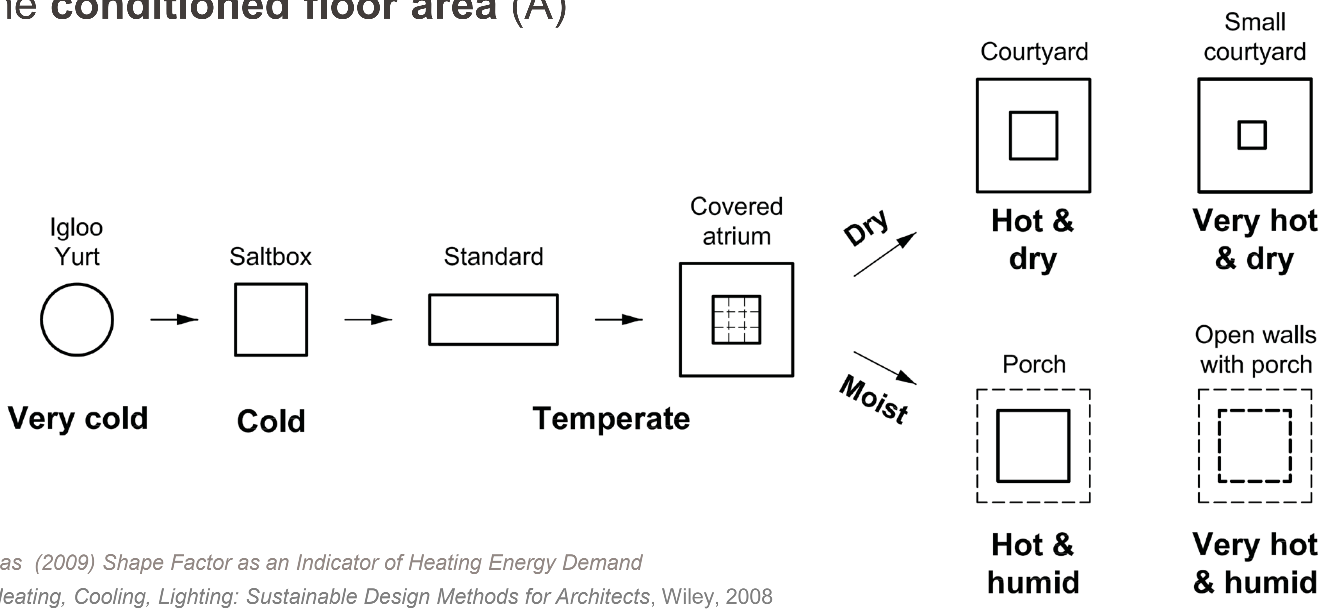
	Heating	Cooling
Tier 1	*Conservation*	*Heat avoidance*
Basic Building Design	1. Surface-to-volume ratio 2. Insulation 3. Infiltration	1. Shading 2. Exterior colors 3. Insulation 4. Mass
Tier 2	*Passive solar*	*Passive cooling*
Natural Energies and Passive Techniques	1. Direct gain 2. Trombe wall 3. Sunspace	1. Evaporative cooling 2. Night-flush cooling 3. Comfort ventilation 4. Cool towers
Tier 3	*Heating equipment*	*Cooling equipment*
Mechanical and Electrical Equipment	1. Furnace 2. Boiler 3. Ducts/Pipes 4. Fuels	1. Refrigeration machine 2. Ducts 3. Geo-exchange



Source: Lechner, Norbert, *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*, Wiley, 2008.

Building Form Implications

- **Shape Factor A/V** - the ratio between **the outside surface area of the thermal insulation in the building envelope** (A) and **the conditioned volume** (V)
- **Shape factor A_{in}/A_{temp}** - a ratio between the **inside surface area of the building** envelope (A_{in}) and **the conditioned floor area** (A_{temp}).
- **Shape factor P/A** – a ratio between **the outside perimeter of the building (P)** and the **conditioned floor area** (A)



Source: K. Lylykangas (2009) Shape Factor as an Indicator of Heating Energy Demand

Lechner, Norbert, *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*, Wiley, 2008

What kind of building shape minimizes heat losses?

Please login:

responseware.eu

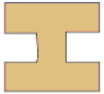
Session ID: **ENG445DK**

A. 

B. 

C. 

D. 

E. 

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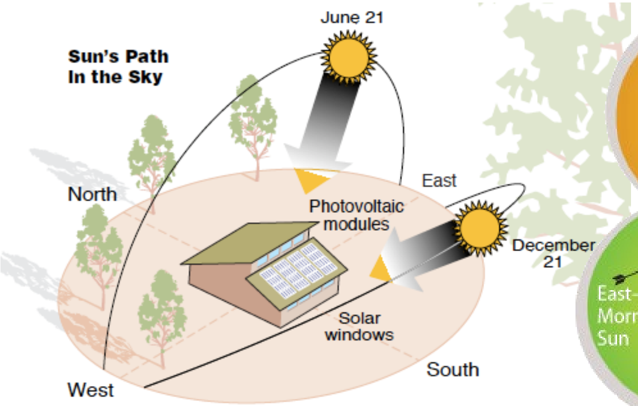
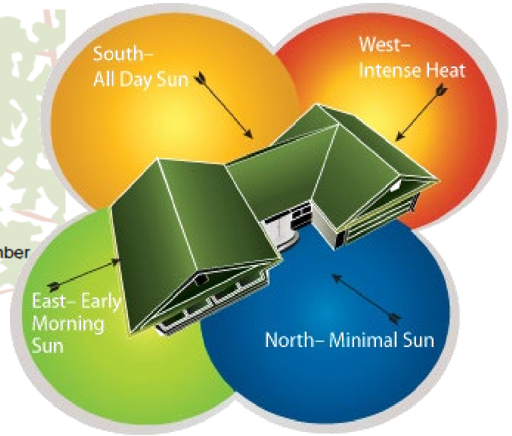
Design Solutions: Solar Control

- The building should be **oriented** in such a way that **heat gains** are *reduced* in **summer** and *maximized* in **winter**





- Solar radiation *transmitted* by *glazed surfaces* is **fully converted to heat** after *being absorbed* by the indoor surfaces on which it is incident. Thus, it is important **to avoid penetration of solar radiation** into the building by the *careful design.*

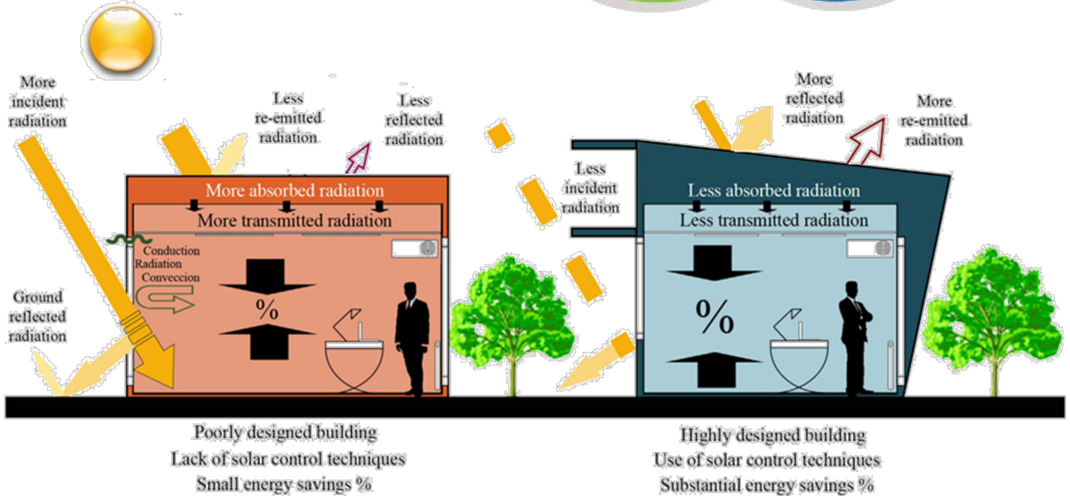
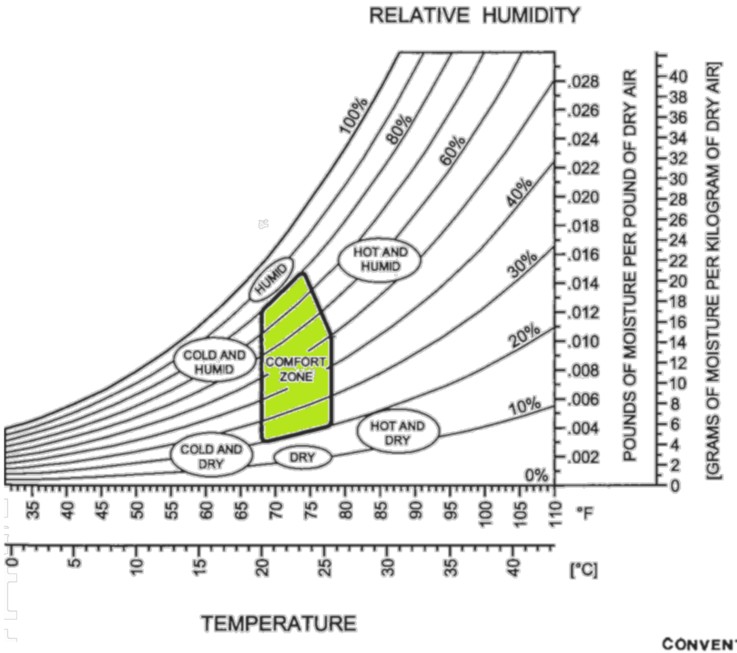
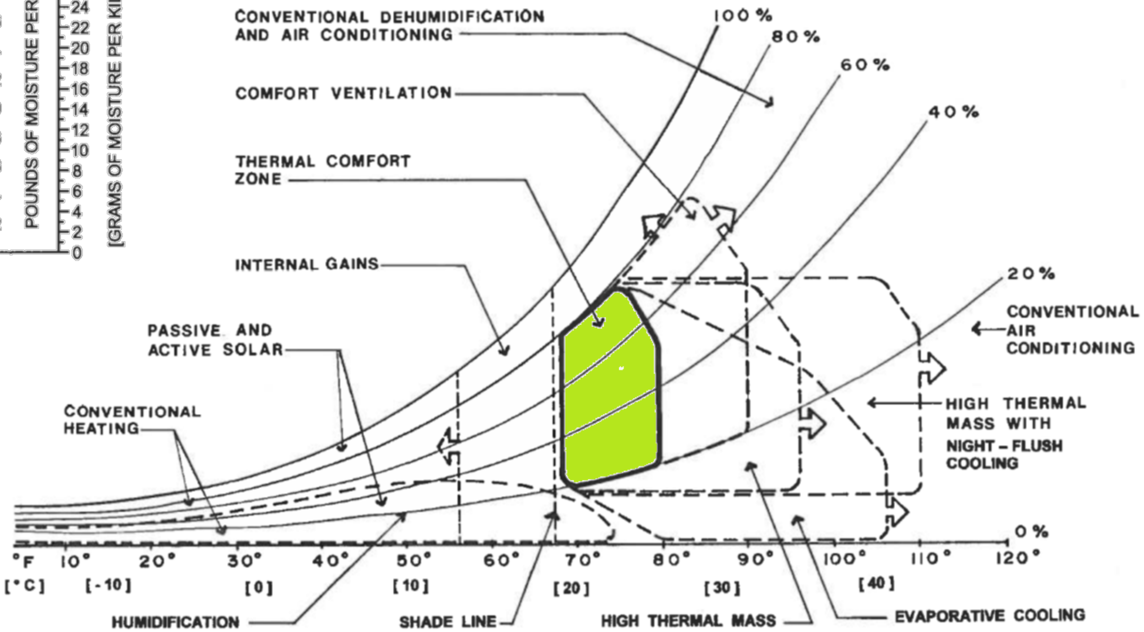


Image from L.G.Valladares-Rendónetal (2017) Energy and Buildings

Building Bioclimatic Chart



Climate analysis is necessary due to the *intrinsic* relation between **climate** and **energy demand for thermal comfort in buildings**



Source: Lechner, Norbert, *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*, Wiley, 2008.

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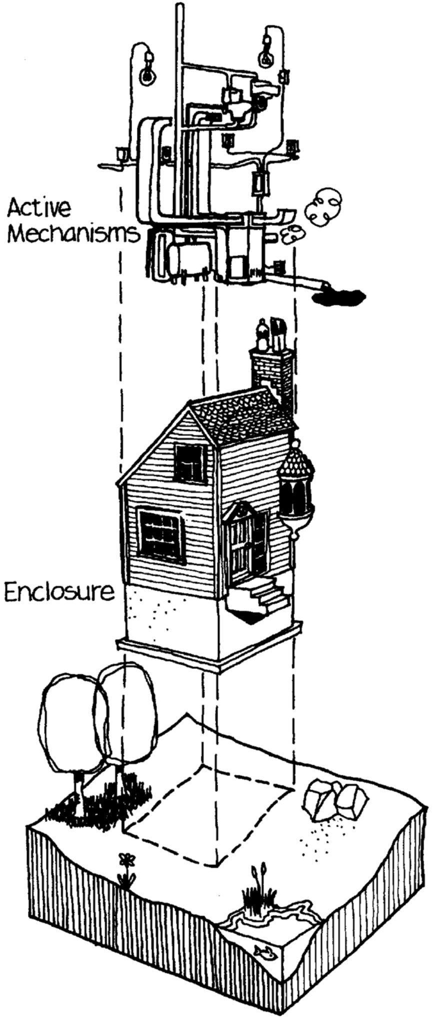
Design Solutions: Heat Storage, Solar Gains Control

***2226 Buildings with NO mechanical systems**, Architects: Baumschlager Eberle Architekten*

Emmenbrücke, Switzerland

Listenau, Austria



Source: Edward Allen «How Buildings Work» (2005)

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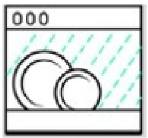
Water Use in Buildings

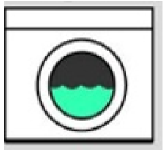
- **High-quality drinking water**

Faucets
> 40 °C

Shower, Bath
> 40 °C



Dishwasher*
> 50°C



Washing machine*
> 50°C

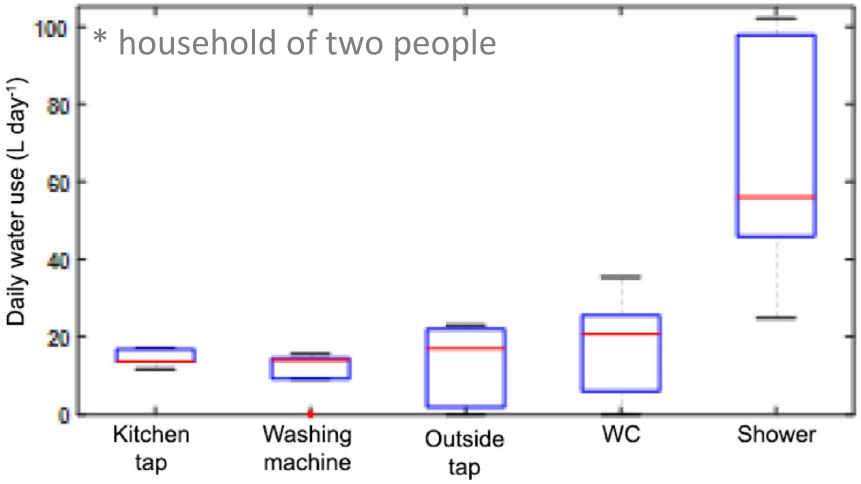
* use an **internal** heater to heat water

- **Low-quality water (non-potable)**

WC

~142 L
of water per person every day*

*in Switzerland



How long do you typically shower?

Please login:

responseware.eu

Session ID: **ENG445DK**

A. < 3 min
B. 3-5 min
C. 5-8 min
D. > 10 min

What is your preferred temperature for showering?

Please login:

responseware.eu

Session ID: **ENG445DK**

A. < $35^{o}C$

B. $36^{o}C$

C. $37^{o}C$

D. $38^{o}C$

E. $39^{o}C$

F. $40^{o}C$

G. > $40^{o}C$

H. I do not know

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Hot Water End Uses in Buildings: Showers

- Participants of the ***ewz Studie Smart Metering***
- **697** Swiss households (**324** single- and **373** two-person households)
- Data collection using **Amphiro** devices for showers

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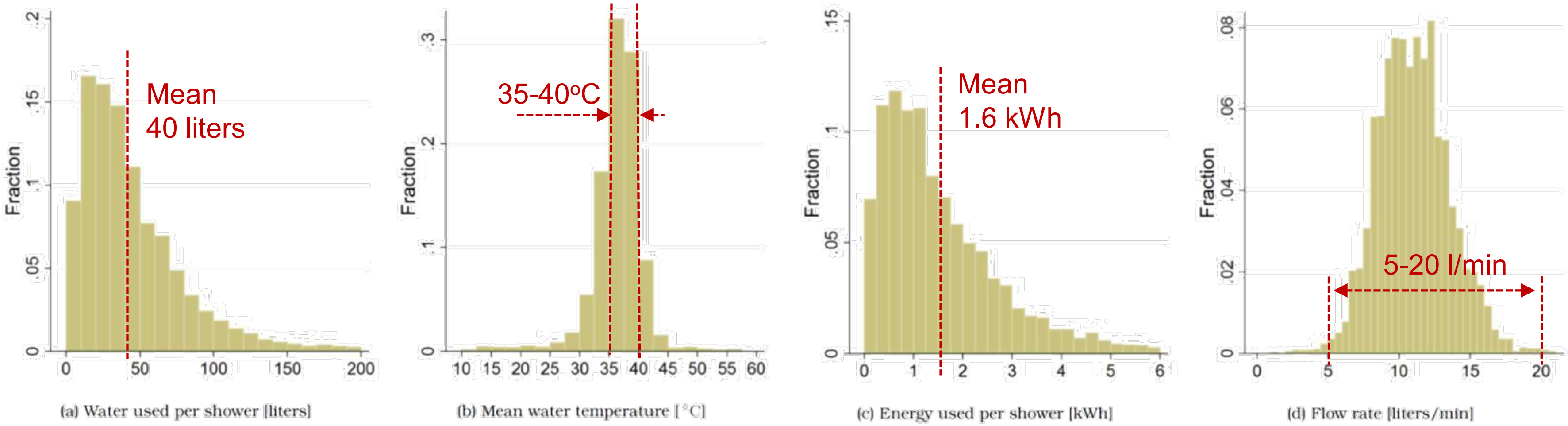
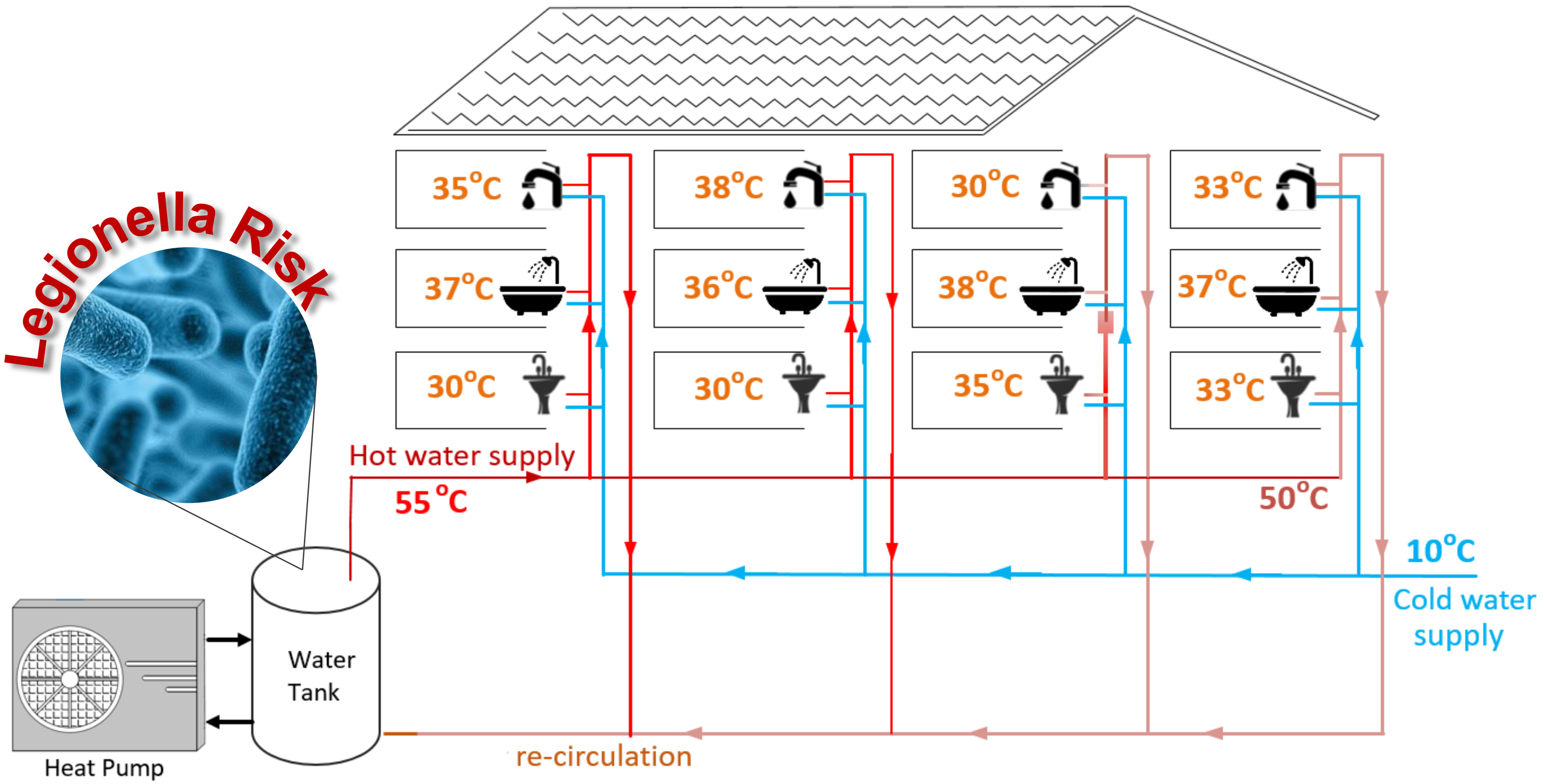


Source: Tiefenbeck V., Degen K., Tasic V., Goette L., Staake T.
"On the Effectiveness of Real-Time Feedback: The Influence of Demographics, Attitudes, and Personality Traits". Final report to the Swiss Federal Office of Energy, Bern, 2014.

Hot Water System in Buildings

- Hot water used by people is **< 40°C** in practice
- However, due to **Legionella risk**, hot water is generated at **> 60°C**



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Standardized Requirements: Hot Water

Influence of hot water temperature on *Legionella* bacteria and corresponding requirements with respect to the permissible temperature of certain components of the hot water supply in accordance with SIA 385/1:

Max. temp. for hot water flashing (periodic increase of water T) (limit - limestone formation) → 65 °C

Min. temp. of hot water *at the storage tank outlet* → 60 °C

Min. temp. of hot water in *the circulation line* → 55 °C

Min. temp. of hot water at *the drawing point* → 50 °C

45 °C

Min. temp. of *hot water supply* → 40 °C

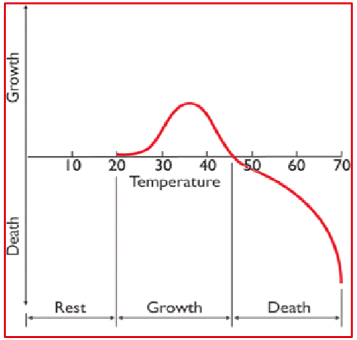
Temp. in the cold water pipes and in hot water discharge pipes → 25 °C

Destruction of *Legionella* bacteria (killed off within seconds at > 60°C)

Viable, but not capable of multiplying

Optimal range for multiplication (the max. rate of growth is at around 37°C, the doubling time is about 4 hour)

Viable, but not capable of multiplying



Source: *Legionella and legionellosis recommendations FOPH / OSAV*

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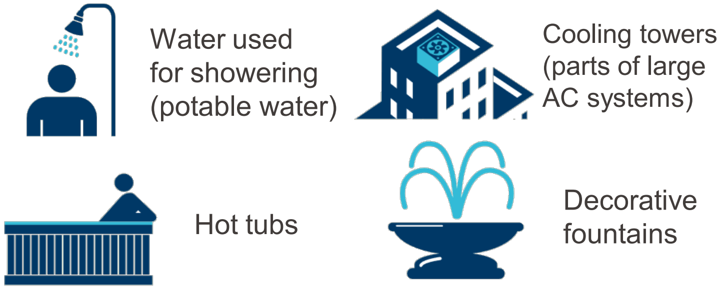
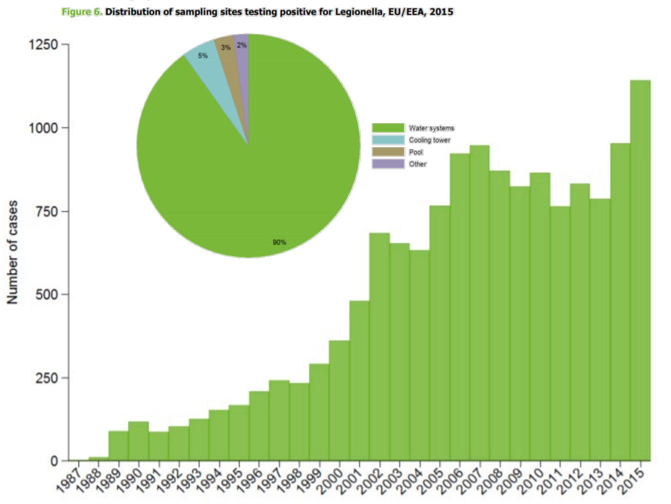
Legionella Control in Plumbing Systems and Buildings

- Outbreaks of Legionnaires' disease are often associated with **large** or **complex water systems** (*i.e.*, in hospitals, hotels, and cruise ships).
- *More cases are lately* reported in **regular buildings**
- COVID19-related shutdown of buildings **increased probability** of **water stagnation in piping** and **Legionella risk**



Legionella Control in Premise Plumbing Systems	
Chemical treatment technologies: • Chlorine-based disinfection • Copper-silver ionization (CSI) • Ozonation	**Physical treatment technologies:** • Thermal inactivation • Filtration • Ozonation
Emerging treatment technologies: • Ultraviolet (UV) irradiation • UV light emitting diodes (LEDs) • Innovative point-of-use (POU) filters	**Other strategies:** • Superheat-and-flush disinfection • Shock hyperchlorination



Cases were reported from 25 countries: 22 EU/EEA Member States and three non-EU/EEA countries: Switzerland (30 cases), the USA (6 cases), and Australia (2 cases). Two-thirds (66.2%) of all TALD cases were reported by only four countries (in decreasing order of frequency): the United Kingdom, Italy, France, and the Netherlands (Table 14).

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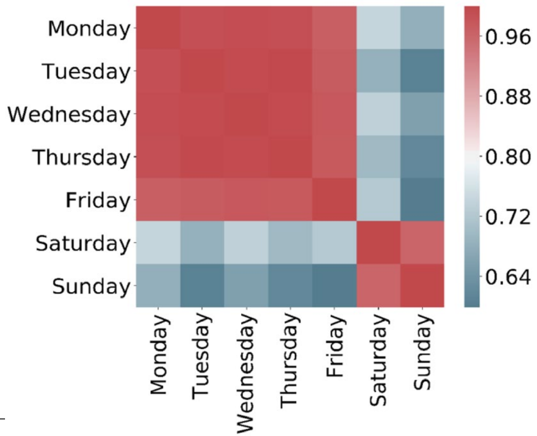
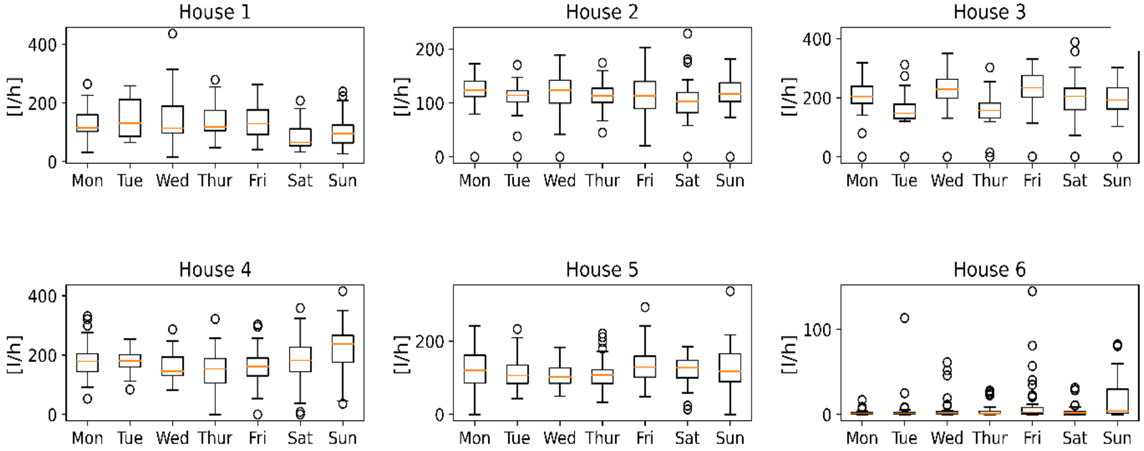
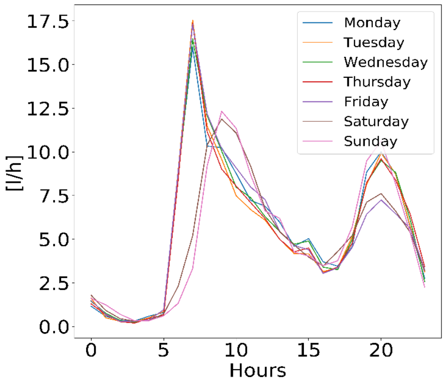
Hot Water Demand Profiles: Residences

- Demands of households in South Africa
- 8 months of monitoring (Aug. 2017 - March 2018)
- Volumetric hot water demand monitoring
- Every houses demand pattern is *different*
- But *there are similarities* in *weekdays* and *weekends*



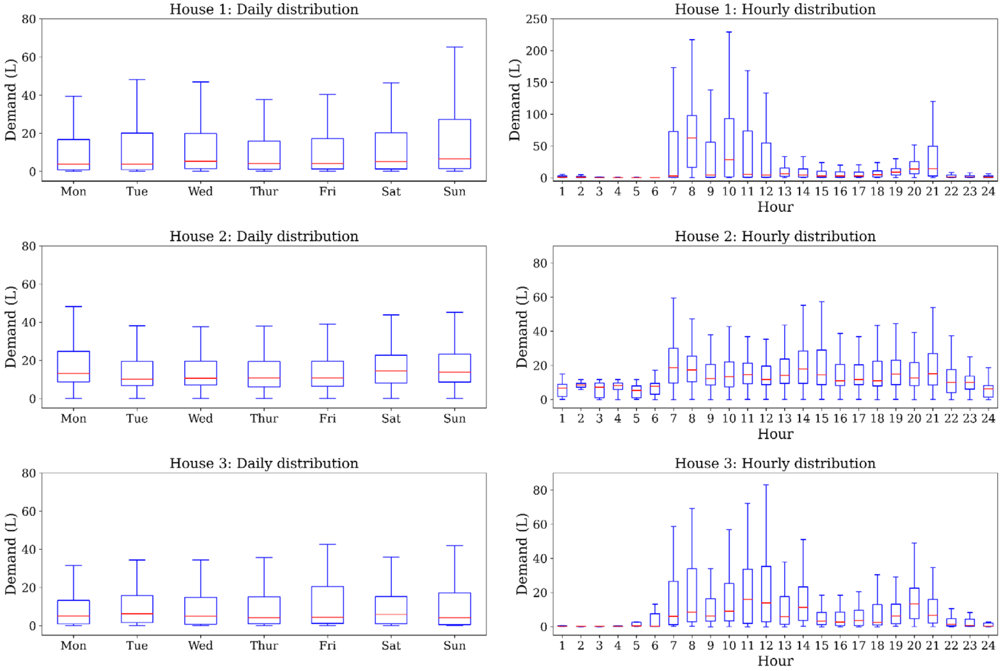


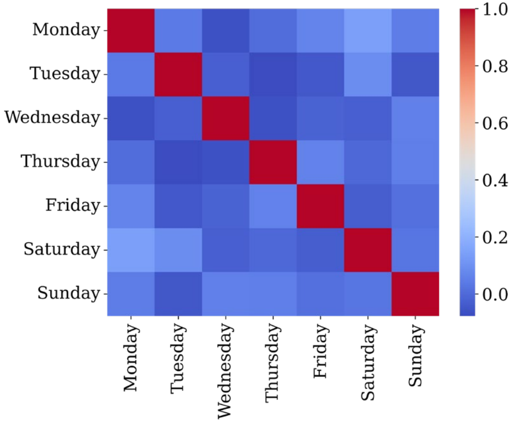


Source: Heidari et al. (2020) Sustainable Societies and Cities, DOI: 10.1016/j.scs.2020.102625

Hot Water Demand Profiles - Residences

- 3 households in Switzerland
- 6-12 months of monitoring (2020-21)
- Volumetric hot water measurements





COVID-19 effect:

- Home office *shifted hot water demand* in households
- *More* hot water use
- Even *more stochastic* behavior of water use

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Sanitary Hot Water: Standardized Requirements

Code	Title
EU Standards:	
EN 12831-3:2017	Energy performance of buildings - Method for calculation of the design heat load - **Part 3**: *Domestic hot water systems heat load and characterization of needs*
Swiss Standards:	
SIA 380:2015	Bases pour les calculs énergétiques des batiments
SIA 380/1:2016	Besoins de chaleur pour le chauffage
SIA 385/1: 2011	Installations d'eau chaude sanitaire dans les bâtiments - Bases générales et exigences

- **Swiss Guidelines:**

Title
***Legionella* and *legionellosis* recommendations of FOPH / OSAV from 22.08.2018** https://www.ge.ch/document/20848/telecharger
SVGW-guideline W3 for drinking water installations (drinking water quality, practices for no growth of legionella, etc.) https://shop.suissetec.ch/de/shop/163/svgw-richtlinie-w3?c=14

Hot Water Demand

- **Average Hourly Demand Method** - utilizes average hourly data in *liters per hour*

Hourly demand (L/h):

$$\dot{M} = f_{use} \cdot \sum_{i=1}^{N} \dot{m}_i$$

N – number of fixtures
$\dot{m}_i$ – rated flow rate (L/h) per fixture
f_{use} – simultaneous usage factor (0.3-0.5, 0.3 for apartments and offices)

Limitations
- It can be applied *only* to the types of end-uses *tabulated*
- It *does not* consider the types of occupants

Advantage
- Requires only number of fixtures as input

Hot Water Demand per Fixture for Various Types of Buildings at a final temperature of 140°F (60°C), gph (L/h)

Fixture	Apartment	Club	Gymnasium	Hospital	Hotel	Industrial Plant	Office	Private Residence	School	YMCA
Basins, private lavatory	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)
Basins, public lavatory	4 (15)	6 (23)	8 (30)	6 (23)	8 (30)	12 (45.5)	6 (23)		15 (57)	8 (30)
Bathtubs	20 (76)	20 (76)	30 (114)	20 (76)	20 (76)		20 (76)		30 (114)	
Kitchen sink	10 (38)	20 (76)		20 (76)	30 (114)	20 (76)	20 (76)	10 (38)	20 (76)	20 (76)
Showers	30 (114)	150 (568)	225 (850)	75 (284)	75 (284)	225 (850)	30 (114)	30 (114)	225 (850)	225 (850)

Source: ASHRAE Handbook—HVAC Applications, 2017

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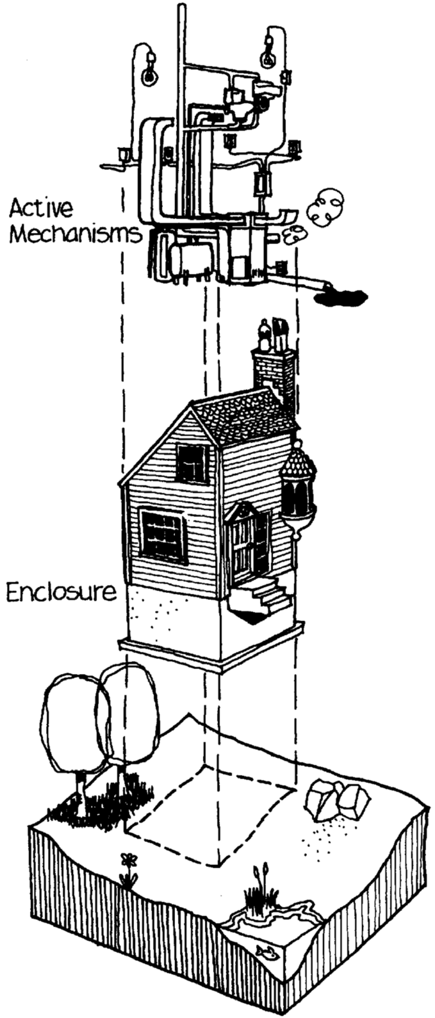

Source: Edward Allen «How Buildings Work» (2005)

CONTENT:

- Introduction
- Space heating/cooling demand:
  - Heat gains and heat losses
  - Dynamic behavior of building envelope (thermal mass effect, time lag, decrement factor)
  - Internal heat gains (appliances, lights, people)
  - Methods to determine the thermal load
  - Strategies to minimize the energy demand
- Sanitary hot water demand:
  - Sanitary requirements
  - Hot water demand
- **Summary**

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Main Concepts of this Lecture

- Concepts of "**thermal demand**" and "**thermal load**"
- **Measures** to **minimize the demand** for space heating and cooling
- **Maximum demand evaluation** for **sizing HVAC equipment**: the *difference* for heating and cooling approaches
- **Design outdoor conditions**: *historical* weather data vs. *future* projection
- **Factors** determining the **dynamic behavior of building envelope** (outdoor weather, thermal mass of materials, time lag φ and decrement factor f)
- **Thermal load calculation methods** and **their difference**
- **Cooling load:** split to *radiative* and *convective* heat gains and *the time lag*
- **TETD method** and **sol-air temperature** T_{sa}
- Strategies **to minimize the space heating/cooling demand at the building design stage** (shape factor, orientation, solar protection, materials)
- **Factors affecting hot water demand** (temperature of water to prevent Legionella growth, occupancy, water demand per fixture type)

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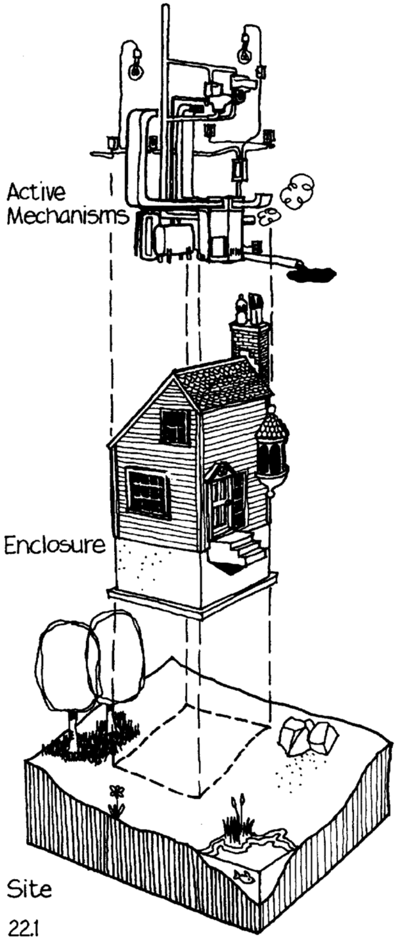

Source: Edward Allen «How Buildings Work» (2005)

Thank you for your attention!

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https://www.epfl.ch/labs/ice/