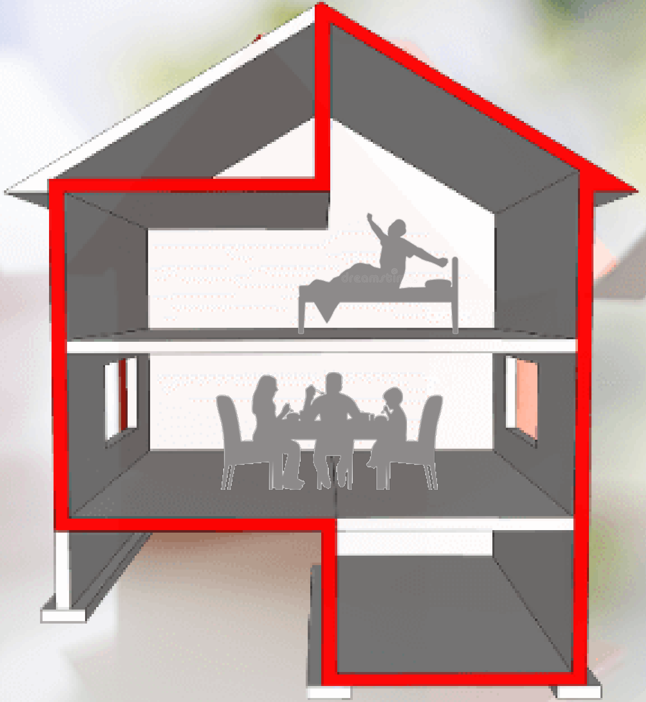
responseware.eu

Session ID: **ENG445**

ENG-445
Building Energetics

Heating in Buildings – Emission Systems and Thermal Comfort

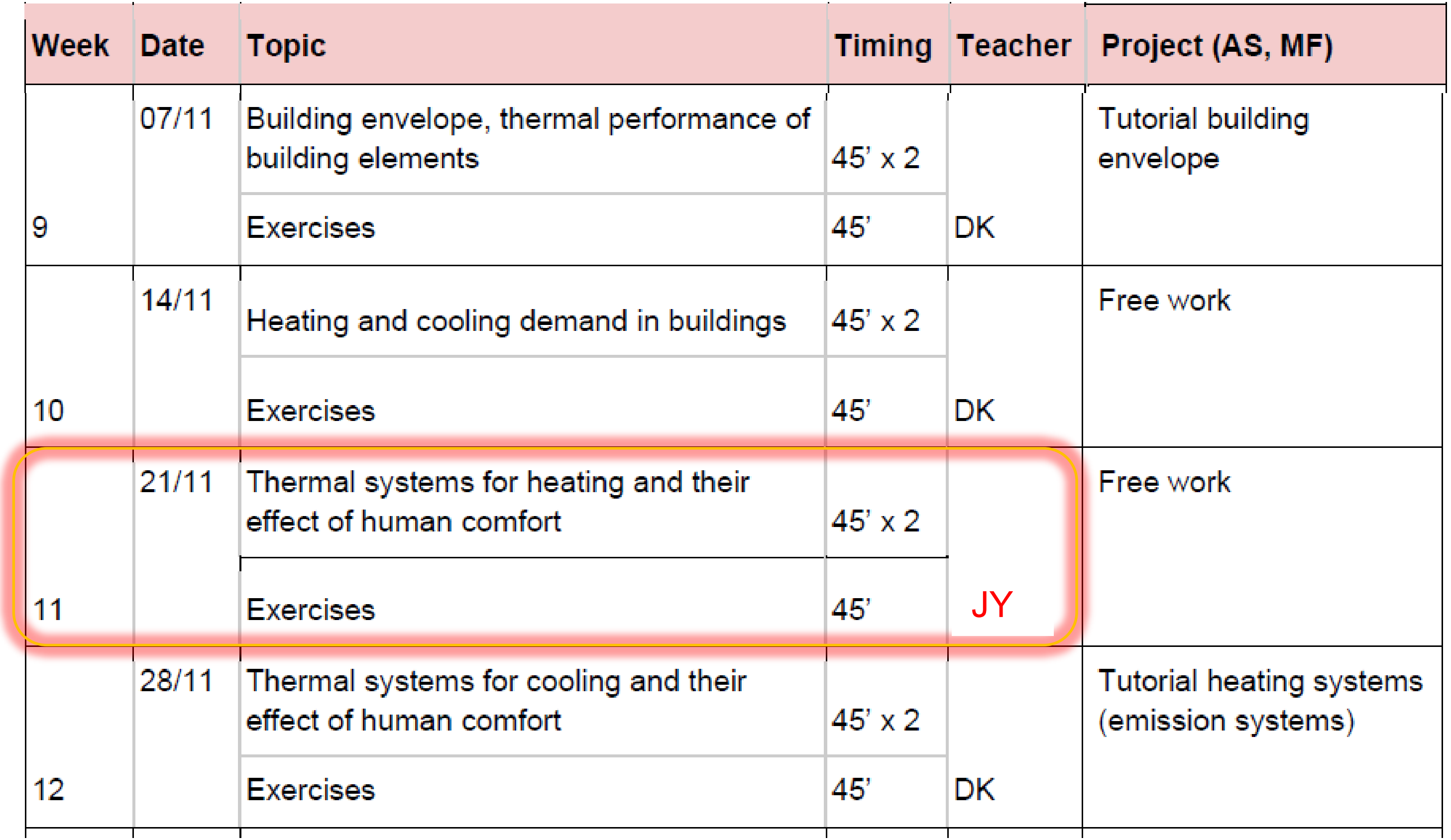


https://www.echotape.com/blog/contractors-field-guide-building-en

Dr. **Jaafar YOUNES**,
Assist. Professor
Dolaana Khovalyg

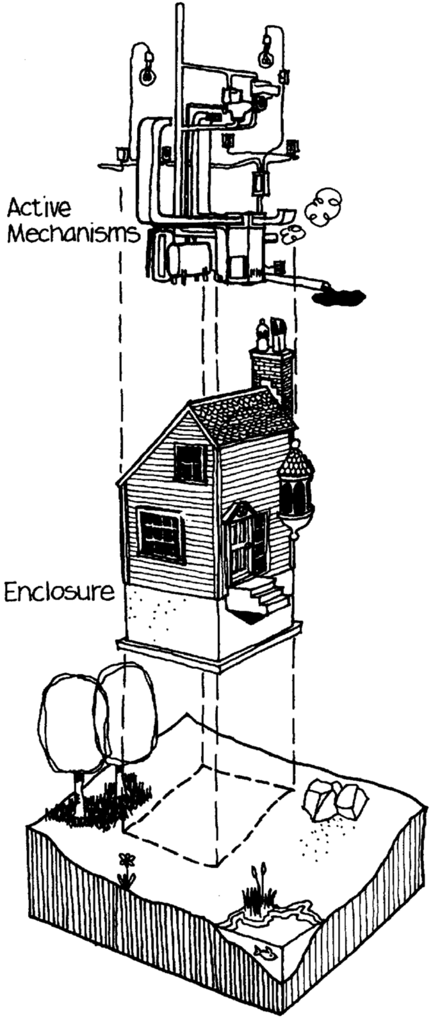
21 November 2024

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



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

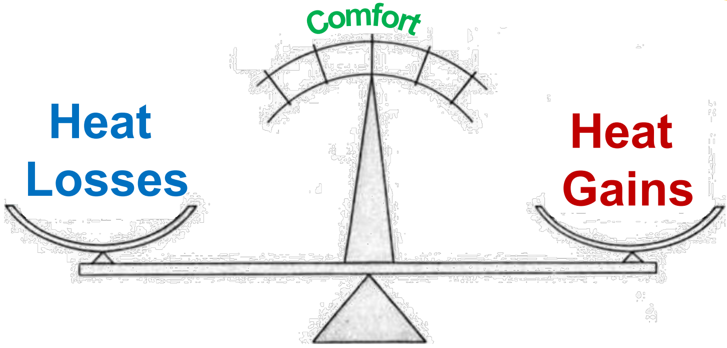
CONTENT:

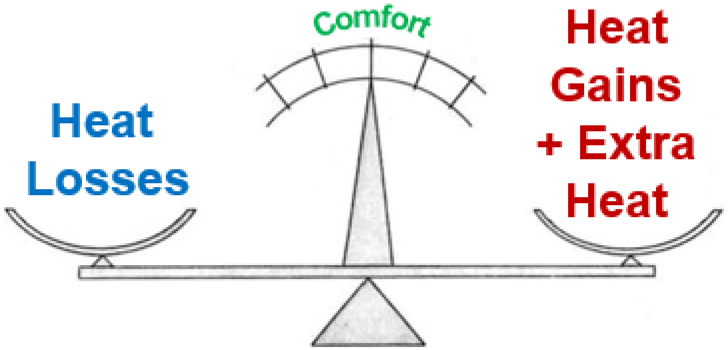
- Introduction
- Overview of Emission Systems:
  - Definition
  - All-air systems
  - Radiators (convectors)
  - Radiant systems
- Technical Characteristics
  - Local discomfort limits
  - Convectors vs. Embedded systems
- Thermal Comfort vs. Emission Systems
  - Comparative study overview
- Standard References
- Summary

Indoor Climatization (Heating/Cooling)

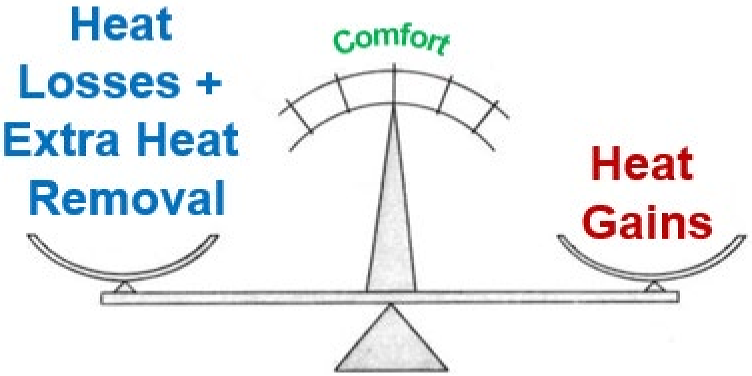
From Week 10

- **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**





HEATING 🔥



COOLING ❄

Assist. Prof. Dolaana Khovalyg

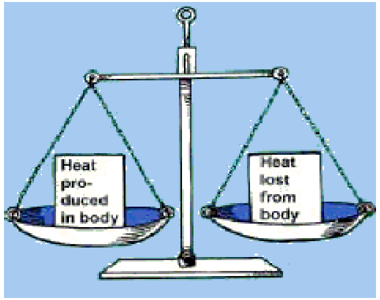
Thermal Comfort: PMV/PPD method

From Week 02

- **Thermal neutrality** for the body as a whole is a necessary, but *not sufficient condition* for thermal comfort.
- **Local thermal discomfort** due to *draught*, *vertical temperature gradient*, *radiant asymmetry*, or *warm* or *cold floors* may cause occupants to find **the thermal conditions unacceptable**.

It is essential to evaluate thermal comfort in 2 steps:

1) Define the **acceptable operative temperature**
2) Check that **there is no local discomfort**



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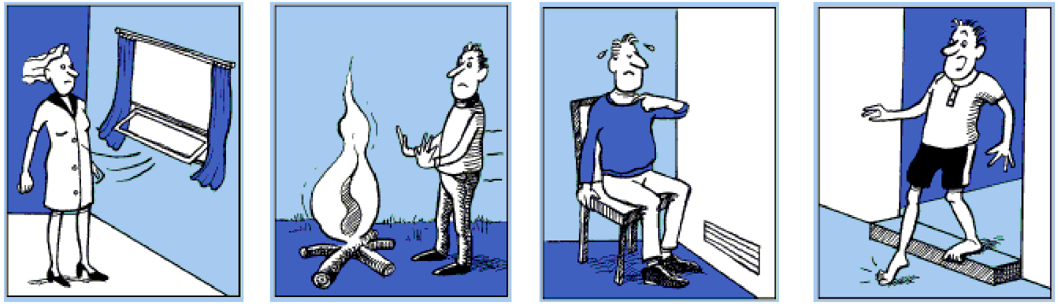
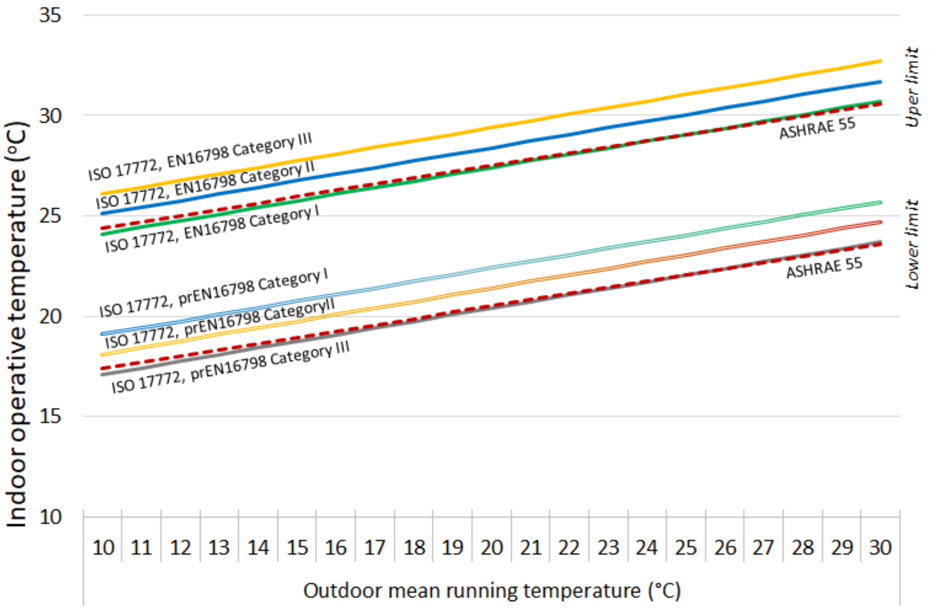


Thermal Comfort: Adaptive Model

From Week 02

- Considers **thermal comfort** as **a result of adaptation** (physiological, behavioral, psychological)
- A *strong* relationship of the **comfortable temperatures** inside a building with **the mean temperatures prevailing outside the building** for *naturally ventilated* buildings (in 'free-running')



Standard	Categories	T_{op} (°C), upper limit	T_{op} (°C), lower limit	T_{rm}(°C), applicability range
ISO 17772, EN 16798	I	$0.33 \cdot T_{rm}+20.8$	$0.33 \cdot T_{rm}+15.8$	10-30
	II	$0.33 \cdot T_{rm}+21.8$	$0.33 \cdot T_{rm}+14.8$	10-30
	III	$0.33 \cdot T_{rm}+22.8$	$0.33 \cdot T_{rm}+13.8$	10-30
ASHRAE 55	acceptable (80%)	$0.31 \cdot T_{rm}+21.3$	$0.31 \cdot T_{rm}+14.3$	10-33.5
	acceptable (90%)	$0.31 \cdot T_{rm}+21.3$	$0.31 \cdot T_{rm}+15.3$	

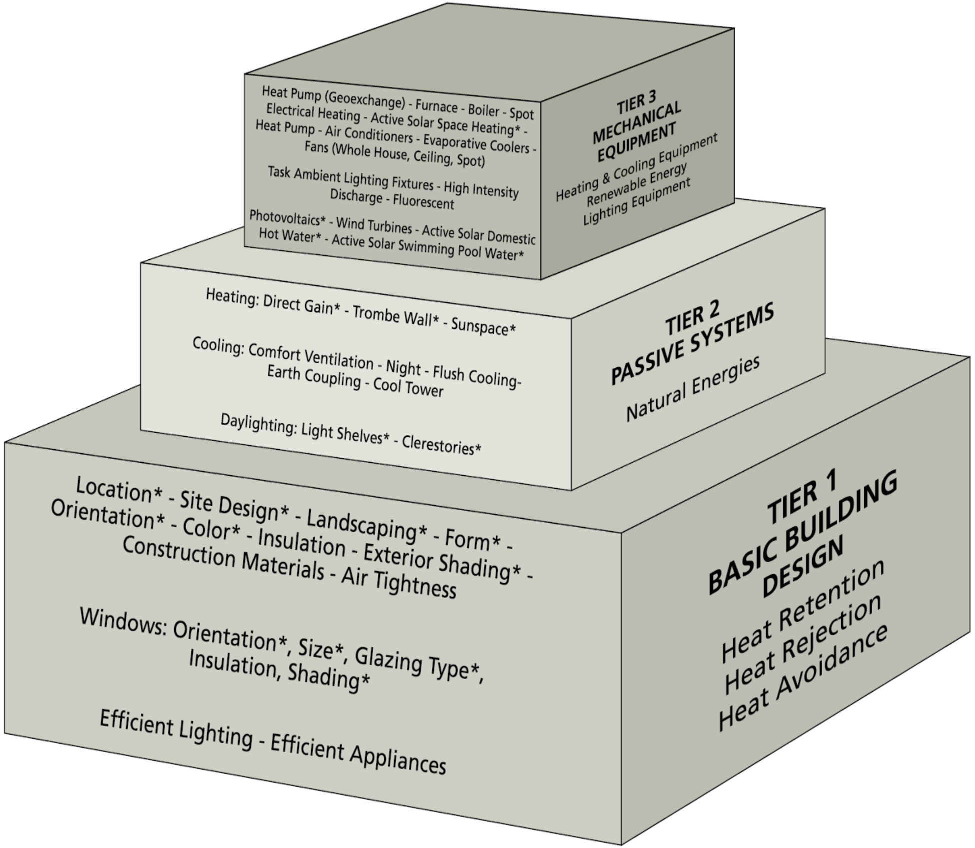
Source: Khovalyg et al. (2019) Energy and Buildings, DOI : 10.1016/j.enbuild.2020.109819.

Three-Tier Design Approach

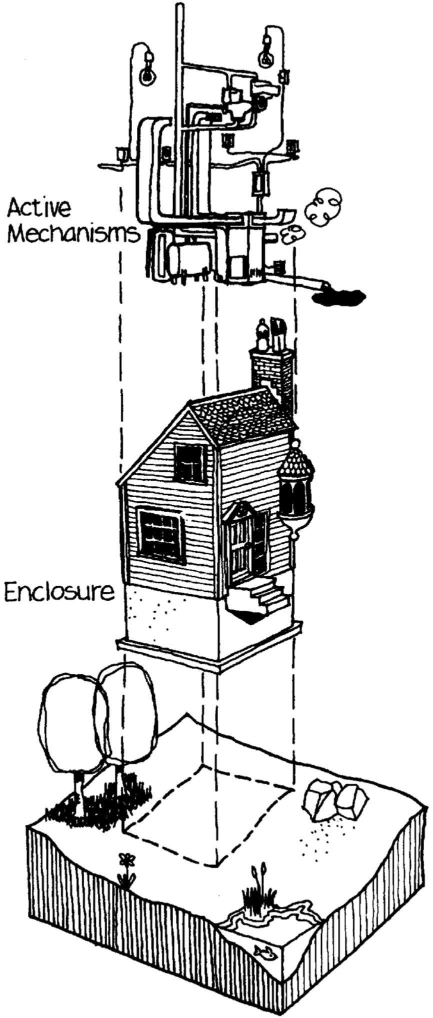
From Week 10

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.



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

CONTENT:

Active Heating Systems

Active (mechanical) Heating/Cooling System

=

1 **Emission system** *(radiators, fan coils, etc.)*

+

2 **Distribution system** *(pipe work, ducts, circulation pumps)*

+

3 **Storage** *(water tanks, etc.)*

+

4 **Generation system** *(heat pump, boiler, etc.)*

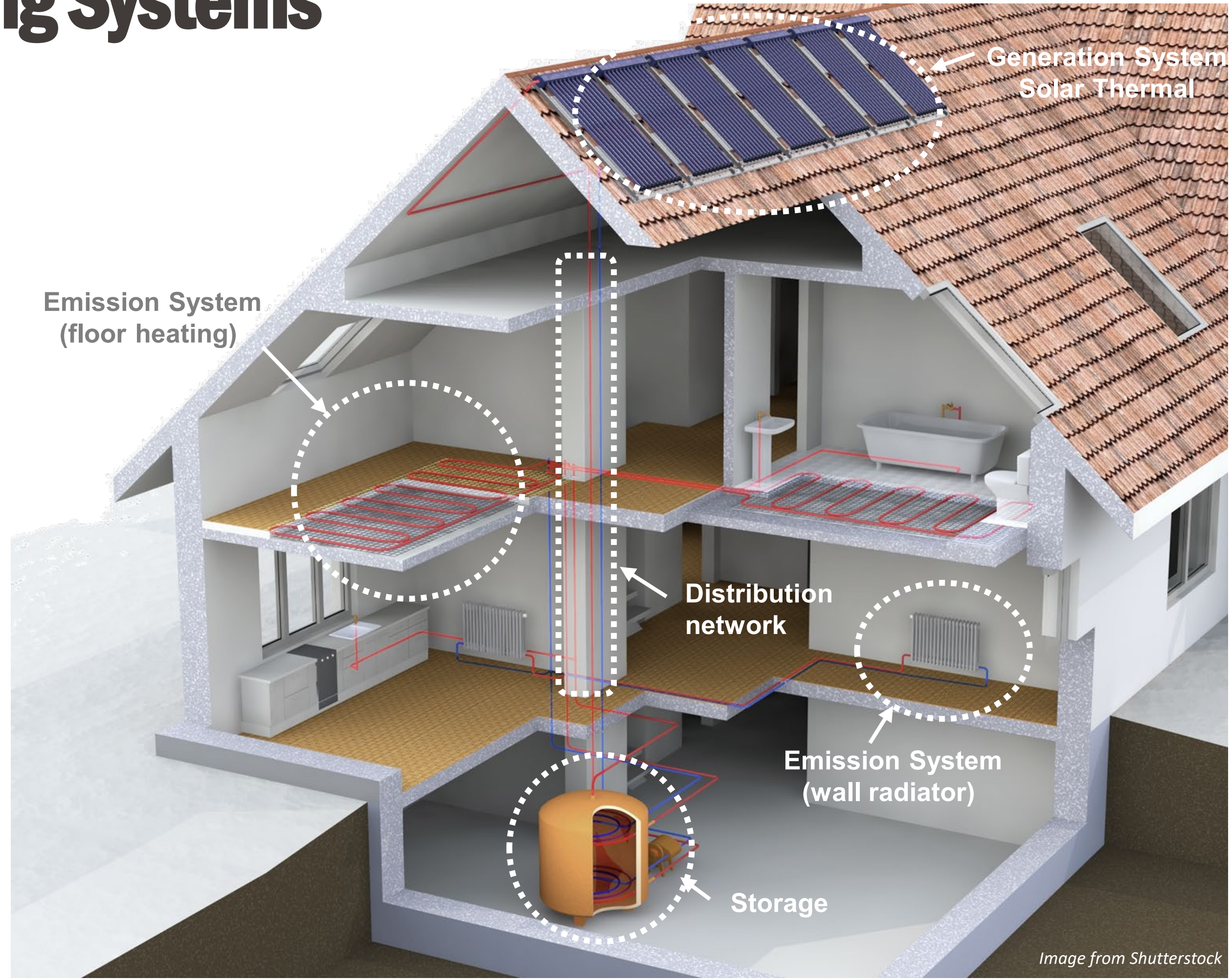
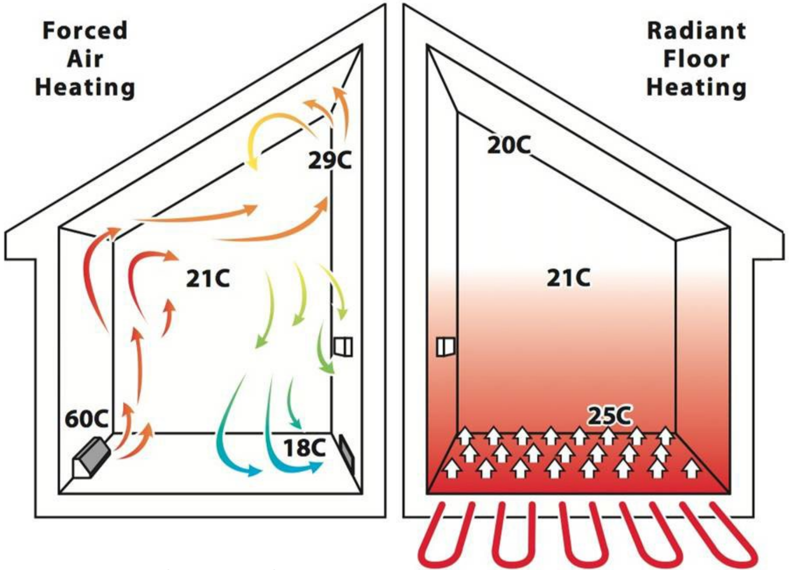


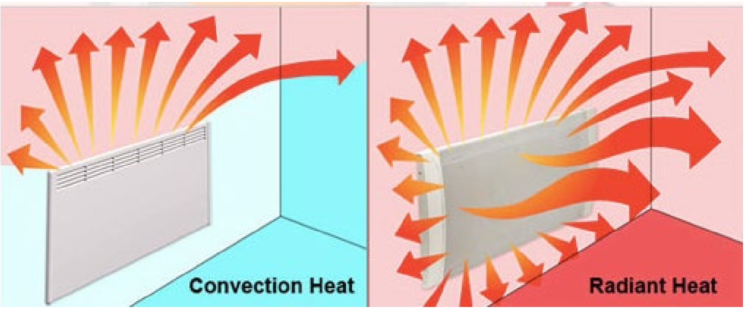
Image from Shutterstock

Indoor Emission Systems

- Multiple ways to name - *indoor emission systems*, *indoor terminal units*, ..
- **Building elements** that use **different heat transfer mechanisms** and **media** to *emit* and *remove* ***heat*** and/or ***moisture*** from indoor spaces
- They differ in their capabilities of *addressing:*
  - **sensible** and **latent loads**
  - **methods** of **heat emission** or **removal:** convection, radiation, combined
  - maximum heating/cooling capacities
  - **medium** of **energy distribution** (i.e., heat carrier) – water, air, electricity
  - ***local*** or ***total*** **volume conditioning** (for convective systems)

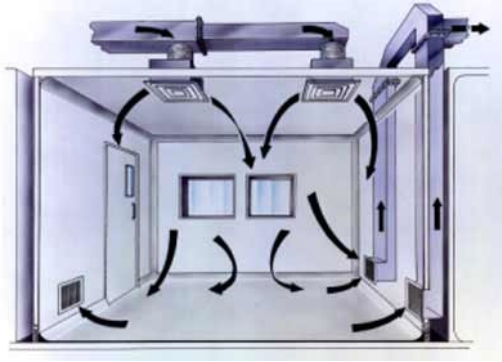


https://airflow.ie/underfloor-heating/



Overview of Emission Systems

All-Air Systems		Radiant systems
centralized air conditioning	**localized** air conditioning	**centralized** water conditioning
heat extraction using: **air**	heat extraction using: **refrigerant**, **water**	heat extraction using: **water**



- *Air supply through* ***grills*** *(no air deflection)*

- *Air supply through* ***diffusers*** *(diffuses air)*

Fancoils, indoor units *(air recirculation)*

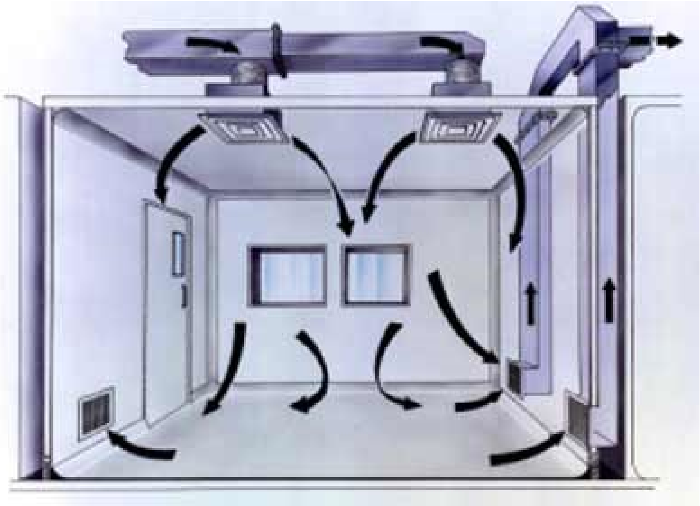
Chilled beams (active** and **passive)
thermal conditioning +
fresh air supply (active only)

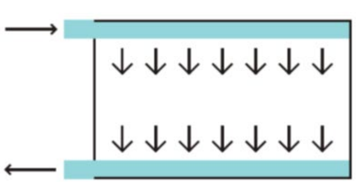
Radiant ceiling

Floor/Wall systems

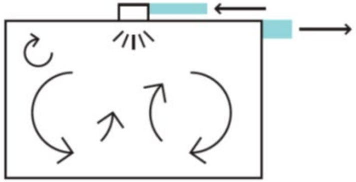
Convective (All-Air) Systems

- A system where the **air** is used as **the heat carrier** (*medium of energy distribution*) and the **heat exchange** with ***the conditioned space*** is entirely by **convection**.
- Require **higher air flow rates** *than radiant systems since* ***the entire heating/cooling load*** *needs* to be addressed **by the ventilation system**
- **Types of systems:** mixing ventilation, displacement ventilation, underfloor air distribution, personalized ventilation, etc.
- Air can be **conditioned** in a **air-handling unit** using *various approaches* (electric heating, with hot water from a boiler or a heat pump, etc.)

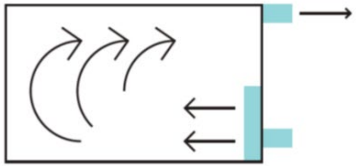




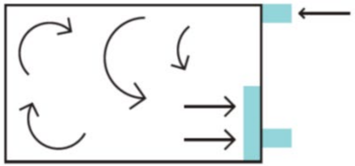
Full displacement



Full mixing

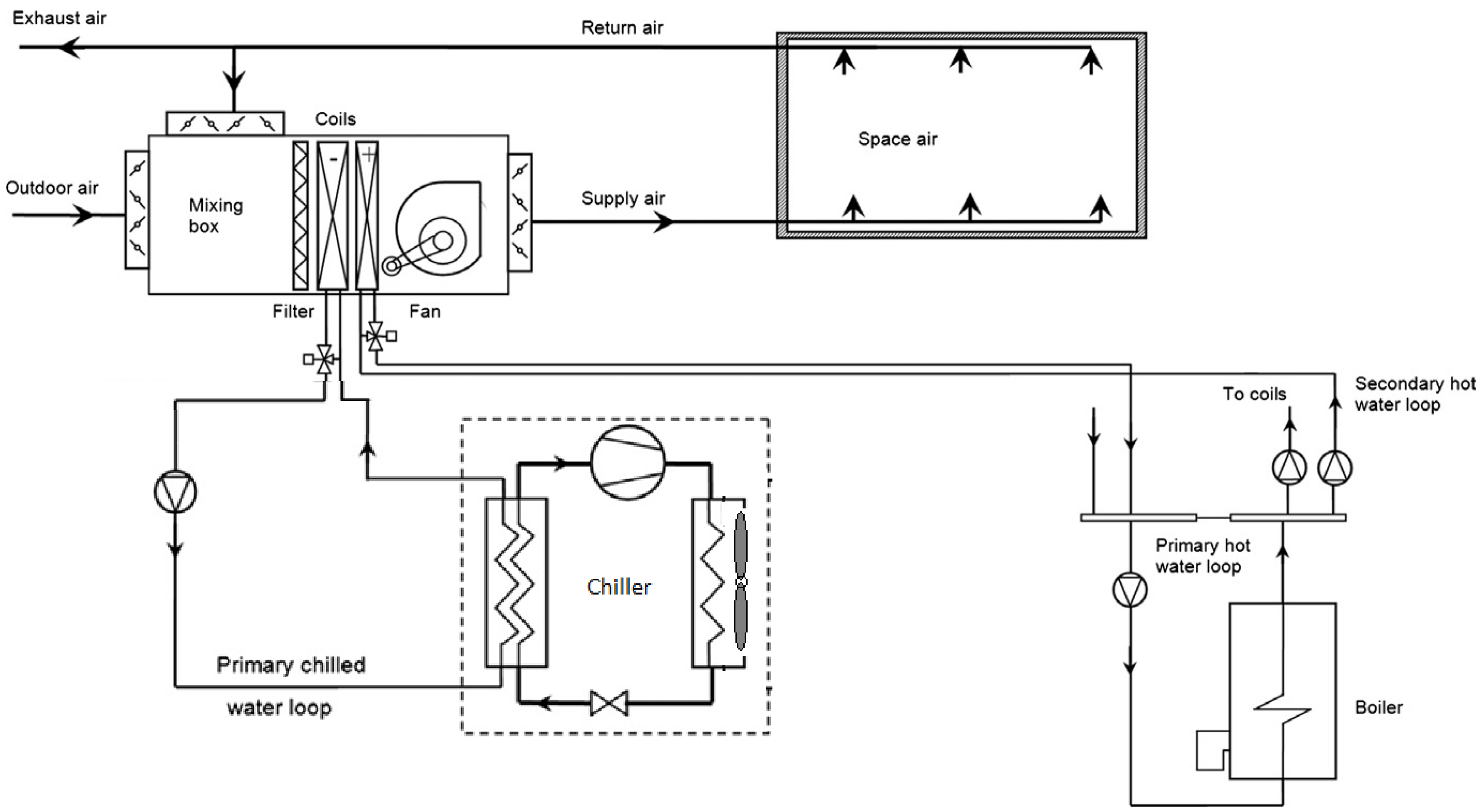


Local displacement



Local exhaust

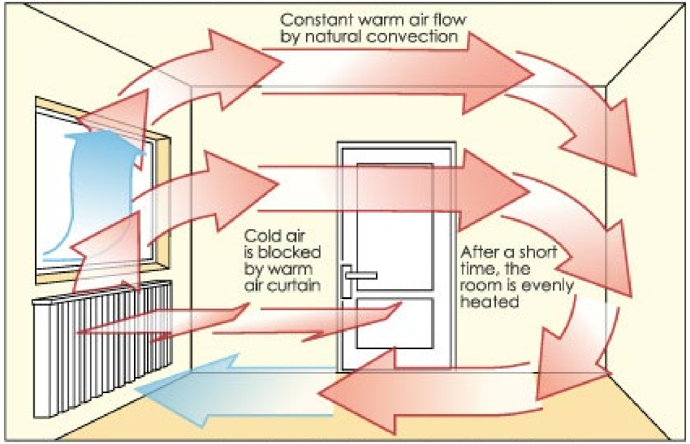
Convective (All-Air) System: **Supply Side**

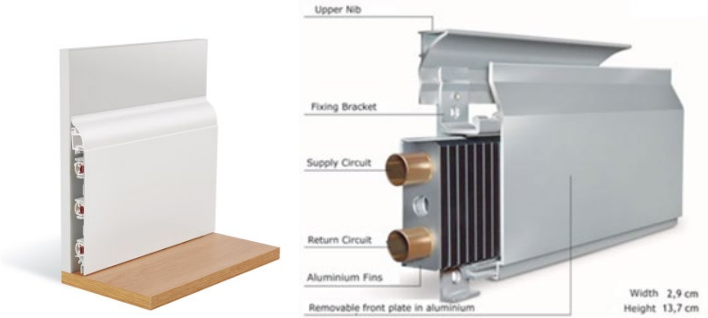


Adapted from Perez-Lombard et al. (2011) Applied Energy, pp. 5020-5031

Radiators/Convectors

- The **most conventional** heating practice
- **Types**: **electric** or **water-heated** (hot water circulates through pipes)
- **Heat transfer** mainly by **natural convection**
- **Fins** are used to *increase* the heat transfer area
- The **source of heat** is *not directly exposed* due to **aesthetic** and **safety purposes**
- **Configuration**: horizontal, column, towel radiators, etc.



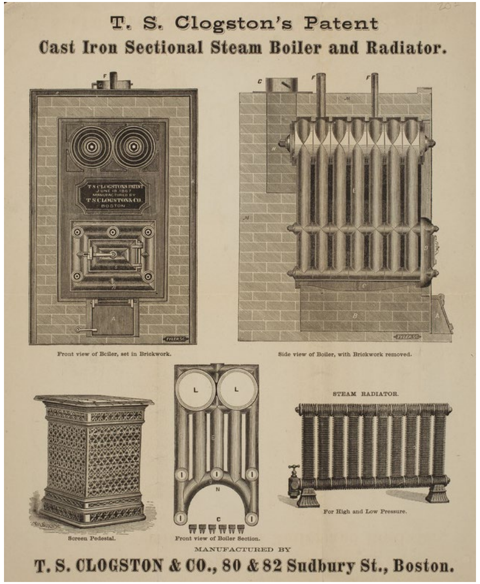


Skirting boards (electric and water-based)

Baseboard radiator

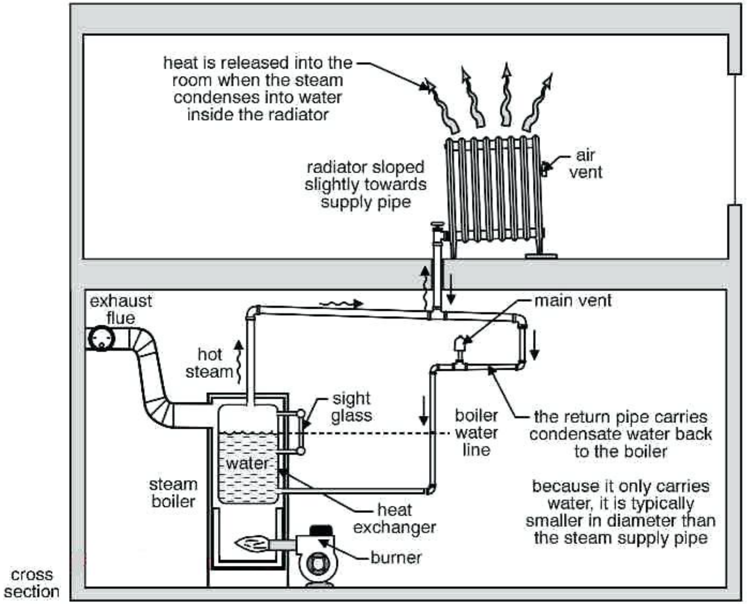
Steam Radiators

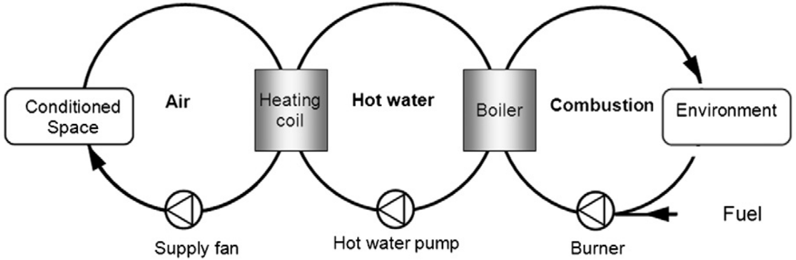
- One of **the "oldest"** heat emitting practices
- **1831**: AM Perkins (England) devised a high-pressure system of hot-water heating (steam at ~170°C and pressure ~15 atm)



Patent from 1867

How steam systems work





Hydronic Radiant Systems

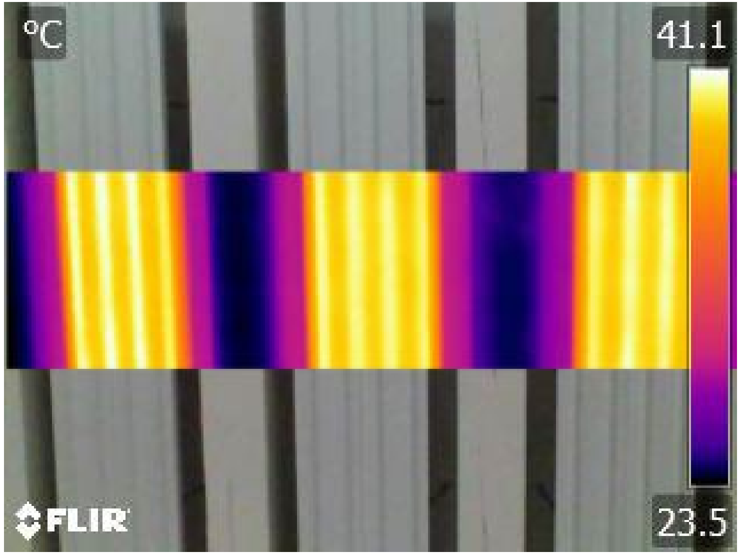
“Steam” Radiators

Wall radiator

- **Small** heat transfer **area**
- **Requires high water temperature (>50 °C)**
- Needs to be coupled **with high temperature water generation system** (district heating, boilers)
- **Non-uniform** indoor thermal environment

Radiant Systems

Radiant ceiling panels



- **Large** heat transfer **area**
- **Low temperature heating (30-40 °C)**
- Better **coupling** with **water generation systems coupled with renewable sources** (HPs, GHX)
- Provides **uniform** indoor environment

Radiant Systems

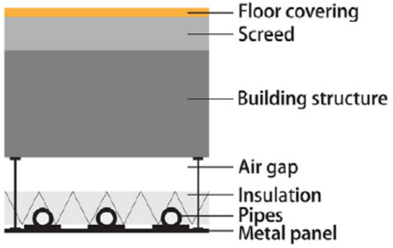
- A system where typically **water** is used as **the heat carrier** (hydronic system) and **more** than ½ of the **heat exchange** with ***the conditioned space*** is by **radiation.**
    - Alternatively, **electric heaters** can also be used *as energy sources.*
- System consists of circuits of **water pipes** *embedded* in floor, wall or ceiling construction.
- Additional **ventilation system** is necessary *to address* the **latent loads** and to provide **the ventilation rates required** for **indoor air quality.**
- Radiant systems enable **lower air flow rates** than all-air convective systems.

https://https://www.giacomini.com/en

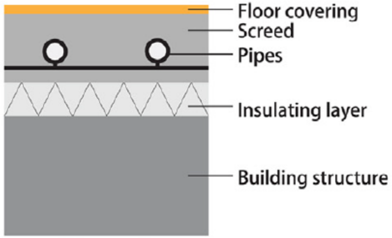
https://plumbisimo.co.uk/benefits-of-underfloor-heating/

Hydronic Radiant Systems: Typology

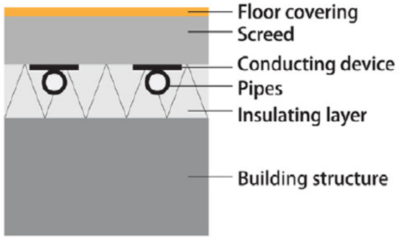
- Three **main categories** of hydronic systems:
  - **radiant ceiling panels** (RCP),
  - **embedded surface systems** (ESS)
  - **thermally activated building systems** (TABS)



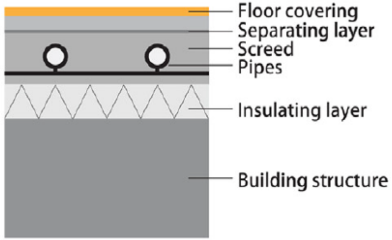
RCP



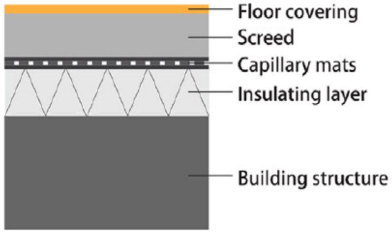
Type A
(ESS)



Type B
(ESS)



Type C
(ESS)



Type D
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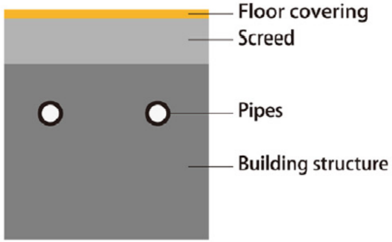
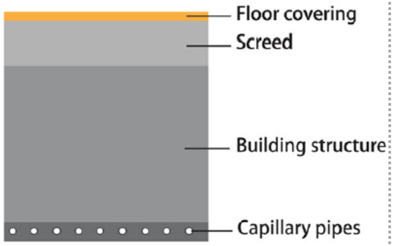
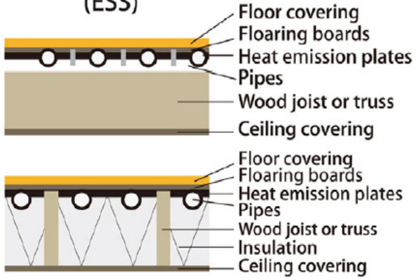


Type E
(TABS)



Type F
(TABS)

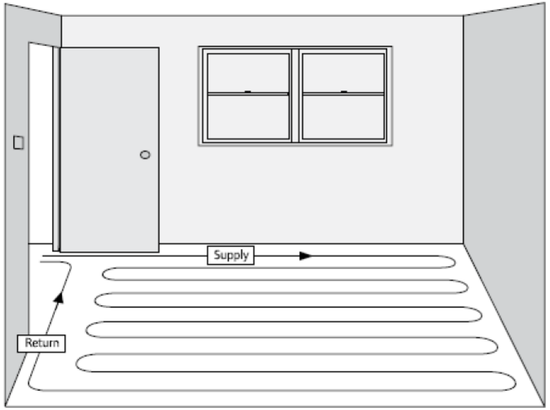


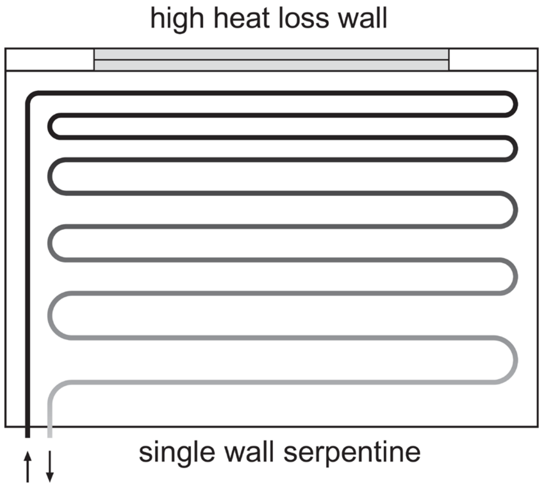
Type G
(ESS)

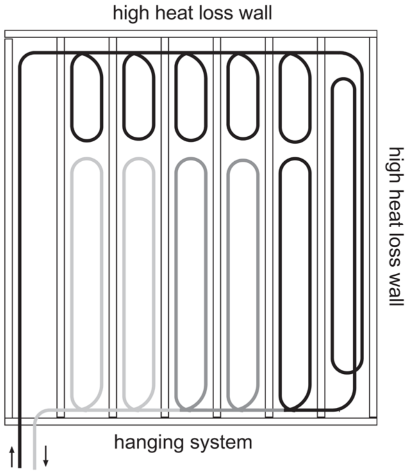
Source: Ning et al. (2017) http://dx.doi.org/10.1016/j.enbuild.2016.12.013

Radiant Systems: Active Surface Area

- **Active surface area** - the surface area conditioned by the *embedded radiant system*
- The **layout of the piping** should consider *variable* heating and cooling demand, i.e., supply the hottest water to the zones with the highest heat losses
- **Water temperature** at the **inlet** corresponds to maximum circulating water temperature required to provide the maximum loads.
- **Piping layouts for floor systems** a single/double/triple-wall **serpentine**, a **counter flow**, and a **reverse-return**

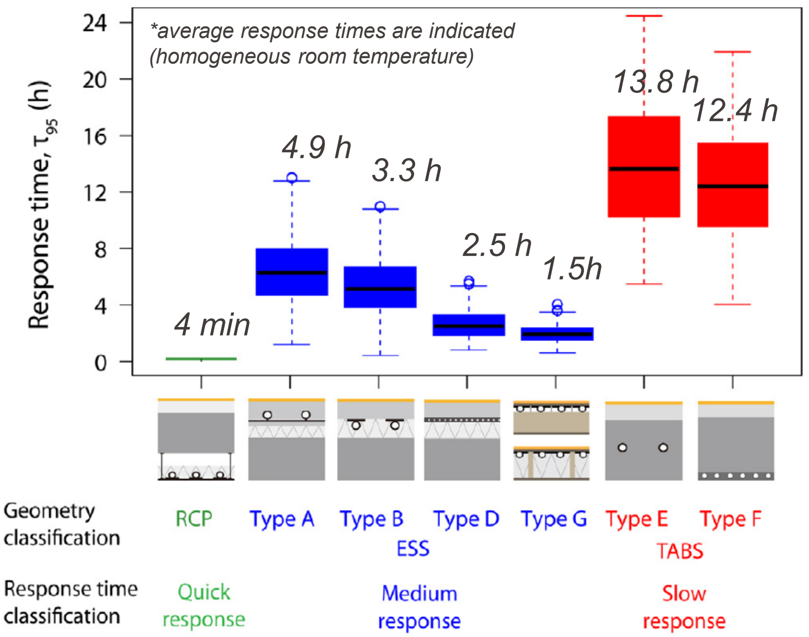


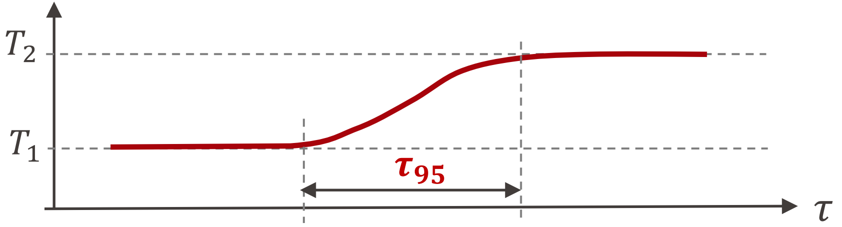




Hydronic Radiant Systems: Response Time

- **Response Time** (a simple definition) – the time for the system to change from one *stable* condition to another
- **Response Time (τ_{95}) -** the time it takes for the surface temperature of a radiant system **to reach 95%** of the **difference** *between* its **final** and **initial values** when a step change in control of the system is applied as input.
- **Determining parameters:**
  - **Geometric parameters** (pipe spacing; pipe diameter, concrete thickness, pipe-embedded depth)
  - **Thermal properties** (concrete type, floor covering material)
  - **Boundary conditions** (operative temperature, water temperature)





Source: Ning et al. (2017) http://dx.doi.org/10.1016/j.enbuild.2016.12.013

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Thermally Activated Building Systems (TABS)

https://www.watts.ca/solutions/systems/hydronic-heating-systems

https://www.rehau.com/uk-en/thermally-activated-building-structures

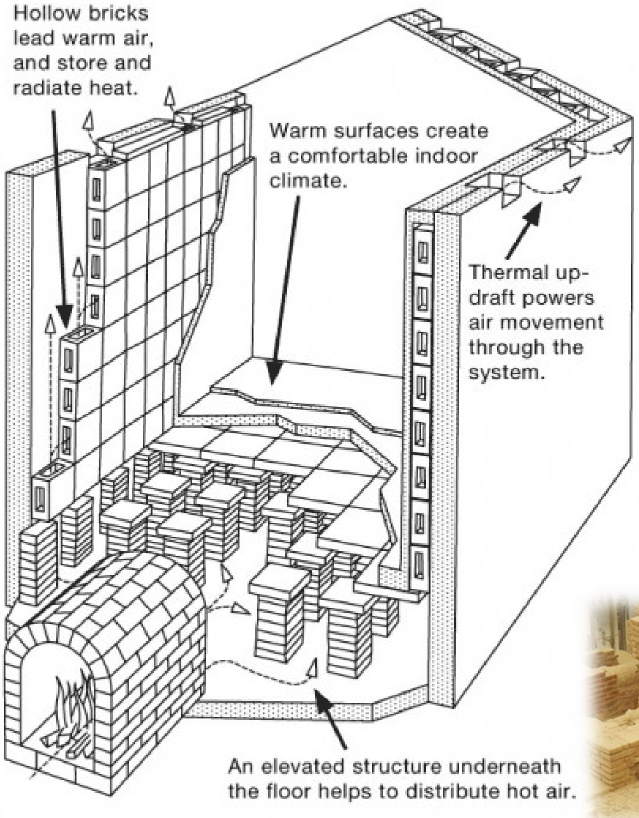
VS

https://beodom.com/en/quality/heating-system.html

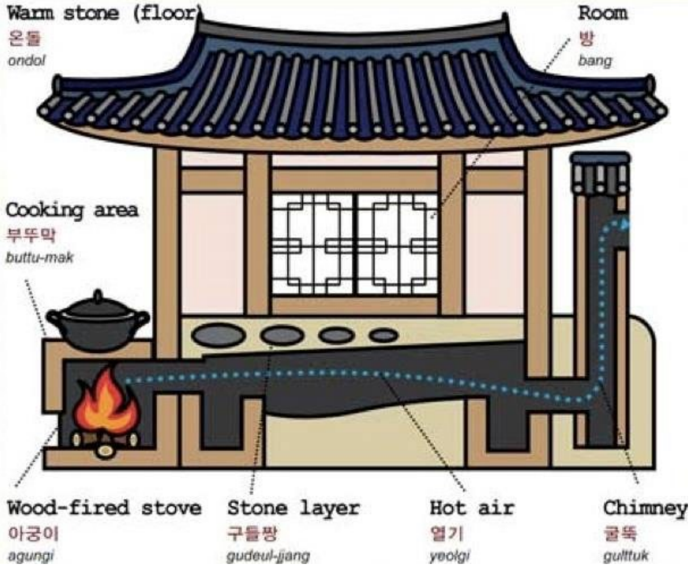
http://www.oorja.in/oorja/projects/radiant-ceiling-cooling/

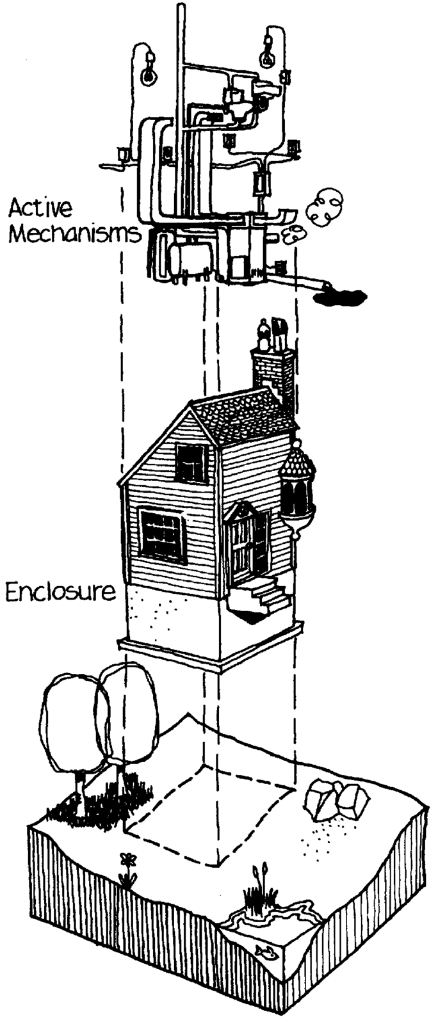
Radiant Floor Heating : Old New?

Roman Hypocaust heating (350 BC):



Traditional Korean heating (Ondol, 5000 BC):



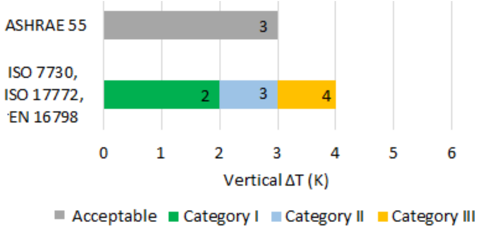


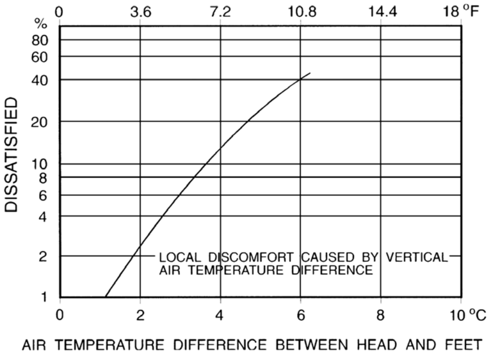
Source: Edward Allen «How Buildings Work» (2005)

CONTENT:

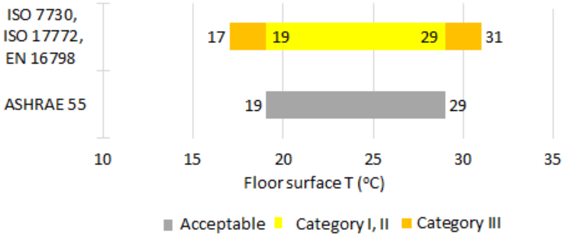
Local Thermal Discomfort: Overview

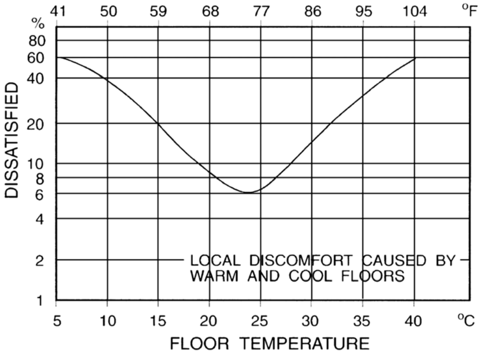
Vertical Air Temperature Difference:



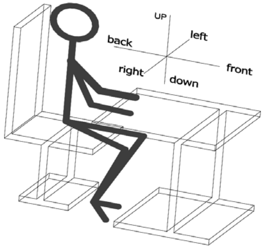


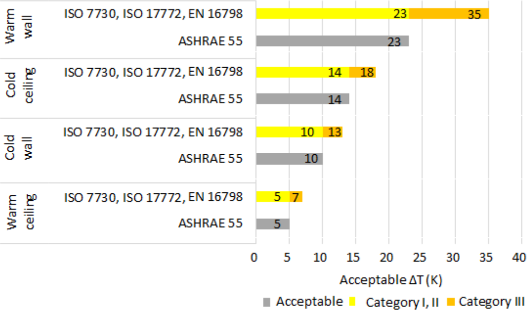
Floor Surface Temperature:

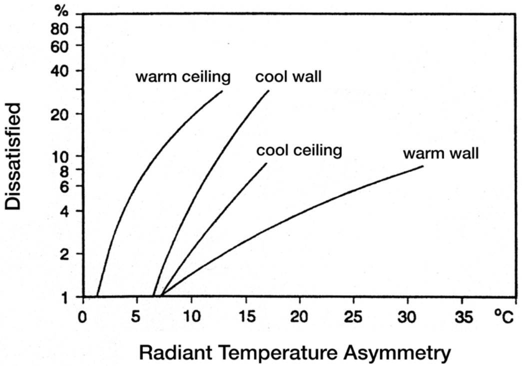




Radiant Temperature Asymmetry:







Source: Khovalyg et al. (2019) DOI : 10.1016/j.enbuild.2020.109819.

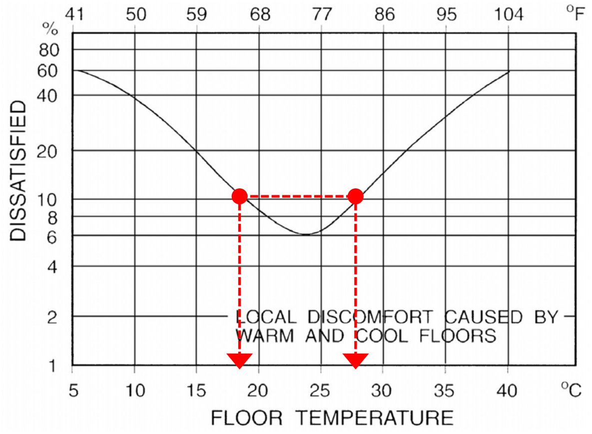
Radiant Systems: Surface Temperature Limits

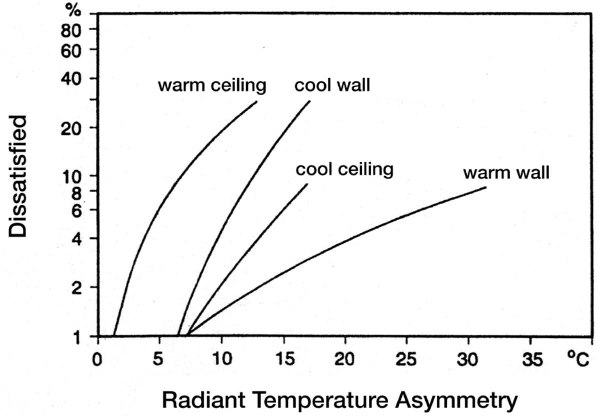
- The maximum surface temperature depends on the criteria for **radiant asymmetry** and **direct contact with the surface**
- Temperature limits **per ISO 7730** for surfaces (floor: occupants with normal shoes - Europe, America):

Floor: +29°C / Ceiling: +27°C / Walls: +40°C

- Acceptable range for **floor surface** *should be adjusted* **for a certain lifestyle** (i.e., in Japan and Korea, occupants spend lots of time sitting on the floor):

ASHRAE Fundamentals handbook, 2009	According to the material of the floor	Textiles (rugs): 21≈28°C Pine floor: 22,5≈28°C Oak floor: 24,5≈28°C Hard linoleum: 24≈28°C Concrete: 26≈28,5°C	In America and Europe
Song, GS et al., 2001	According to the material of the floor	Clay: 24,9≈31,5°C Pine: 18,1≈29,0°C Urethane: 12,7≈23,2°C Veneer: 24,7≈31,0°C	In Korea
Ling Zhang et al.		Allowable range of floor surface temperature: 25≈31°C Comfortable range of floor surface temperature: 26≈30°C	In Japan

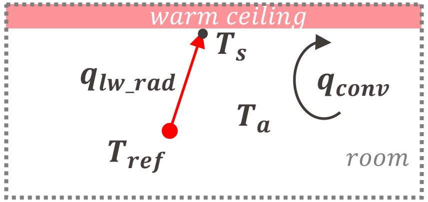




Sources: ISO 11855-1:2012, ISO 7730, ASHRAE 55-2017

Embedded Radiant Systems: Rated Heat Flux

- Surface convective heat transfer: $q''_{conv} = h_c \times (T_a - T_s)$
- Longwave radiation heat transfer: $q''_{lw\_surf} = h_{rad} \cdot (T_s - T_{ref})$
- Total surface heat flux*: (heat flow density, W/m^2) $\boxed{q = h_t \cdot |T_s - T_{ref}|}$



$T_s = T_{m,s}$ *mean surface temperature*
$T_{ref} = T_{op}$ *operative temperature (per ISO 18555)*

- **Heat transfer coefficient** between radiant surface and room condition:

Combined convection and (longwave) radiation heat transfer coefficient h_t*:*

Heating:		Cooling	
Floor heating (FH)	**11** W/m^{2}K	Floor cooling (FC)	**7** W/m^{2}K
Wall heating (WH)	**8** W/m^{2}K	Wall cooling (WC)	**8** W/m^{2}K
Ceiling heating (CH)	**6** W/m^{2}K	Ceiling cooling (CC)	**11** W/m^{2}K

Radiant (longwave) heat transfer coefficient h_{rad} = **5.5** W/m^{2}K
(less than **4%** error for surface temperatures in the range of **15-30°C**)

- **Heat flow density (W/m^2):** at steady-state
  - ○ ***floor heating*** / ***ceiling cooling:*** $q = 11 \cdot |T_{m,s} - T_{op}|$
  - ○ ***wall heating*** / ***wall cooling:*** $q = 8 \cdot |T_{m,s} - T_{op}|$
  - ○ ***ceiling heating:*** $q = 6 \cdot |T_{m,s} - T_{op}|$
  - ○ ***floor cooling:*** $q = 7 \cdot |T_{m,s} - T_{op}|$

Source: ISO 11855-2:2012

* Shortwave radiation heat transfer **is not considered** in the *standard approach* of defining total heat flow density which might become problematic **for floor cooling** with direct sunlight

What is the comfort-related limiting heat flux for FLOOR heating in the case of indoor operative temperature 20ºC?

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A. 80 W/m^2

B. 90 W/m^2

C. 100 W/m^2

D. None above

What is the comfort-related limiting heat flux for CELING heating in the case of indoor operative temperature 20ºC?

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Session ID: **ENG445**

A. **32** W/m^2

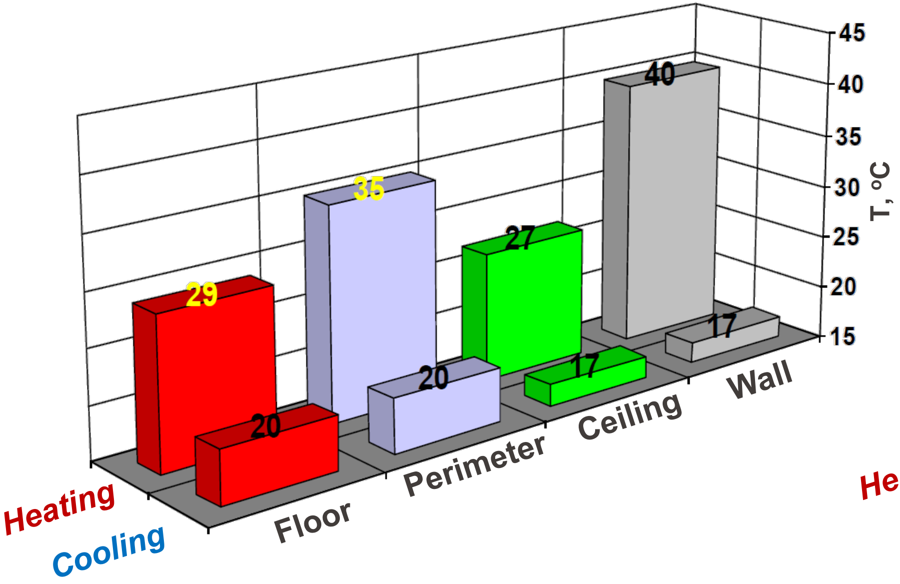
B. **42** W/m^2

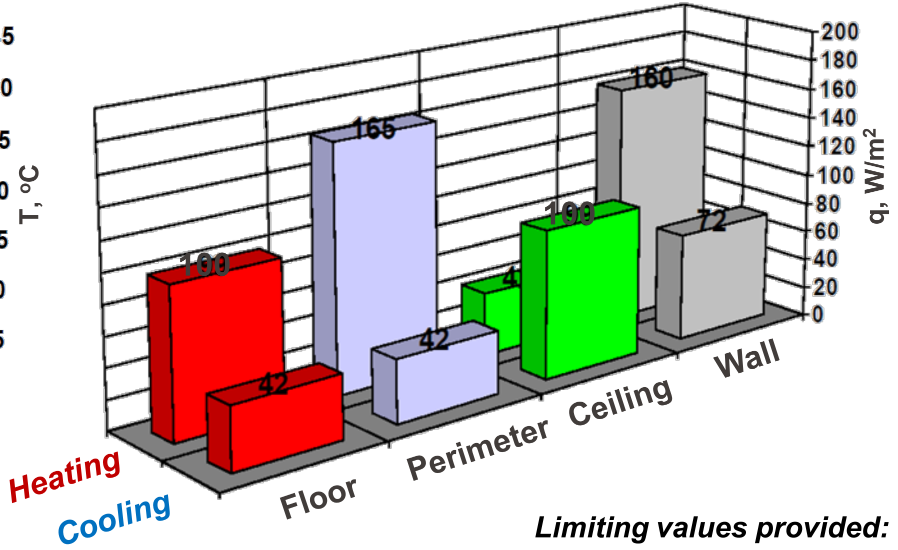
C. **52** W/m^2

D. None above

Radiant Systems: Maximum Heat Output

- **Maximum** heating and cooling capacity depends *on the position* of the radiant surface
- The heating/cooling capacity *is limited* by **relatively small convective heat transfer coefficient** between *the surface* and *air*, risk of condensation and concerns about surface temperature, radiant asymmetry, vertical air stratification and draft from comfort perspective





Limiting values provided:

- for **heating**: T_{op}=20°C
- for **cooling**: T_{op}=26°C

(for V_{air} < 0.2 m/s)

Source: Olesen (2018), Radiant heating/cooling dimensioning

Heat Exchangers Analysis: Quick Overview

- In heat exchangers, **the heat transfer** between ***the hot stream*** (water) and ***the cold stream*** (room air) occurs over ***a finite area*** A_s of the heat exchange.

- To determine the heat transfer $\boldsymbol{Q}$ [W] in heat exchangers, ***LMTD* method** can be used
  - ○ $\boldsymbol{LMTD}$ [K] - log-mean temperature difference
  - ○ $\boldsymbol{U}\ [W/m^2K]$ – overall heat transfer coefficient

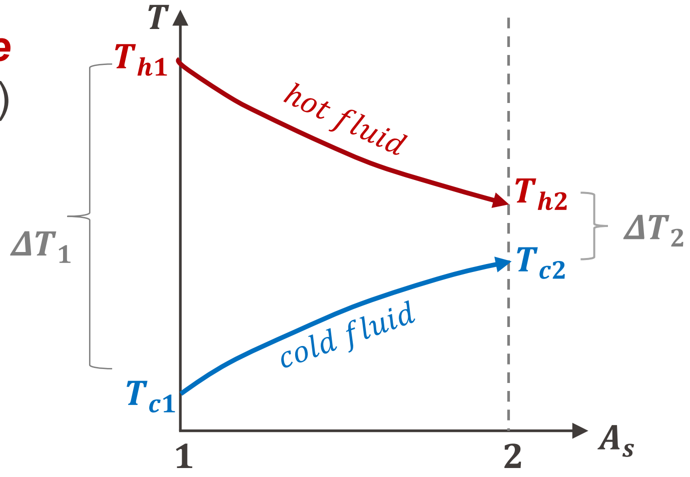
$$\boldsymbol{Q} = \boldsymbol{U} \cdot A_s \cdot \Delta T_{lm}$$

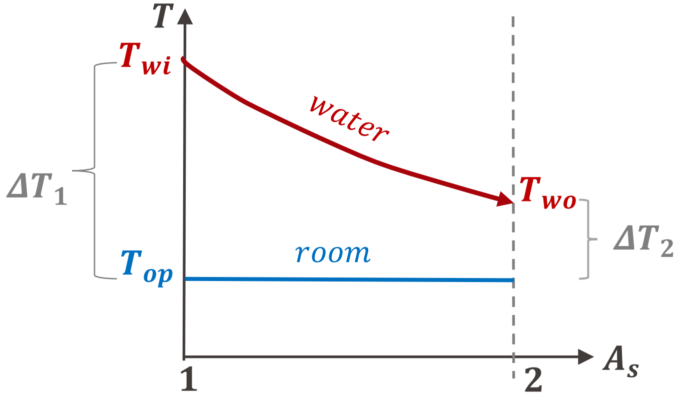
$$\boldsymbol{\Delta T_{lm}} = \frac{\Delta T_1 - \Delta T_2}{ln[\Delta T_1/\Delta T_2]}$$

- $LMTD$ considering constant operative temperature $\boldsymbol{T_{op}}$ to be maintained indoors:

$$\Delta T_1 = T_{wi} - T_{op}\ ,\quad \Delta T_2 = T_{wo} - T_{op}$$

$$\boldsymbol{\Delta T_{lm}} = \frac{(T_{wi} - T_{wo})}{ln[(T_{wi} - T_{op})/(T_{wo} - T_{op})]}$$





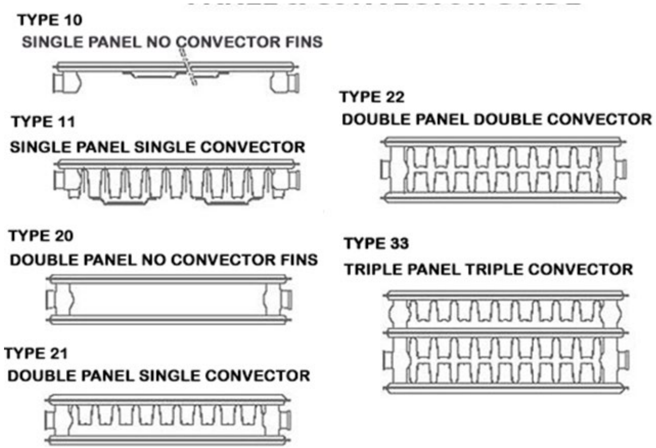
Radiators/Convectors: Selection

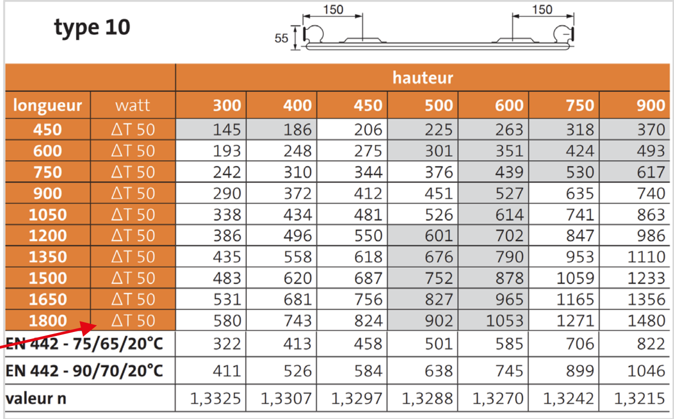
1. Determine **the room peak heating demand** Q_{demand}
2. Measure **the room size** and **space** available
3. Choose **type** of the radiator (i.e., type 11, 22, 33, etc.)
4. Choose **required device** from a manufacturer's catalogues and determine $\boldsymbol{Q_{fabricant}}$ close to $\boldsymbol{Q_{demand}}$
5. Determine exponent ***n*** value indicated in the catalogue
6. Typical water temperature drop $(\boldsymbol{T_{wi}} - \boldsymbol{T_{wo}})$ in radiators is **limited to 10 K**
7. Determine **water temperature** using the following formulation considering (7):

$$\boldsymbol{Q_{demand} = Q_{fabricant} * (\frac{\Delta T_{actual}}{\Delta T_{standard}})^n}$$

where $$\Delta T_{actual} = \frac{(T_{wi}+T_{wo})}{2} - T_{room}$$

$$\Delta T_{standard} = 50K \ (see\ the\ catalogue)$$





type 10

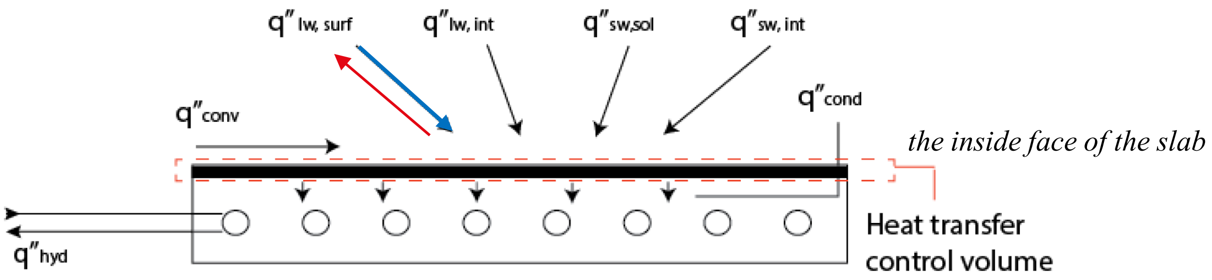
		hauteur						
longueur	watt	300	400	450	500	600	750	900
450	ΔT 50	145	186	206	225	263	318	370
600	ΔT 50	193	248	275	301	351	424	493
750	ΔT 50	242	310	344	376	439	530	617
900	ΔT 50	290	372	412	451	527	635	740
1050	ΔT 50	338	434	481	526	614	741	863
1200	ΔT 50	386	496	550	601	702	847	986
1350	ΔT 50	435	558	618	676	790	953	1110
1500	ΔT 50	483	620	687	752	878	1059	1233
1650	ΔT 50	531	681	756	827	965	1165	1356
1800	ΔT 50	580	743	824	902	1053	1271	1480
EN 442 - 75/65/20°C		322	413	458	501	585	706	822
EN 442 - 90/70/20°C		411	526	584	638	745	899	1046
valeur n		1,3325	1,3307	1,3297	1,3288	1,3270	1,3242	1,3215

Source: https://www.radson.com/docs/Radson-Fiche-technique-CLD-FR.pdf
Source: http://cruzoe.free.fr/enr/donn%E9es%20diverses/Les%20radiateurs%20Calculs.pdf

Assist. Prof. Dolaana Khovalyg

Embedded Radiant Systems: Heat Transfer

- **Two heat transfer (HT) processes** involved:
  - HT *between* **the surface of the radiant layer** and **the space** it is conditioning
  - The HT *between* **the radiant layer** and **the water loop**



$$q''_{conv} + q''_{lw,surf} + q''_{lw,int} + q''_{sw,sol} + q''_{sw,int} + q''_{cond} = 0$$

The amount of **heat supplied** *by* **an activated heating surface** is a **combination** of *convection* and *radiation*:

$$\boxed{q''_{surf}} = -q''_{cond} = q''_{conv} + q''_{lw,surf} + q''_{lw,int} + q''_{sw,sol} + q''_{sw,int} = \boxed{q''_{conv} + q''_{rad\_surf}}$$

$$\boxed{q''_{hyd}} = (\dot{m}c_p)_{water}(T_{wi} - T_{wo})$$

$\dot{m}$ = Mass flow rate of water, kg/s;

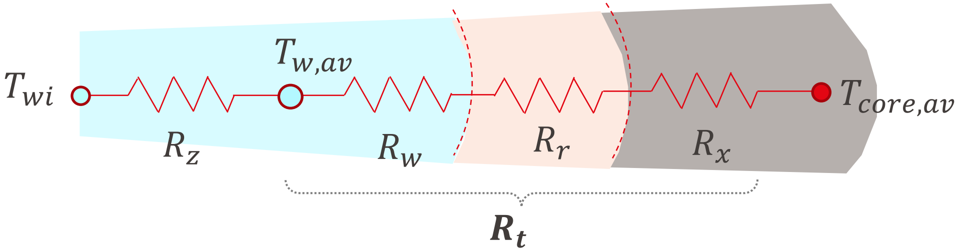
c_p = Specific heat of water $J/kg \cdot K$;

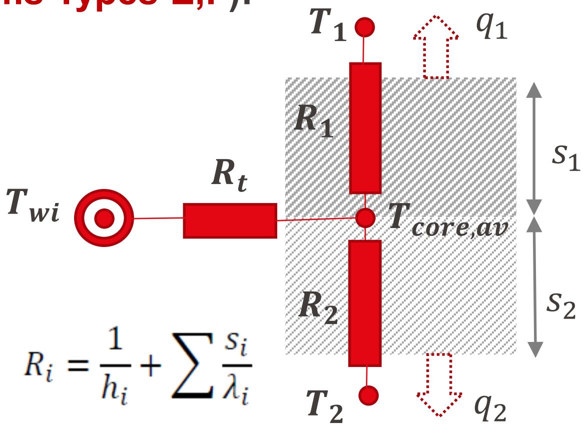
T_{wi}, T_{wo} = Supply and return water temperature respectively, °C.

Source: Feng (2014) Design and Control of Hydronic Radiant Cooling Systems

Embedded Radiant Systems: Heat Transfer

- **Conduction heat transfer** is *the major* heat transfer mechanism *between* **the surfaces** and **the hydronic loop** once *heat has been absorbed* by the radiant surfaces
- Thermal resistance network in the slab and between the slab and water loop is used to solve the conduction problem to determine the cooling/heating capacity for **Type E** and **F** systems
- **Heating capacity estimation using resistance method (systems Types E,F):**





$$R_i = \frac{1}{h_i} + \sum \frac{s_i}{\lambda_i}$$

  - R_t - total resistance between the heat source and the conducting layer
  - R_z - resistance between the supply water at temperature T_{wi} and the average water at temperature $T_{w,av}$
  - R_w - resistance between water at average temperature $T_{w,av}$ and internal wall surface of the pipe $(1/h_w)$
  - R_r - resistance between water and the outside pipe wall
  - R_x - resistance between the pipe outside wall temp. and the conductive layer (a fictive core) at average temp. of $T_{core,av}$
  - R_i - thermal resistance *in the heat-conducting layer* (from the heat-conducting plate to the room *above* “1” or *below* “2”)

$$\boxed{q'' = K_H \cdot \Delta T_h}$$

$$\boxed{K_H = 1/(R_t + R_i)}$$

Source: ISO 11855-2:2012

Embedded Radiant Systems: Heat Transfer

- **Universal power law** (for embedded systems **Type A, B, C, D**):

  ○ **Heat flux at a surface:** $q'' = K_H \cdot \Delta T_h^n$, *where 1<n<1.05*

  ○ **Mean temperature difference** between heat carrier (water) and the space:

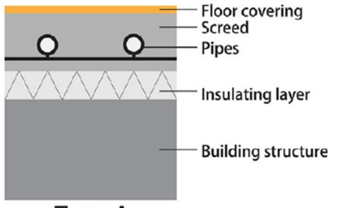
$$\Delta T_h = \frac{(T_{wi} - T_{wo})}{\ln\left[\left(T_{wi} - T_{op}\right) / \left(T_{wo} - T_{op}\right)\right]}$$

  ○ **Lumped thermal resistance:**

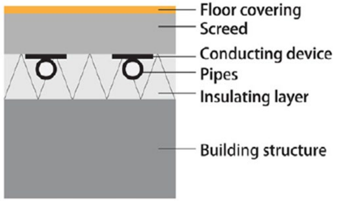
$$K_H = B \cdot \underbrace{\prod (a_i^{m_i})}$$

system dependent coefficient, W/(m²K)

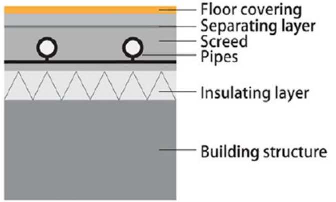
a power product linking parameters of the structure



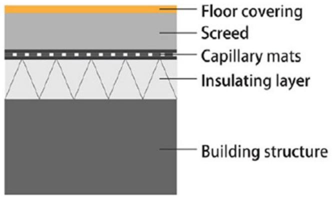
Type A



Type B



Type C

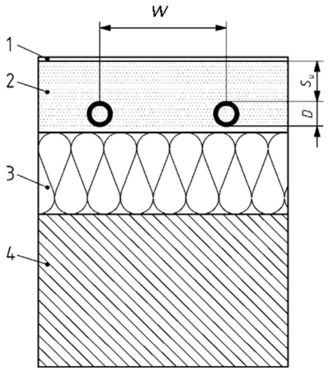


Type D
(ESS)

Source: ISO 11855-2:2012

Embedded Radiant Systems: Heat Transfer

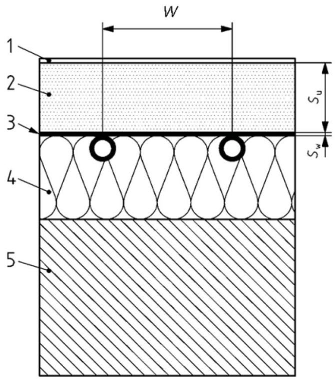
Systems Types A, C:



$$q = B \cdot a_B \cdot a_W^{m_w} \cdot a_U^{m_u} \cdot a_D^{m_D} \cdot \Delta T_h$$

B=6.7 W/(m²K)

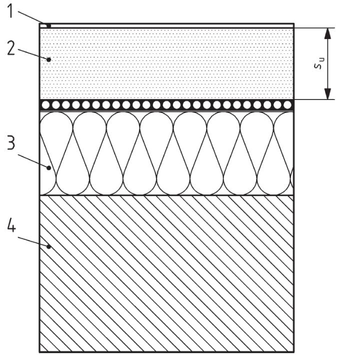
System Type B:



$$q = B \cdot a_B \cdot a_W^{m_w} \cdot a_U \cdot a_{WL} \cdot a_K \cdot \Delta T_h$$

B=6.5 W/(m²K)

System Type D:



$$q = B \cdot a_B \cdot a_W^{m_w} \cdot a_U \cdot \Delta T_h$$

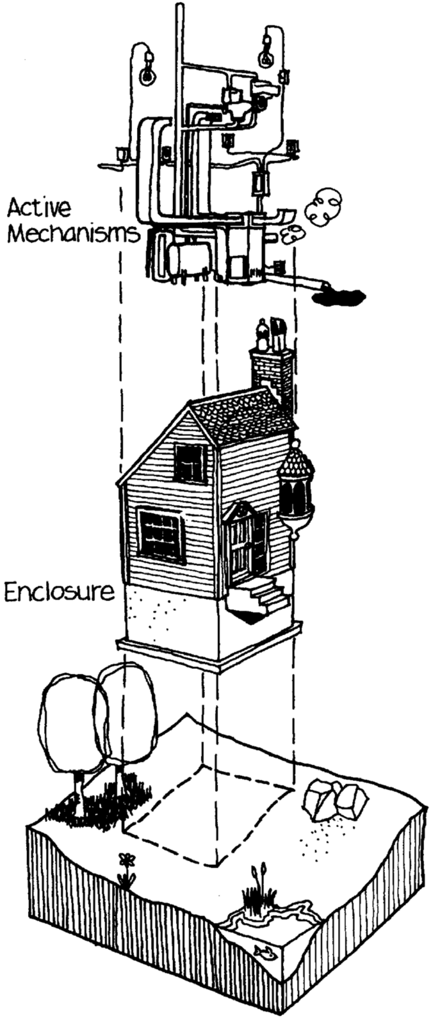
B=6.5 W/(m²K)

- a_B - surface covering factor
- a_W - the pipe spacing factor, $f(R_{\lambda,B})$
- a_U - the screed covering factor, $f(W, R_{\lambda,B})$
- a_D - the pipe external diameter factor, $f(W, R_{\lambda,B})$
- a_B - heat conduction device factor, $f(K_{WL}, W, D)$
- a_K - correction factor for the contact, $f(W)$

Values are tabulated in ISO 11855

- *Factor considering spacing of pipes:*
  $$m_w = 1 - W/0.075$$
- *Factor considering covering thickness:*
  $$m_u = 100 \cdot (0.045 - s_u)$$
- *Factor considering diameter of pipes:*
  $$m_D = 250 \cdot (D - 0.020)$$

Source: ISO 11855-2:2012



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

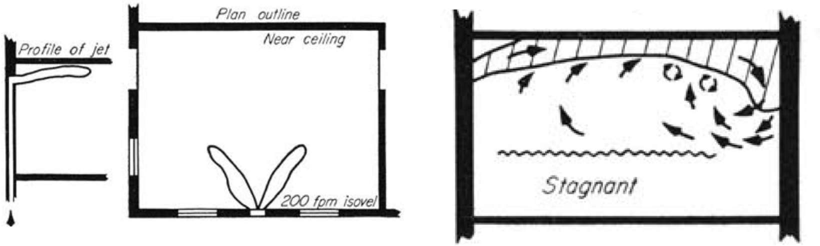
CONTENT:

- Introduction
- Overview of Emission Systems:
  - Definition
  - All-air systems
  - Radiators (convectors)
  - Radiant systems
- Technical Characteristics
  - Local discomfort limits
  - Convectors vs. Embedded systems
- **Thermal Comfort vs. Emission Systems**
  - **Comparative study overview**
- Standard References
- Summary

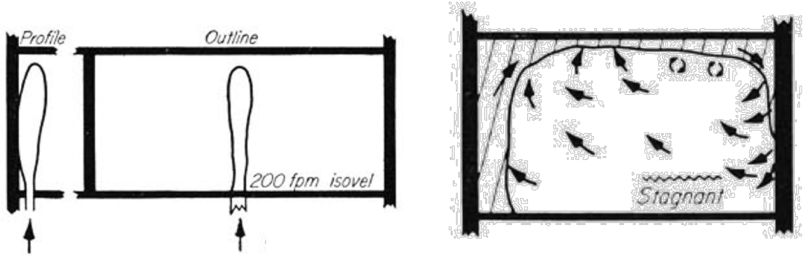
Convective (All-Air) Heating: Airflow

Distinct groups of air patterns:

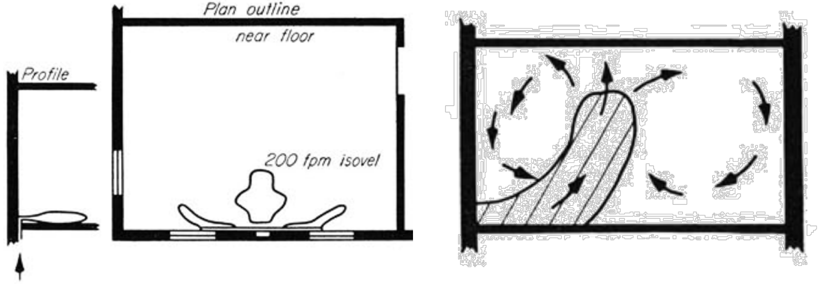
- Air is discharged at the ceiling level



- Air is discharged vertically from floor grill (non-spreading floor outlet)

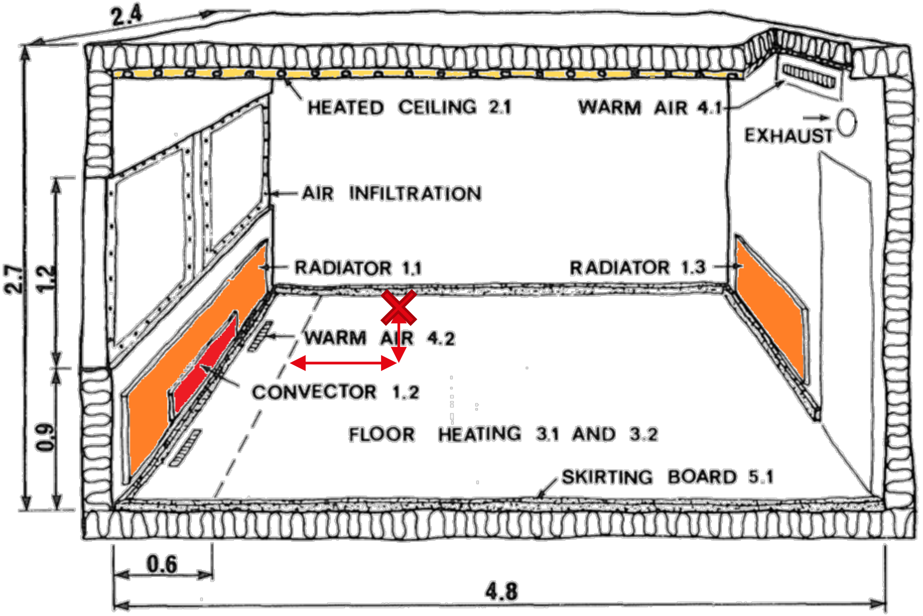


- Air spread horizontally across the floor (long baseboard units that spread air over a wide floor area)



Source: H Straub (1956)

Heating Systems: Comfort



- Test room: 4.8 x 2.4 x 2.7 m^3
- Outside air temperature simulation: **-5ºC** and **+4ºC** (only for the front wall with windows)
- Multiple space heating approaches **comparison** for **PMV=0** condition *at the reference point* (**1 m** away from window at the height of **0.6 m**)

Sources: Olesen B. W. et al. (1978). Thermal comfort in a room heated by different methods

No	Emission	Description	Heat carrier	T_{supply} (ºC)
1.1	**Radiator**	Single panel radiator beneath the window covering most of the lower wall	**Warm water**	37-48
1.2	**Convector**	3 *panel* convectors beneath the window	**Warm water**	39-53
1.3	**Radiator**	*Single* panel radiator at the back wall	**Warm water**	46-63
2.1	**Ceiling**	Aluminium plates with water-filled coils, supply along the frontage and return at the back wall	**Warm water**	34-42
3.1	**Floor (uniform)**	Electrical heating foil covered by a 2 mm aluminium plate (uniform distribution)	**El. Heater**	--
3.2	**Floor (non-unif)**	As 3.1, but the effect on a 0.6 m strip along the frontage was higher (T_{surf}=29°C)	**El. heater**	--
4.1	**Warm air**	Outlet in the back wall near the ceiling, 4 ACH, V=1.2 m/s.	**Warm air**	34-43
4.2	**Warm air**	2 outlets in the floor beneath the window, 4 ACH, V= 1.2 m/s.	**Warm air**	34-43
5.1	**Skirting board**	Small electrical heated panels along the periphery of the room	**El. heater**	--

What type of system would lead to the highest vertical air temperature difference at the reference point (X)?

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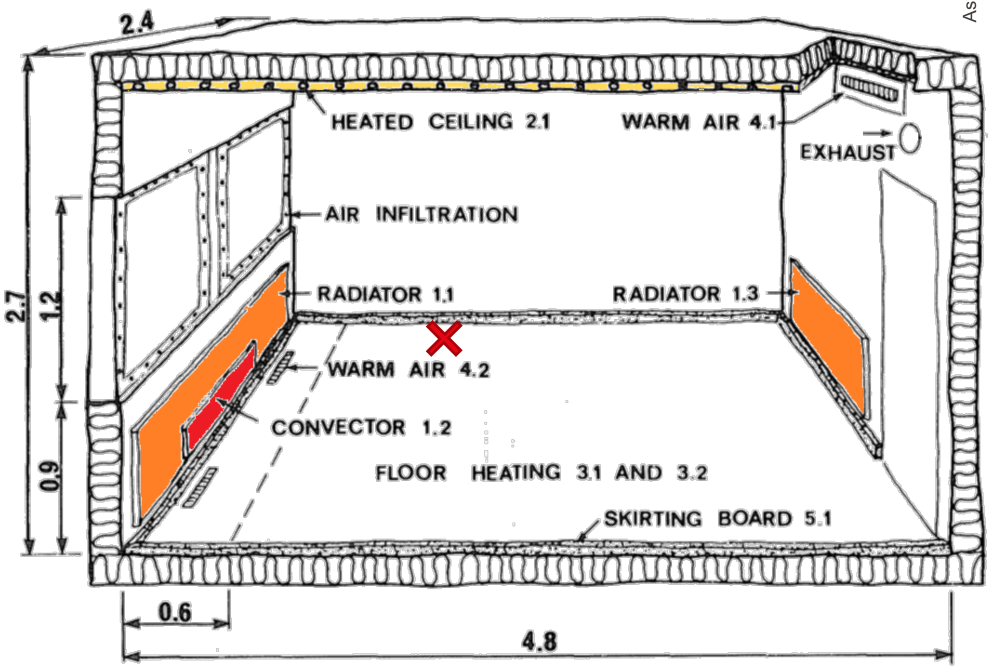
A. Radiator (1.3)

B. Warm air (4.1)

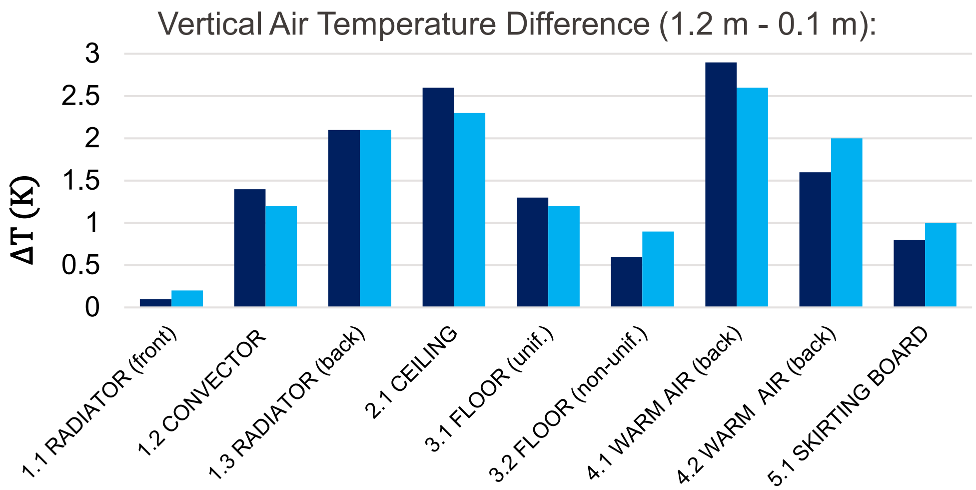
C. Warm air (4.2)

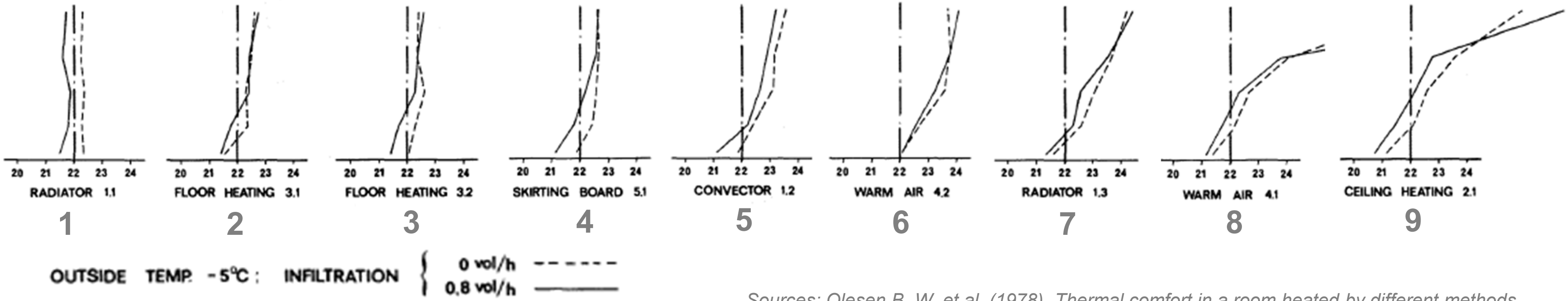
D. Heated ceiling (2.1)



Heating Systems: Vertical Air Temperature

- The *highest vertical air temperature difference (0.1-1.8m)* is for **warm air system (4.1)** with outlet in the back wall near the ceiling, and **a heated ceiling (2.1)**
- *Increased* **air infiltration rate** *decreased* vertical air temperature difference *slightly*





Sources: Olesen B. W. et al. (1978). Thermal comfort in a room heated by different methods

What type of system would lead to the highest VERTICAL radiant temperature asymmetry at the reference point (X)?

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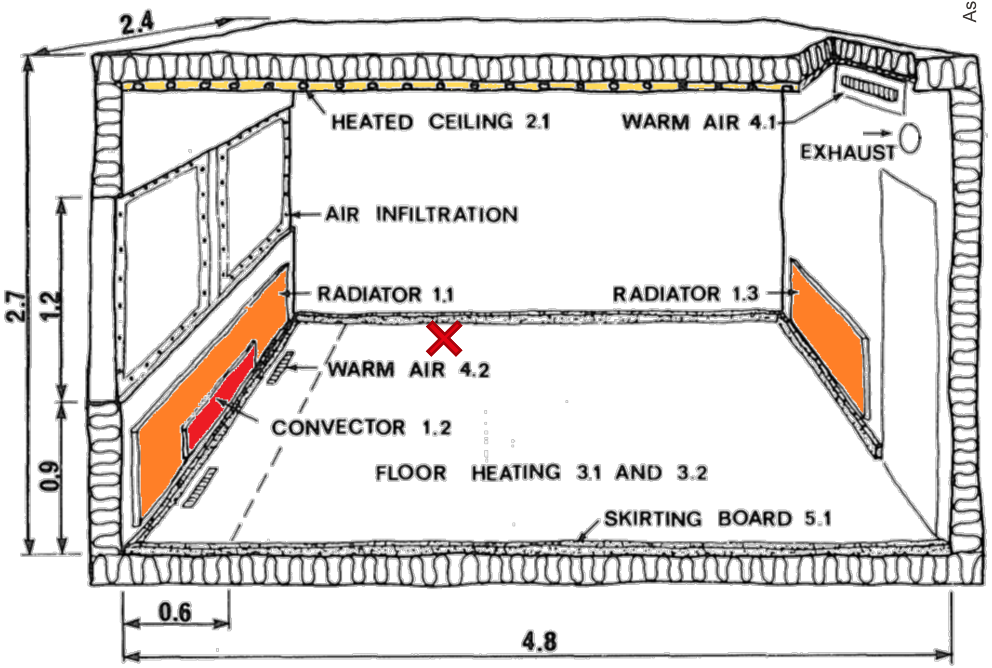
A. Radiator (1.3)

B. Warm air (4.1)

C. Warm air (4.2)

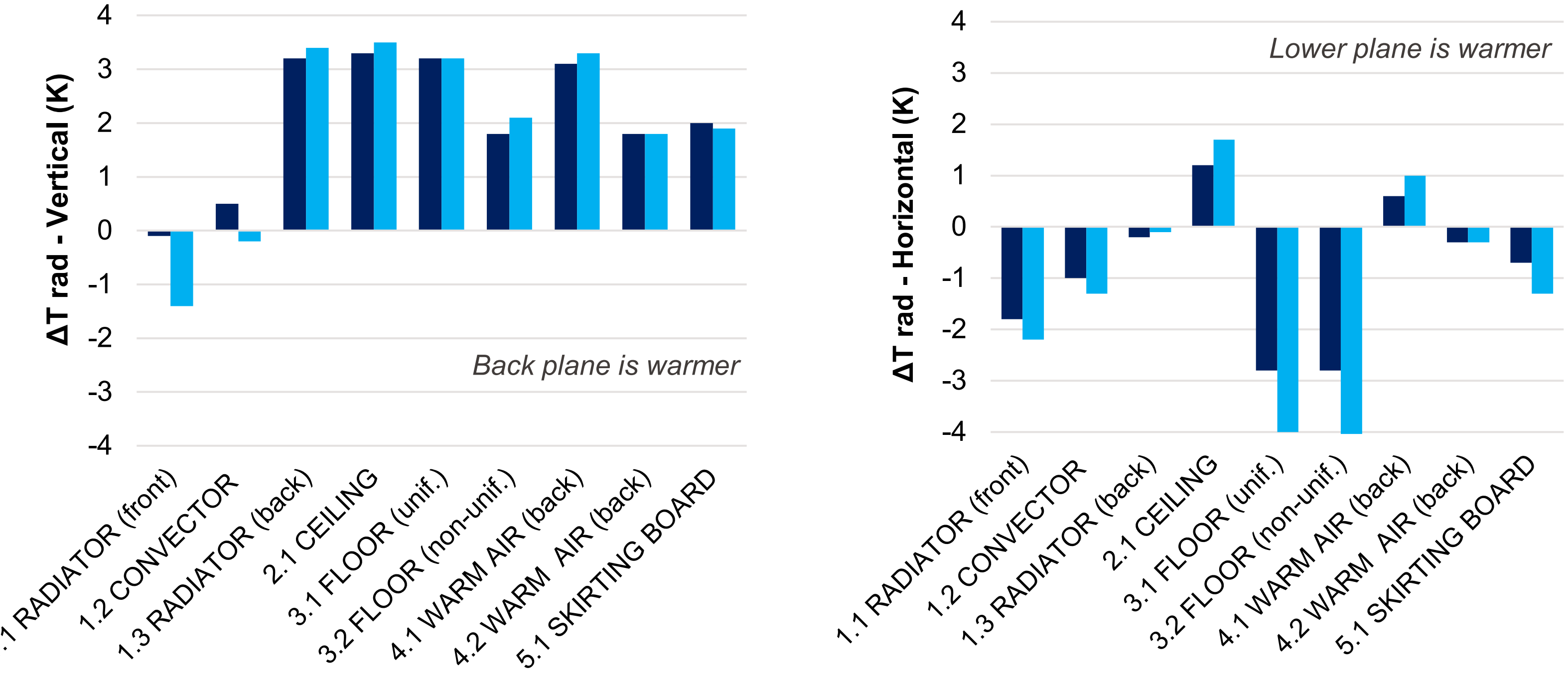
D. Heated ceiling (2.1)



Heating Systems: Radiant Asymmetry

■ -5°C, 0 ACH
■ -5°C, 0.4 ACH

Radiant Temperature Asymmetry (Vertical & Horizontal Plane):



Back plane is warmer

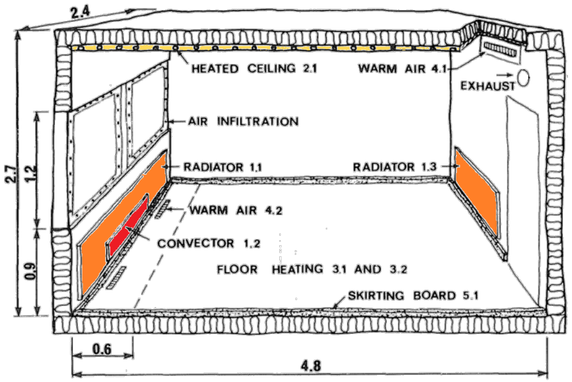
Lower plane is warmer

Sources: Olesen B. W. et al. (1978). Thermal comfort in a room heated by different methods

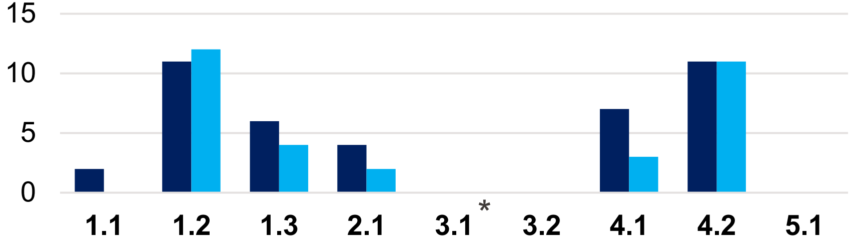
Heating Systems Comparison: **Heat Losses**

🟦 -5°C, 0 ACH
🟦 -5°C, 0.4 ACH

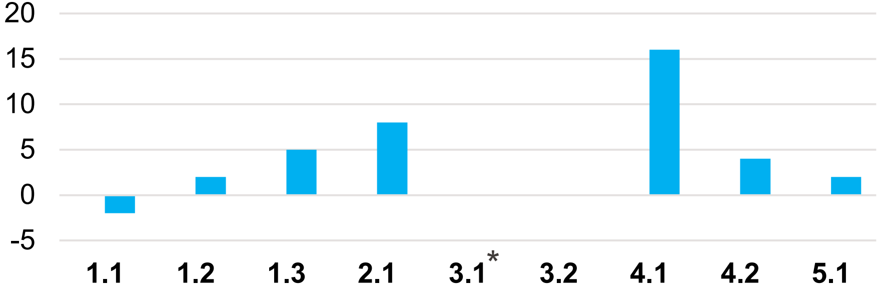
- **Total heat losses:** *the lowest* for the floor heating system (3.1)
- **The heat loss through the window:** *the highest* for **convector** (**1.2**) and **warm air** (**4.2**) due to *increased air velocity* and *air temperature* along the window surface (upward natural/forced convection)
- **The heat loss by infiltration:** *the highest* with **warm air (4.1)** system *with air supply from the back*



Heat losses through the window (in %):



Heat losses by infiltration (in %):



* **Uniform floor heating (3.1)** is considered **as the baseline**

What is the optimal location of the radiator from comfort and energy perspective?

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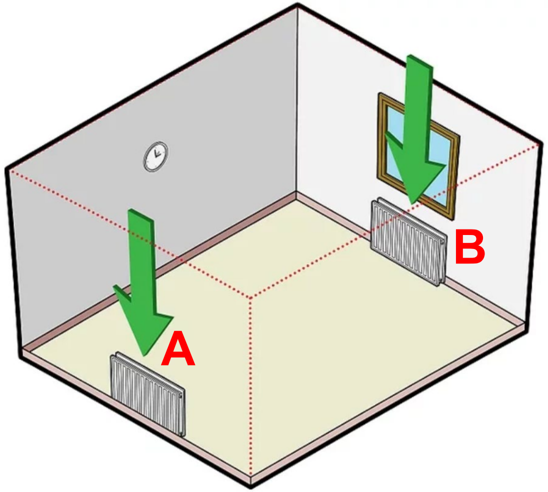
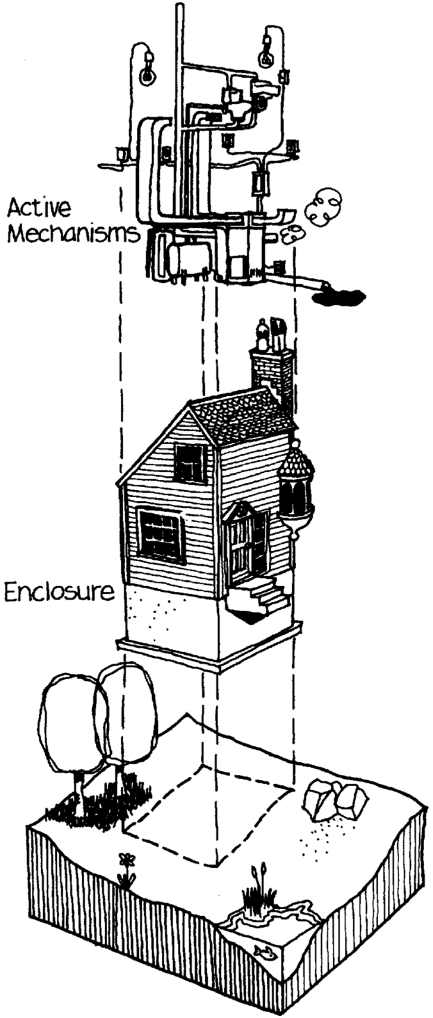
A. A

B. B

C. Need more information to answer





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

CONTENT:

Standards: Heating Load, Emission and Generation

Code	Title
EN 12831-1:2017	Energy performance of buildings - Method for calculation of the design heat load – **Part 1**: *Space heating load*
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*
EN 15316-2:2017	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies – **Part 2:** *Space emission systems (heating and cooling)*
EN 15316-3:2017	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies – **Part 3:** *Space distribution systems (DHW, heating and cooling)*
EN 15316-4-1:2017	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies – **Part 4-1:** *Space heating and DHW generation systems, combustion systems (boilers, biomass)*
	Swiss Regulations:
SIA 380:2015	Bases pour les calculs énergétiques des batiments
SIA 384.201:2017	Performance énergétique des bâtiments - Méthode de calcul de la charge thermique nominale - Partie 1: Charge de chauffage des locaux, module M3-3
SIA 380/1:2016	Besoins de chaleur pour le chauffage

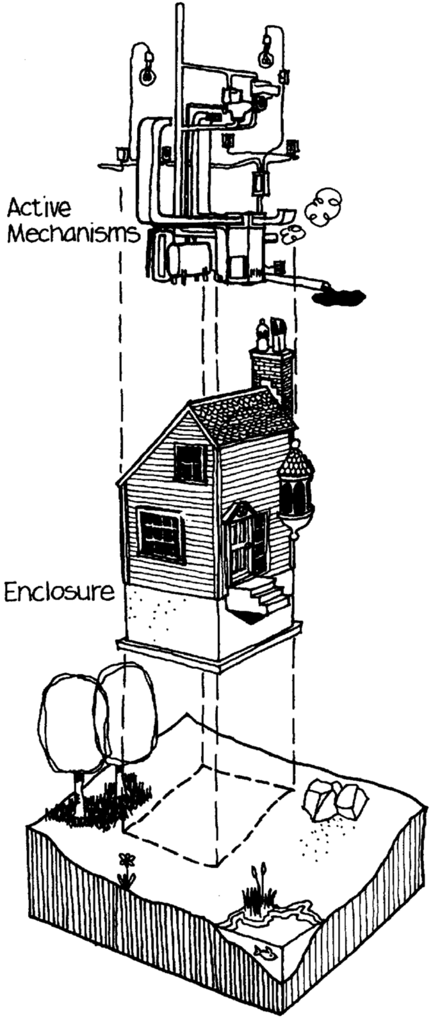
Standards: Radiators and Hydronic Radiant Panels

Code	Title
EN 442-1:2014	**Radiators and convectors** - Part 1: Technical specifications and requirements
EN 442-2:2014	**Radiators and convectors** - Part 2: Test methods and rating

Code	Title
ISO 18566-1:2017	Building environment design — Design, test methods and control of **hydronic radiant heating and cooling panel systems —** **Part 1: Vocabulary, symbols, technical specifications and requirement**
ISO 18566-2:2017	Building environment design — Design, test methods and control of hydronic radiant heating and cooling panel systems — **Part 2: Determination of heating and cooling capacity of ceiling mounted radiant panels**
ISO 18566-3:2017	Building environment design — Design, test methods and control of hydronic radiant heating and cooling panel systems — **Part 3: Design of ceiling mounted radiant panels**
ISO 18566-4:2017	Building environment design — Design, test methods and control of hydronic radiant heating and cooling panel systems — **Part 4: Control of ceiling mounted radiant heating and cooling panels**
ISO 18566-6:2019	Building environment design — Design, test methods and control of hydronic radiant heating and cooling panel systems — **Part 6: Input parameters for the energy calculation**

Standards: Embedded Radiant Systems

Code	Title
ISO 11855-1:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 1: Definition, symbols, and comfort criteria**
ISO 11855-2:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 2: Determination of the design heating and cooling capacity**
ISO 11855-3:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 3: Design and dimensioning**
ISO 11855-4:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 4: Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)**
ISO 11855-5:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 5: Installation**
ISO 11855-6:2012	Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — **Part 6: Control**



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

CONTENT:

- Introduction
- Overview of Emission Systems:
  - Definition
  - All-air systems
  - Radiators (convectors)
  - Radiant systems
- Technical Characteristics
  - Local discomfort limits
  - Convectors vs. Embedded systems
- Thermal Comfort vs. Emission Systems
  - Comparative study overview
- Standard References
- **Summary**

Main Concepts of this Lecture

- **Heating/Cooling Emission Systems Overview**

  Role of emission systems within active heating and cooling systems.
- **Heating Emission Systems Categorization**

  Types of systems: **All-air systems**, **radiators (convectors),** and **radiant systems**.
  - **All-Air Systems:** Definition, key characteristics, and configuration options.
  - **Radiators/Convectors:** Definition, main features, and common setup types.
  - **Radiant Systems:** Definition, attributes, layout designs, and key considerations.
- **Types of Radiant Systems:** Radiant Ceiling Panels (RCP), Embedded Surface Systems (ESS), and Thermally Activated Building Systems (TABS)
- **Local Thermal Discomfort Overview**

  Impact of radiant asymmetry and surface temperature limits on comfort.
- **Technical Overview/Considerations:** Heat transfer and heat exchanger analysis, rated heat flux, and selection criteria.

Assist. Prof. Dolaana Khovalyg

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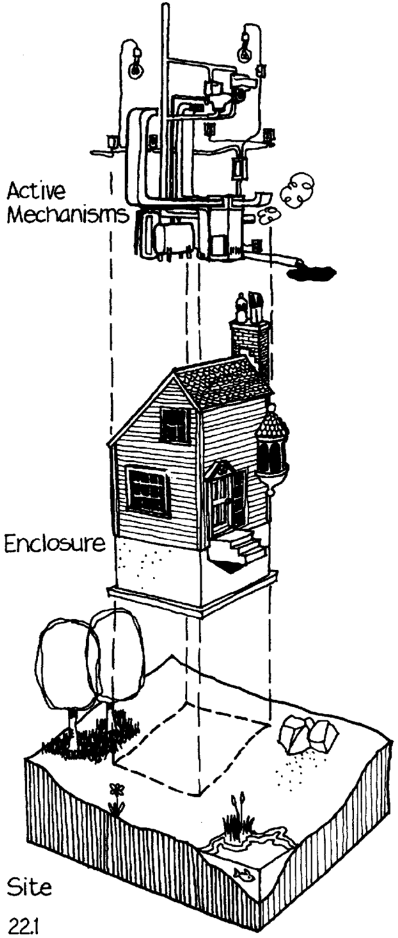

Source: Edward Allen «How Buildings Work» (2005)

Thank you
for your attention!

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