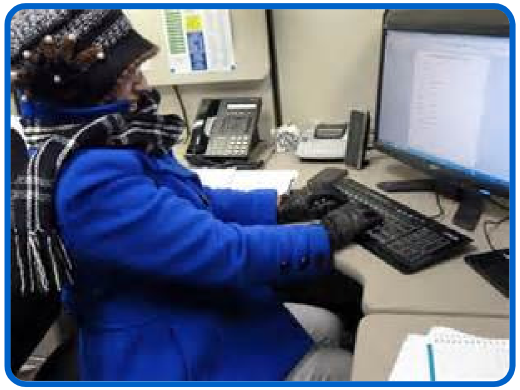
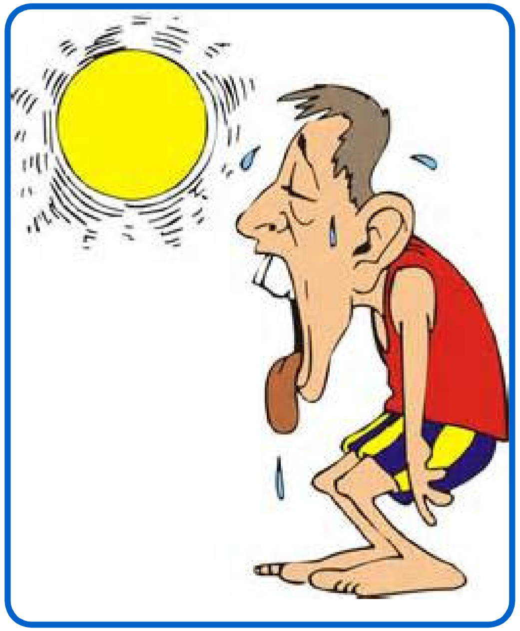
uponor

Radiant Heating & Cooling

Why Heating and Cooling is Necessary?





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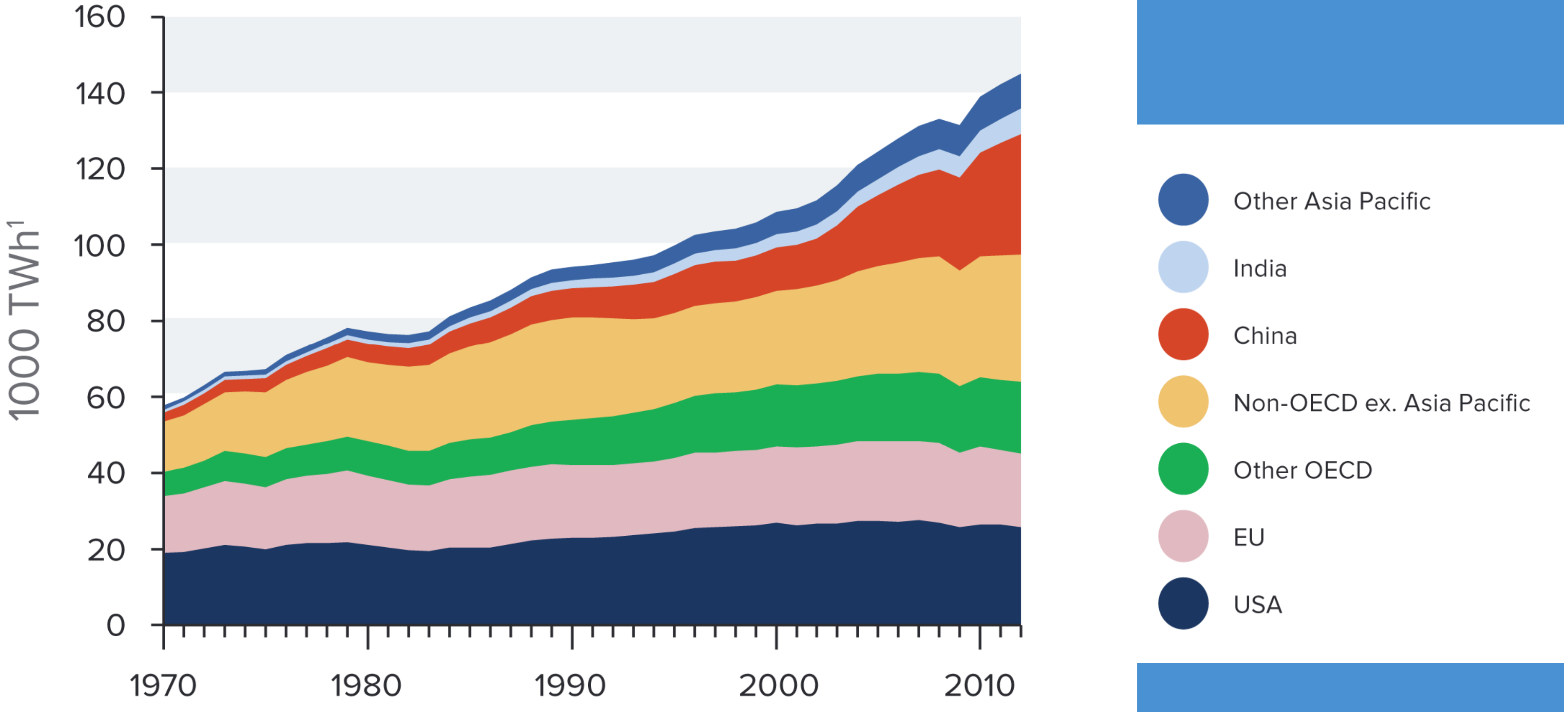
Global Primary Energy Consumption



1: *A terawatt-hour (TWh) is a trillion watt-hours, or the annual power consumption of about 100,000 average US homes. Primary energy refers to energy inputs not yet subject to conversion or waste.*

NOTE: *"Primary energy" refers to energy inputs not yet subject to conversion or waste.*

SOURCE: *BP Statistical Review of World Energy 2013.*

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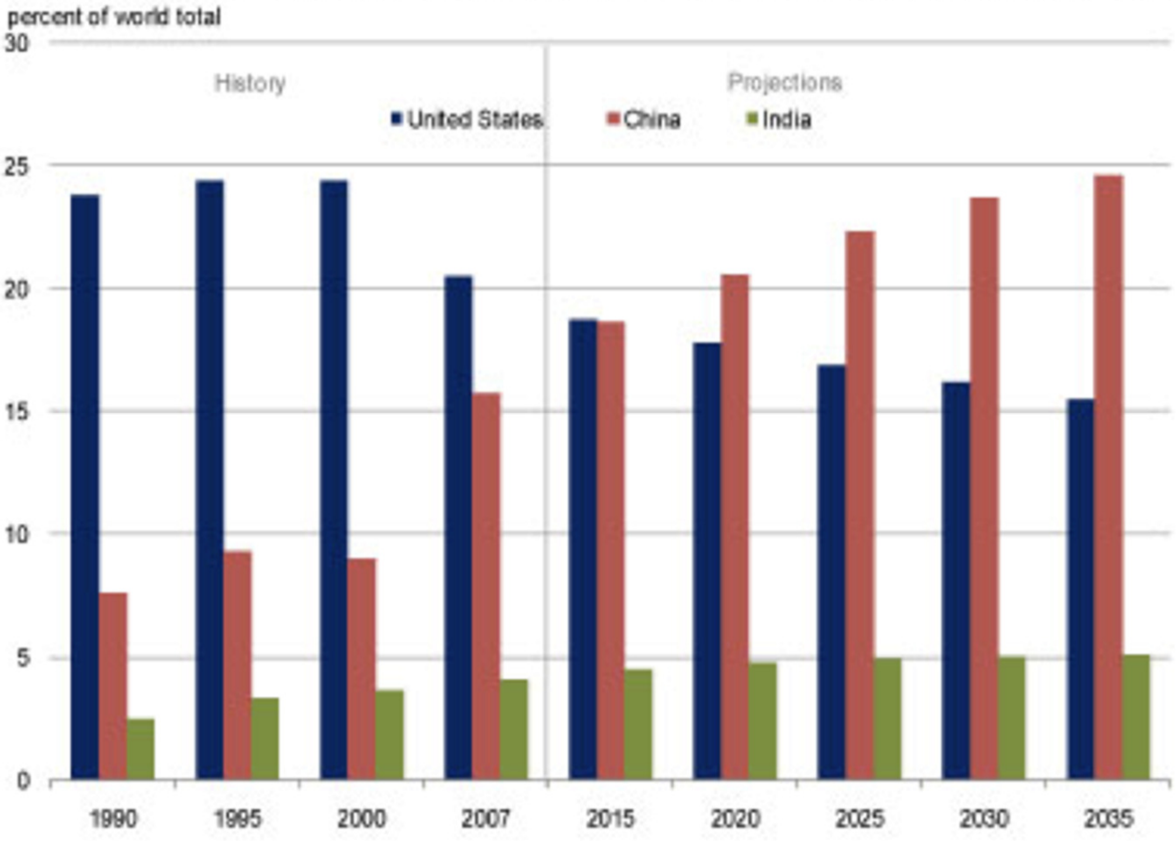
Global Primary Energy Consumption

Figure 14. Shares of world energy consumption in the United States, China, and India, 1990-2035



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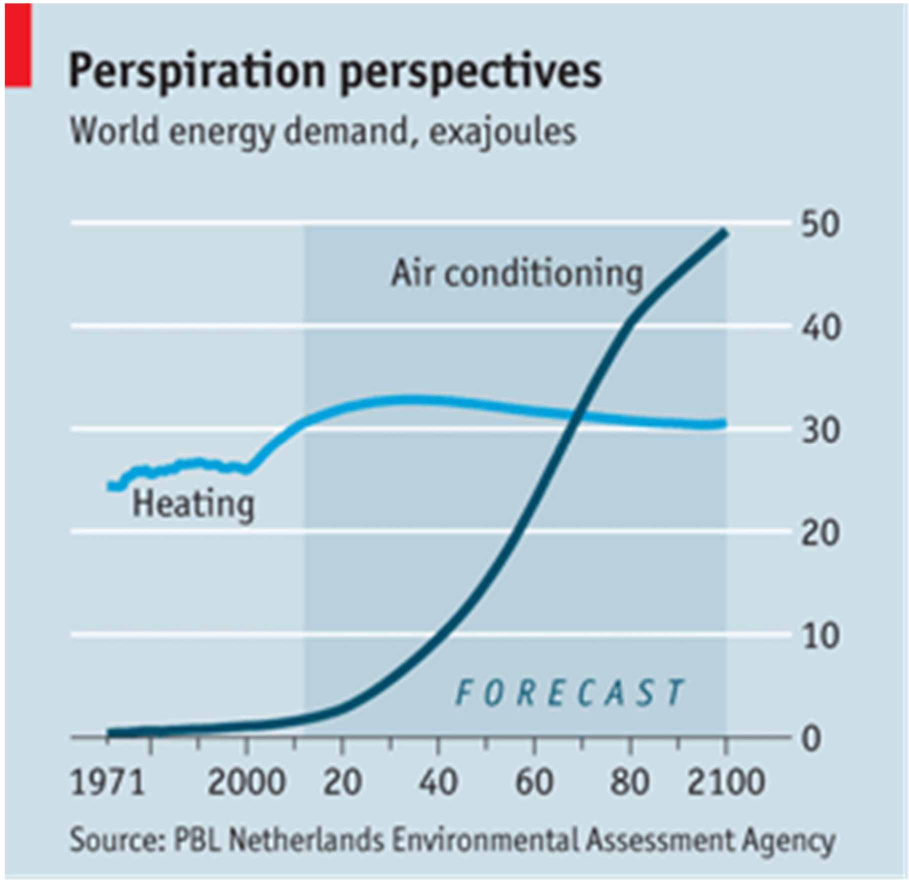
No Sweat

Artificial cooling makes hot places bearable – but at a worryingly high costs



Source: PBL Netherlands Environmental Assessment Agency

- Between 1995 and 2004 the proportion of homes in Chinese cities with air conditioning rose from 8% to 70%.
- Asia already accounts for more than half the global air-conditioning market, and China alone for 70% of production.
- Global warming will further stoke demand.

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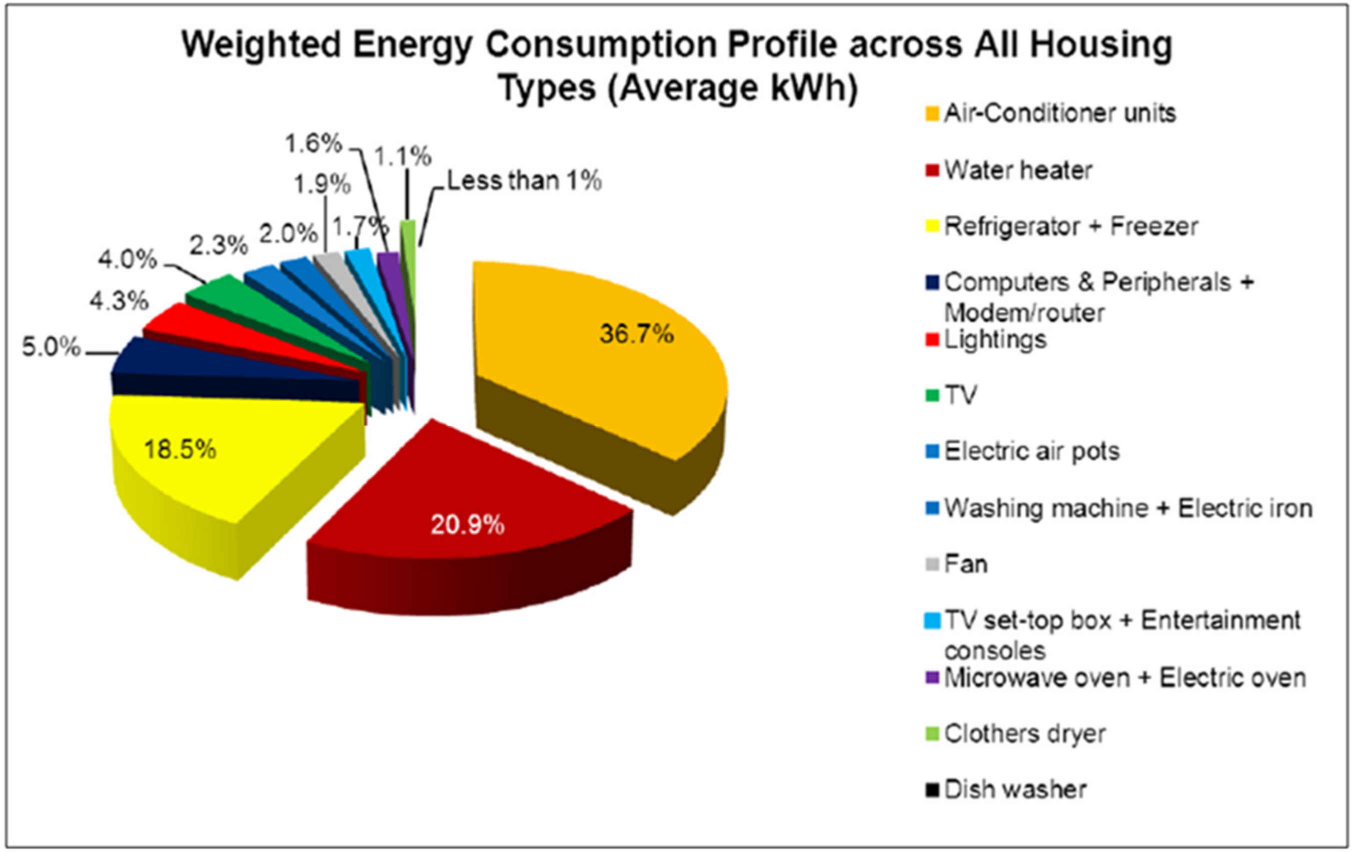
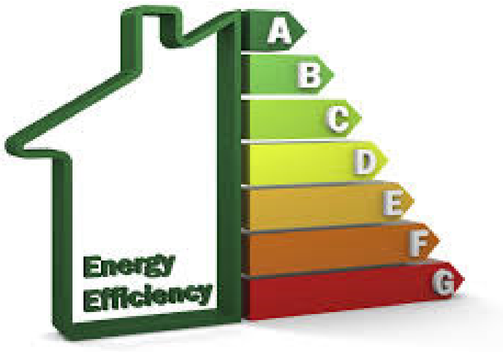
Energy Consumption Profile



Source: Household consumption Survey 2012
National Environment Agency Singapore



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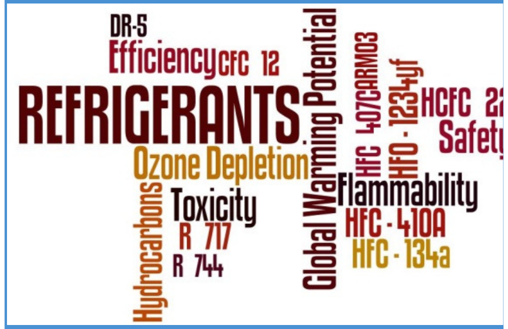
Invasion of Air Conditioners



More Air Conditioners than Citizens

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ENERGY EFFICIENCY

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Green Buildings

- Proper ventilation for healthy indoor air and reducing energy costs are the most important "green" factors (from list provided) in considering a new home to buy

Most Important 60%+ rated "extremely important"	• Proper ventilation: **63%** • Reducing energy costs: **61%**
Some Importance 40%-60% rated "extremely important"	• High insulation levels: **53%** • Appliances use less electricity: **53%** • Appliances use less water: **43%**
Least Important <30% rated "extremely important"	• Construction uses least waste possible: **27%** • Eco-friendly materials used in construction: **22%** • Uses solar energy: **17%** • Home is close to public transportation: **14%** • Uses wind energy: **11%**

*Top importance ratings shown.

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Convective vs. Radiant

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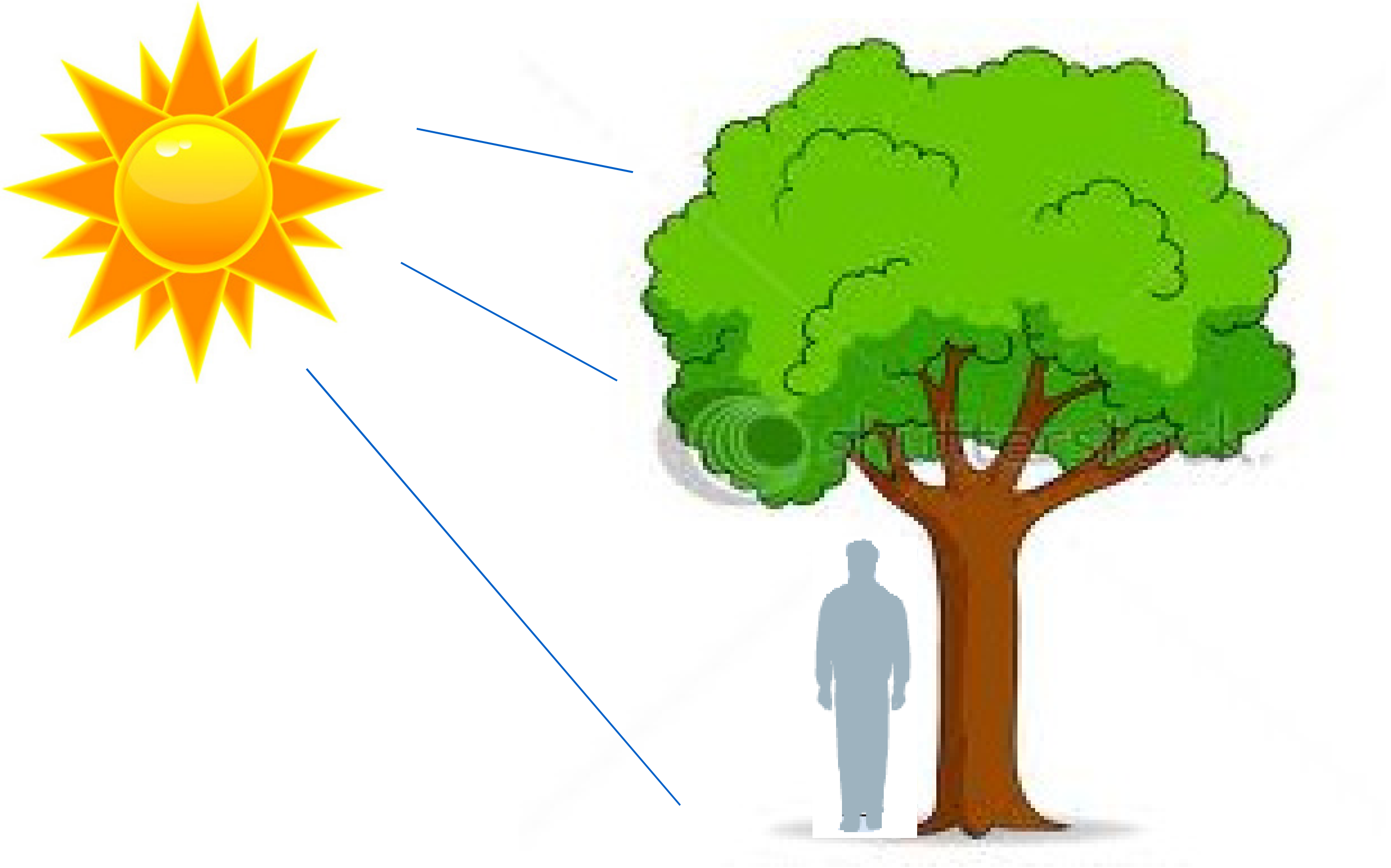
"Radiant energy does not heat the air, it heats objects."



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Radiant Energy

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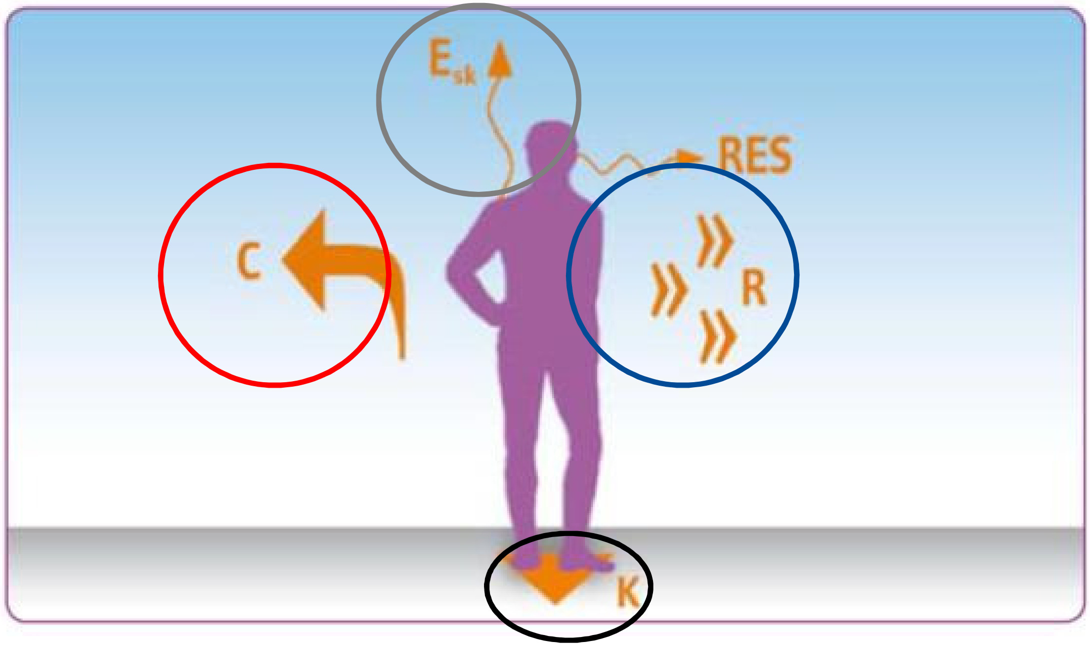
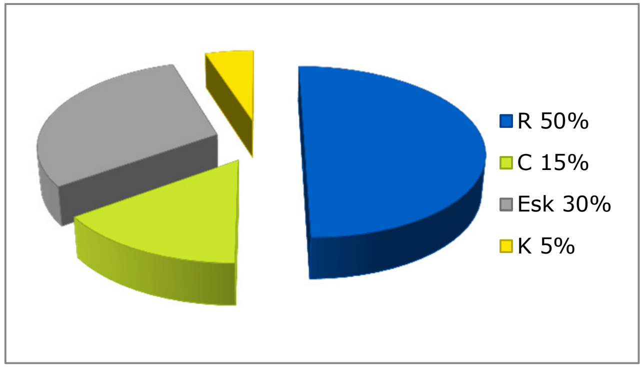
Modes of Heat Transfer from the Human Body





Heat transfer	Radiant cooling	Conventional HVAC
Radiation	65%	5%
Convection	35%	95%

$S=M-W-R-C-K-E_{sk}-RES$

where:

S: internal heat variation

M: metabolic rate

W: external work

R: radiant heat transfer

C: convective heat transfer

K: conductive heat transfer

E_{sk}: evaporation

RES: respiration

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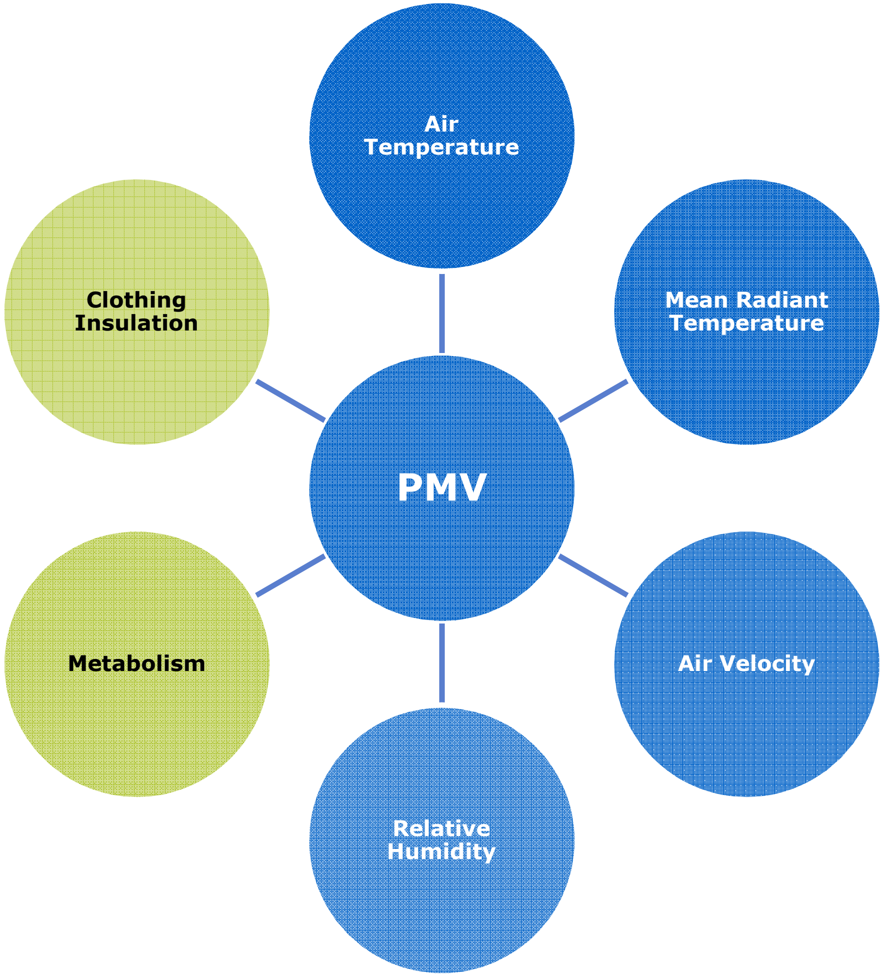
Thermal Comfort According to ISO 7730



PMV – Predicted mean vote

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale, based on the hear balance of human body.

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

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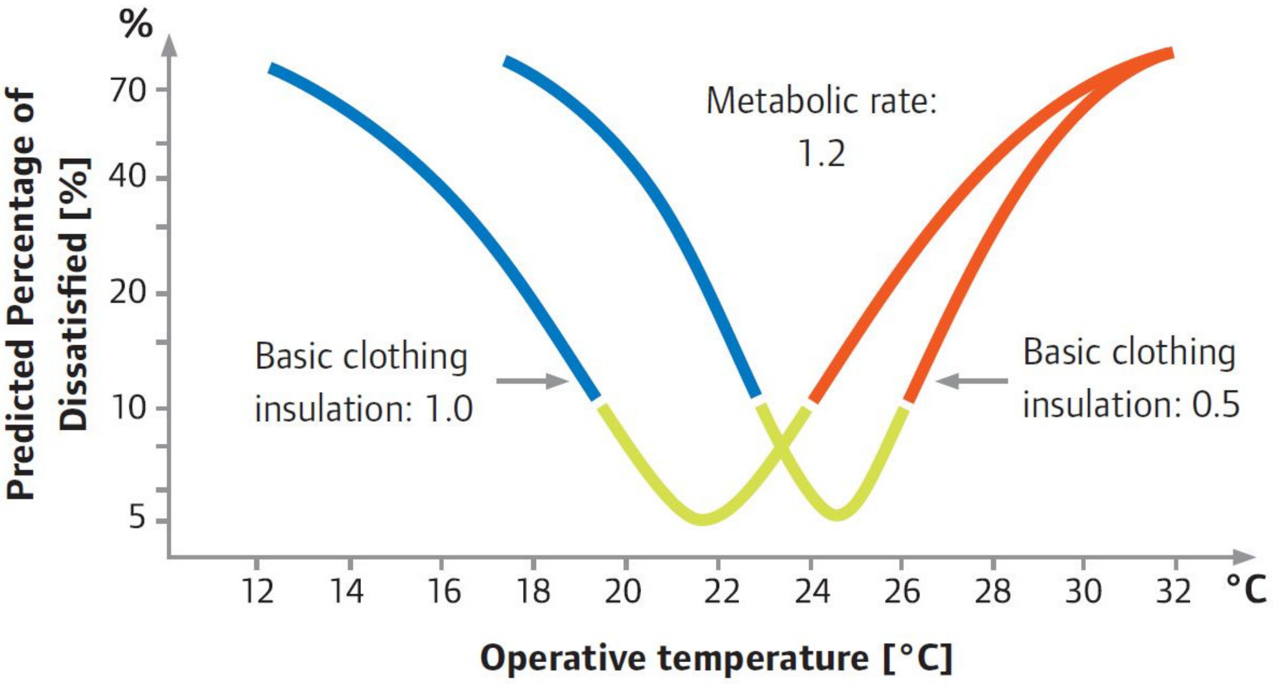
Thermal Comfort According ISO 7730



Target Temperature

- Winter - 22 ℃
- Summer - 24.5 °C

PPD – Predicted percentage dissatisfied

The PPD is an index that established a quantitative prediction of the percentage of thermally dissatisfied people who fell too cool or too warm.

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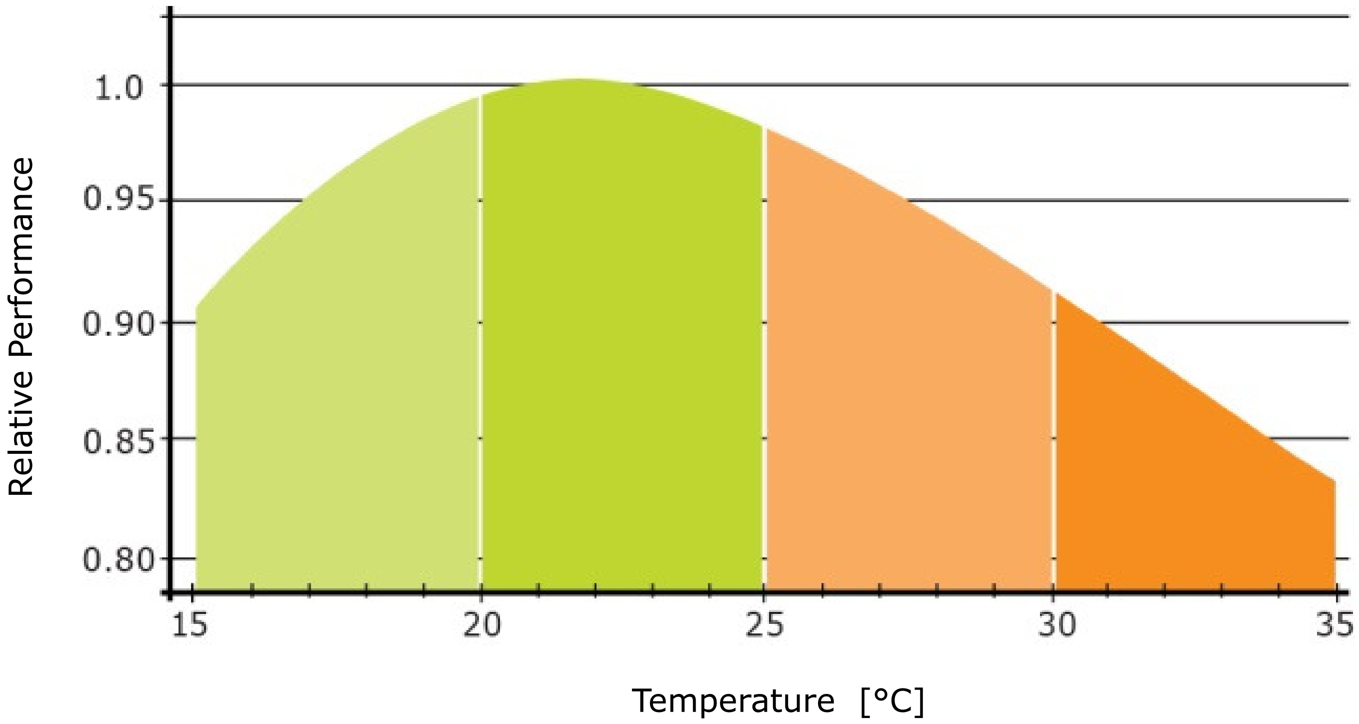
Work Productivity



Low quality and deteriorated thermal comfort due to inappropriate conditioning systems means that initially saved investment costs (or selection of a wrong HVAC concept) will quickly be outweighed through illness-related absence and low staff productivity.

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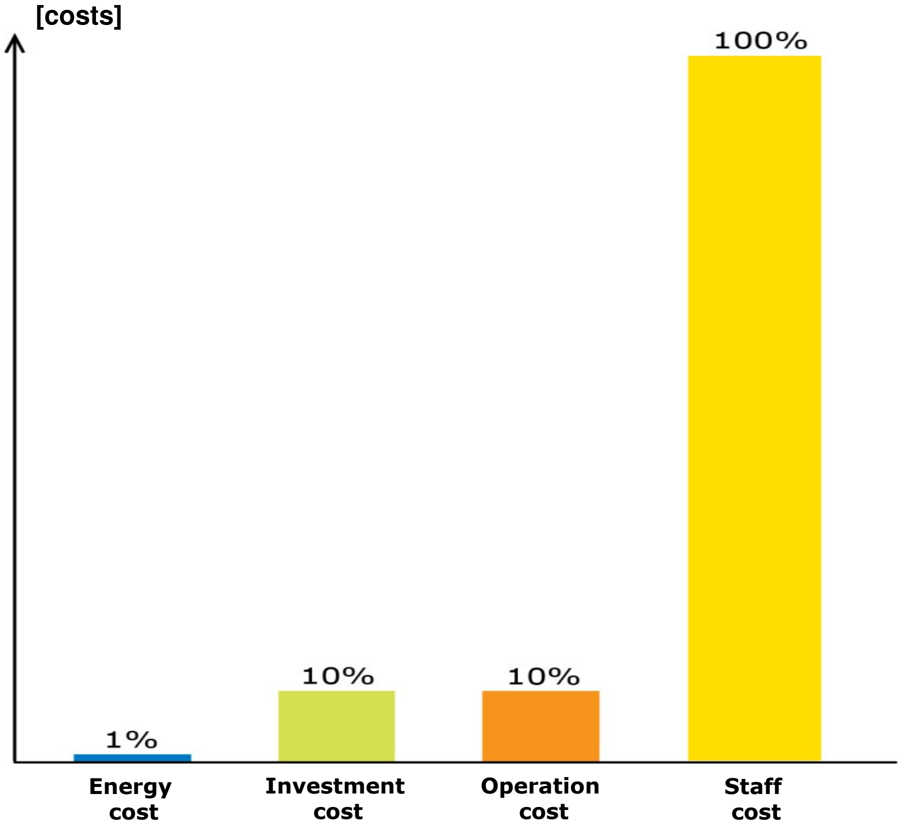
Cost Model - Office Building

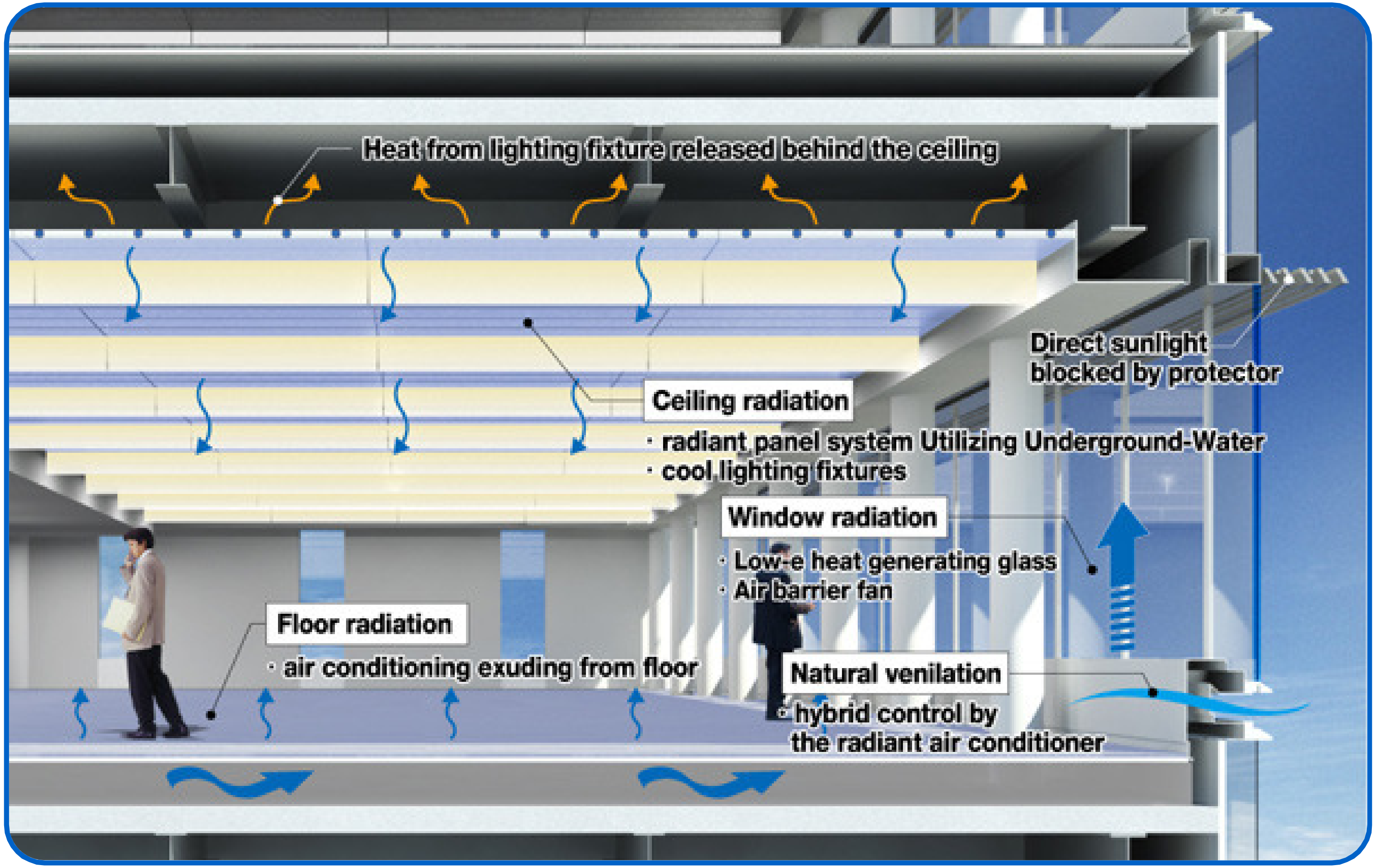


- Relationship between energy, investment, running and staff costs for office buildings during its life cycle
- Any deterioration in the quality of the indoor climate due to energy saving measures has a negative impact on the performance of the occupants and therefore reduces the overall efficiency

“Moreover, the cost-benefit simulation made by Djukanovic et al. (2002) showed that the annual increase in productivity was worth at least 10 times as much as the increase in annual energy and maintenance costs, when improving the perceived air quality in office buildings, specifying a pay-back time of no more than 4 months due to the productivity gains achieved.”

[Djukanovic, R., Wargocki, P., Fanger, P.O. (2002) ‘Cost-benefit analysis of improved air quality in an office building’. In: Proceedings of Indoor Air 2002, Monterey, The 9th International Conference on Indoor Air Quality and Climate, Vol. 1, pp. 808-813]

Radiant Concepts



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Principle of Radiant Cooling and Heating:

Heating:

Human body absorbs radiation from ceiling

Cooling:

Ceiling absorbs radiation from human body

Radiant heating and cooling system refer to temperature-controlled surfaces that exchange heat with their surrounding environment through convection and radiation.

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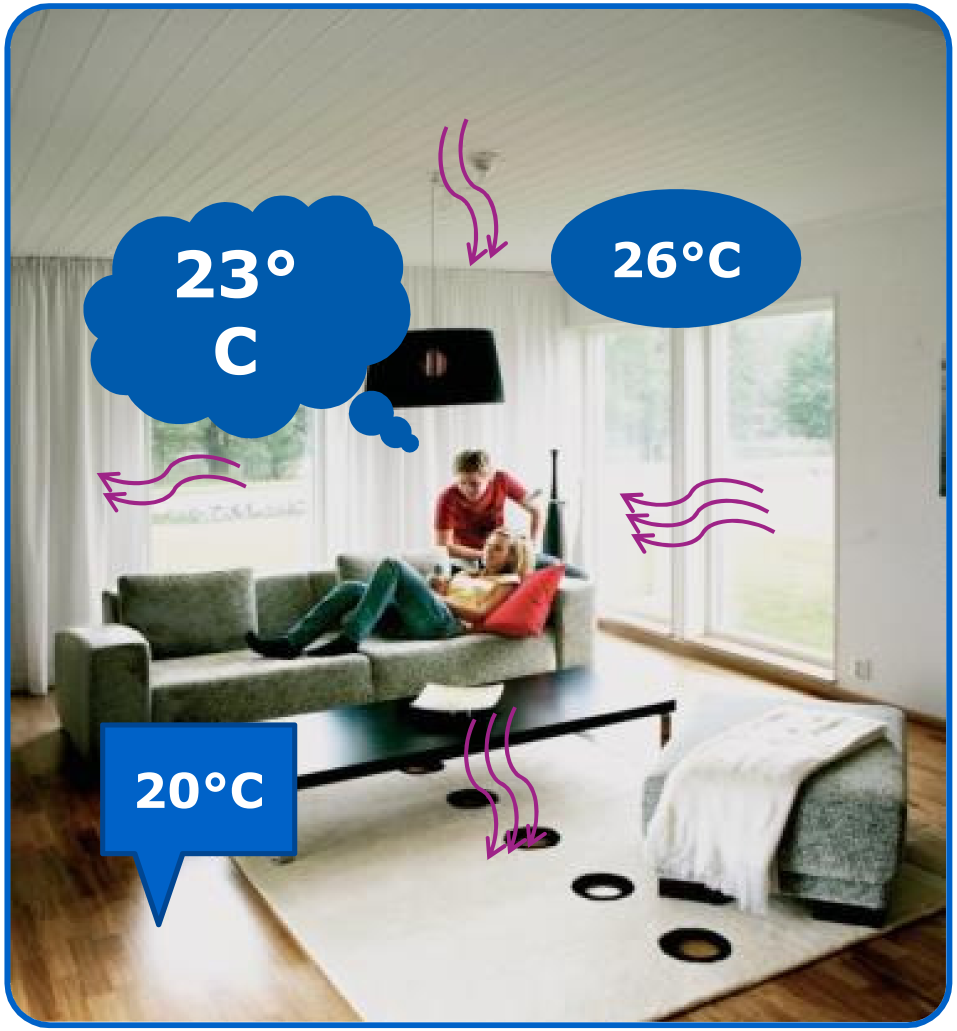
Basic Knowledge of Radiant H&C

Operative Temperature



Air temperature: 26°C

Radiant Temperature: 20°C

Operative temperature: 23°C

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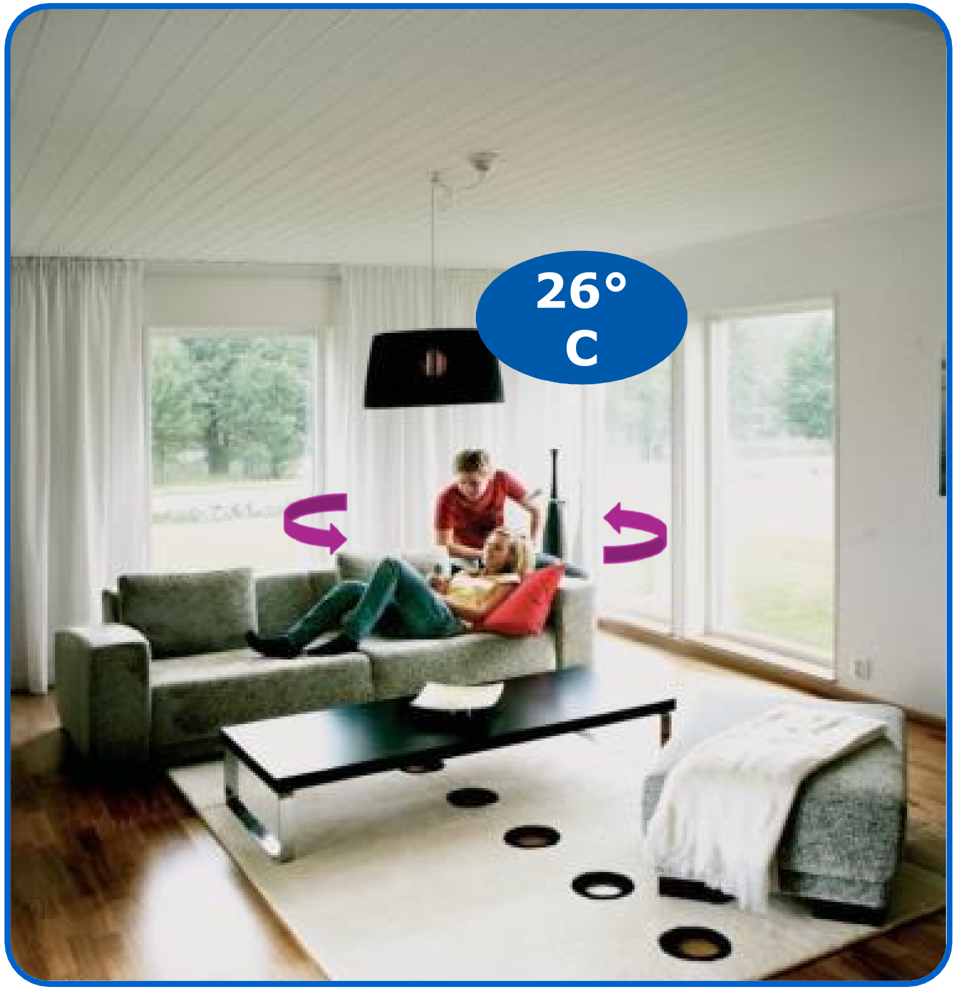
Basic Knowledge of Radiant H&C

Heat Exchange by Convection



Human body exchanges energy by convection with the air in contact with the skin.

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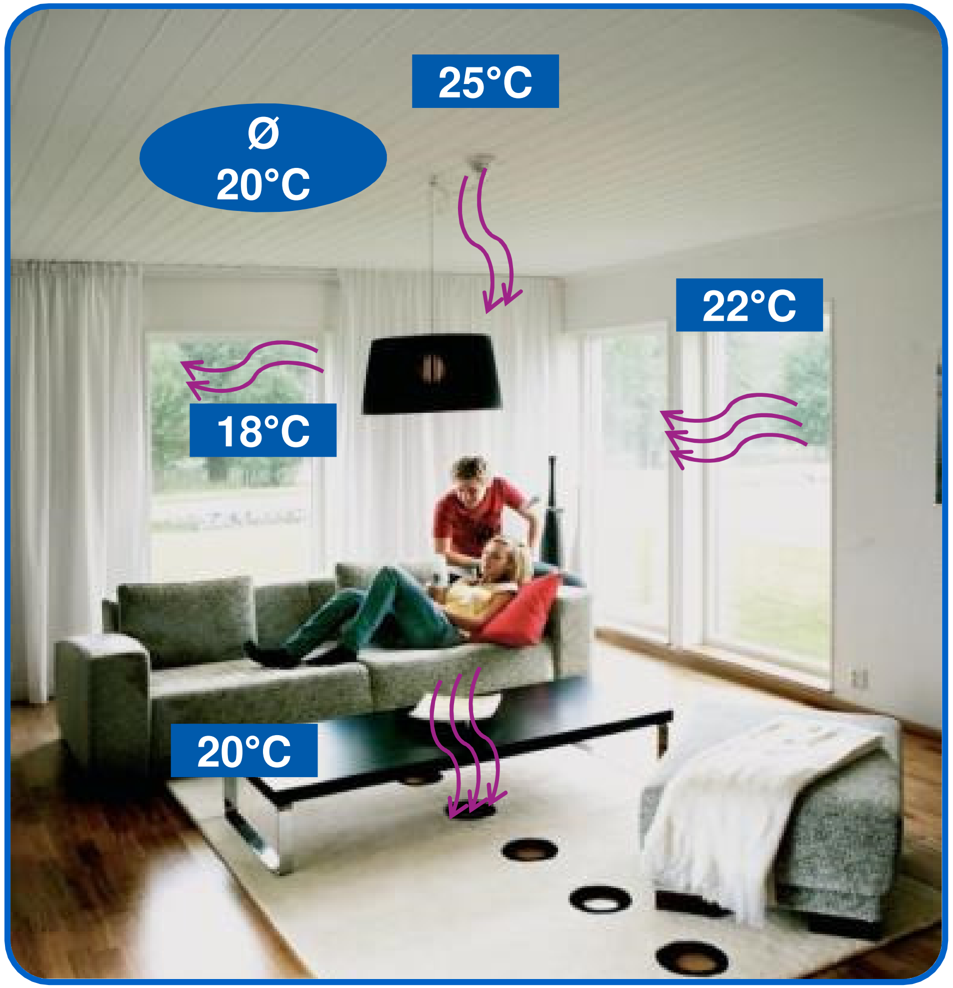
Basic Knowledge of Radiant H&C

Heat Exchange by Radiation



Human body exchanges energy by radiation with all surrounding surfaces.

The average radiation temperature we feel depends on the temperature of the surfaces and how close we to them.

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Basic Knowledge of Radiant H&C

Thermal Comfort VS. Temperature

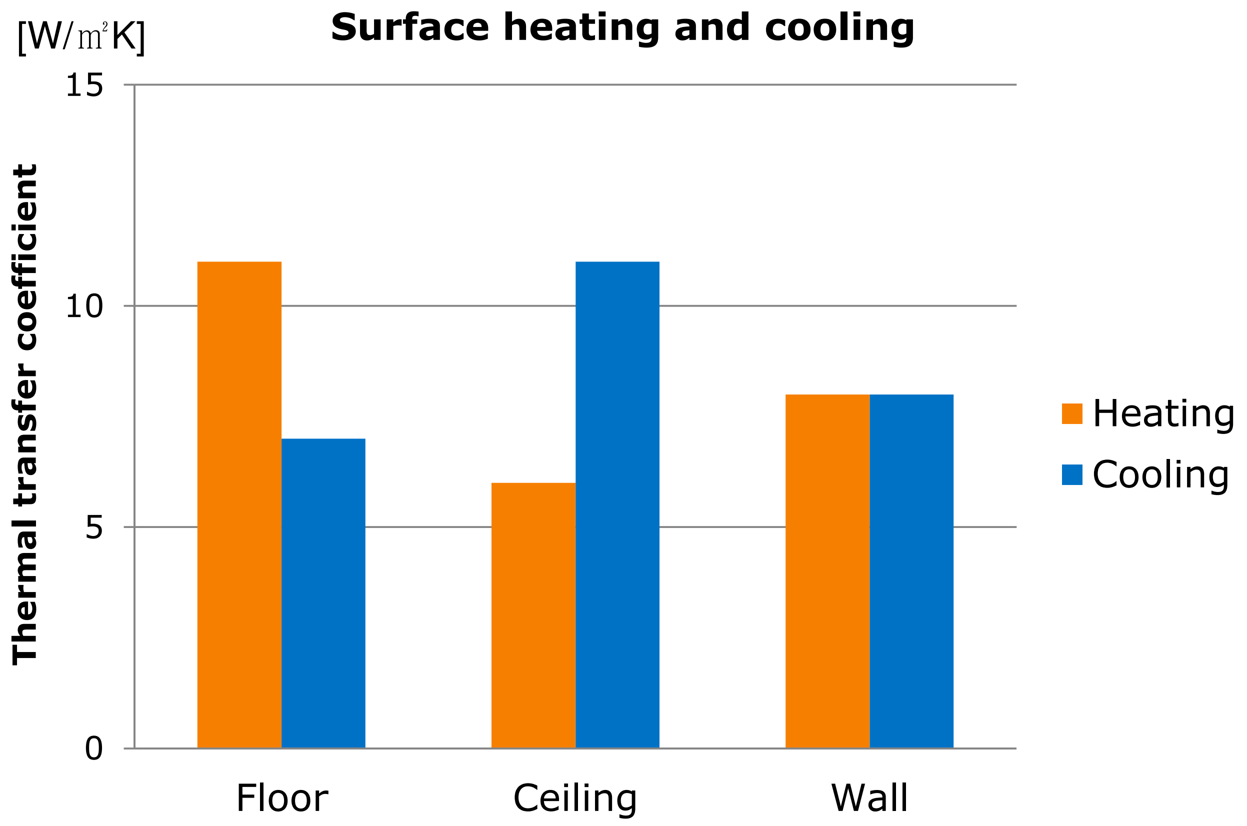
- cool air + warm surfaces

=

- warm air + cool surfaces

Building a sustainable future together…

Thermal Transfer Coefficient



Due to natural convection, the floor provides the best thermal transfer coefficient for heating while the ceiling provides the best thermal transfer coefficient for cooling.

Thermal transfer coefficient is an expression of how large an effect per m² the surface is able to transfer to the room, per degree of the temperature difference between the surface and the room. The figure below shows the thermal transfer coefficient for different surfaces for heating and cooling respectively.

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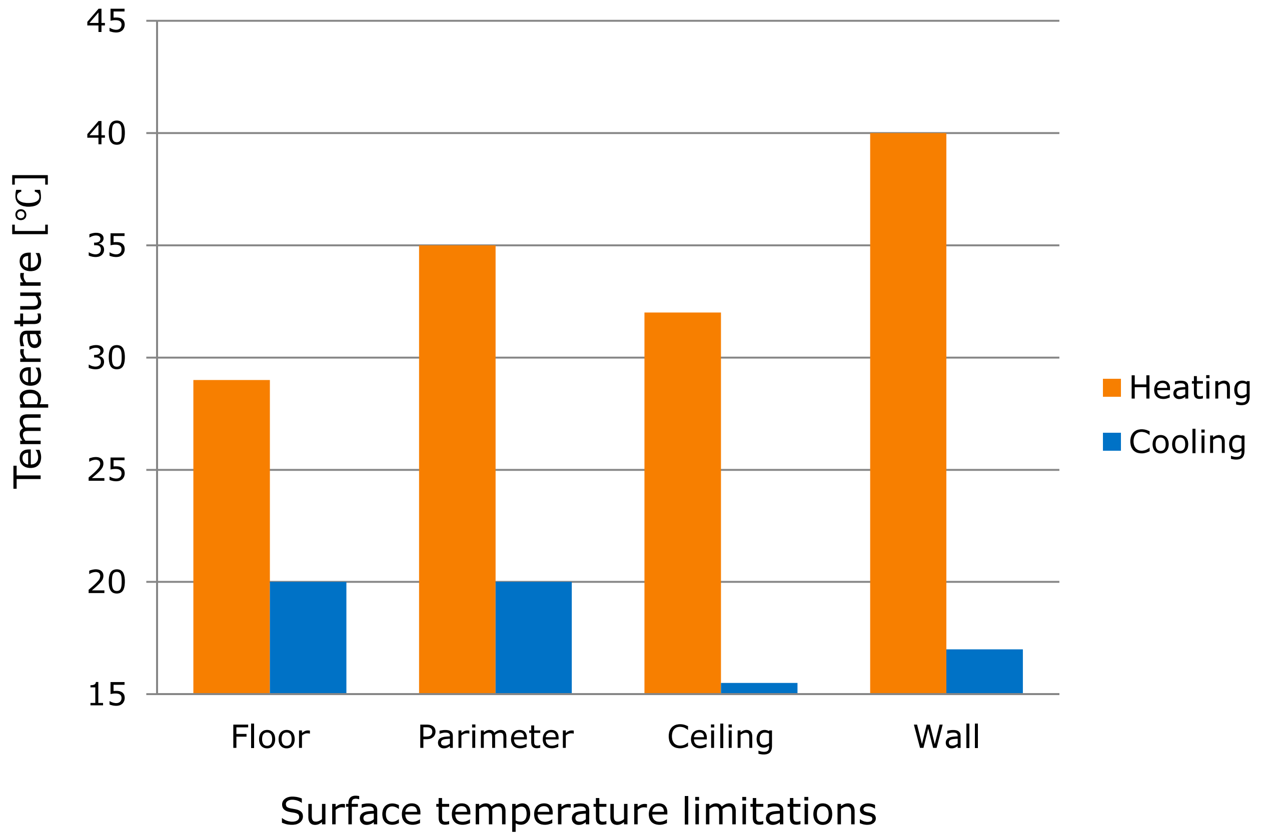
Surface Temperature Limitation



Taking both ISO 7730 (surface temperatures, radiant asymmetry, and down draught) and the dew point imitations into account, the following surface temperature limitations exist.

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Capacity Calculation

Floor heating, ceiling cooling: $q = 8.92\,(\theta_{s,m} - \theta_i)^{1.1}$

Wall heating, wall cooling: $q = 8\,(|\,\theta_{s,m} - \theta_i\,|)$

Ceiling heating: $q = 6\,(|\,\theta_{s,m} - \theta_i\,|)$

Floor cooling: $q = 7\,(|\,\theta_{s,m} - \theta_i\,|)$

Where

q is the heat flux density in W/m²

$\theta_{s,m}$ is the average surface temperature (always limited by dew point)

θ_i is the room design temperature (operative)

With these surface temperature limitations in mind, the maximum capacities of different radiant emitter systems can be calculated.

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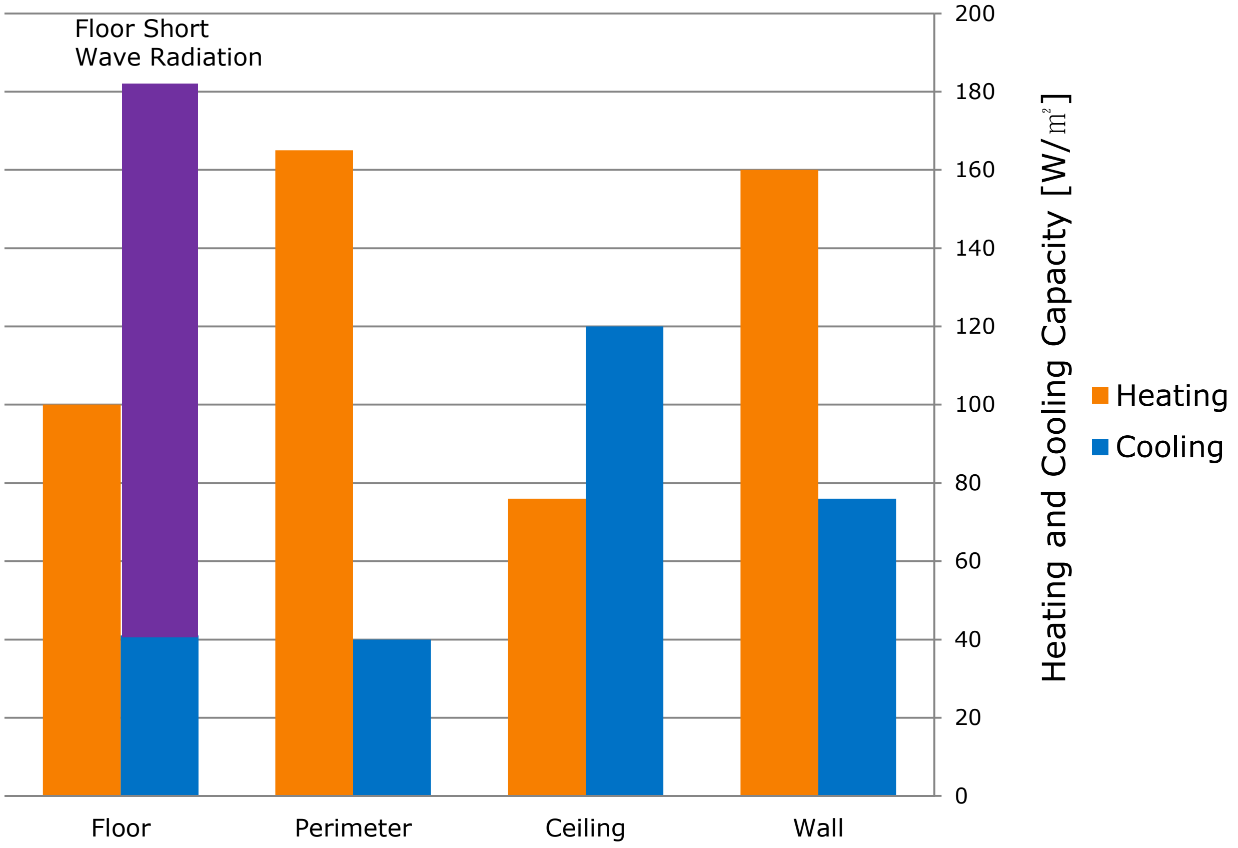
Heating and Cooling Capacity



- In theory, the highest heating capacity can be achieved from the wall.
- The biggest capacity can be achieved by heating from the floor, and cooling from the ceiling.
- In practice, either a floor system or a ceiling system is installed and used for both heating and cooling

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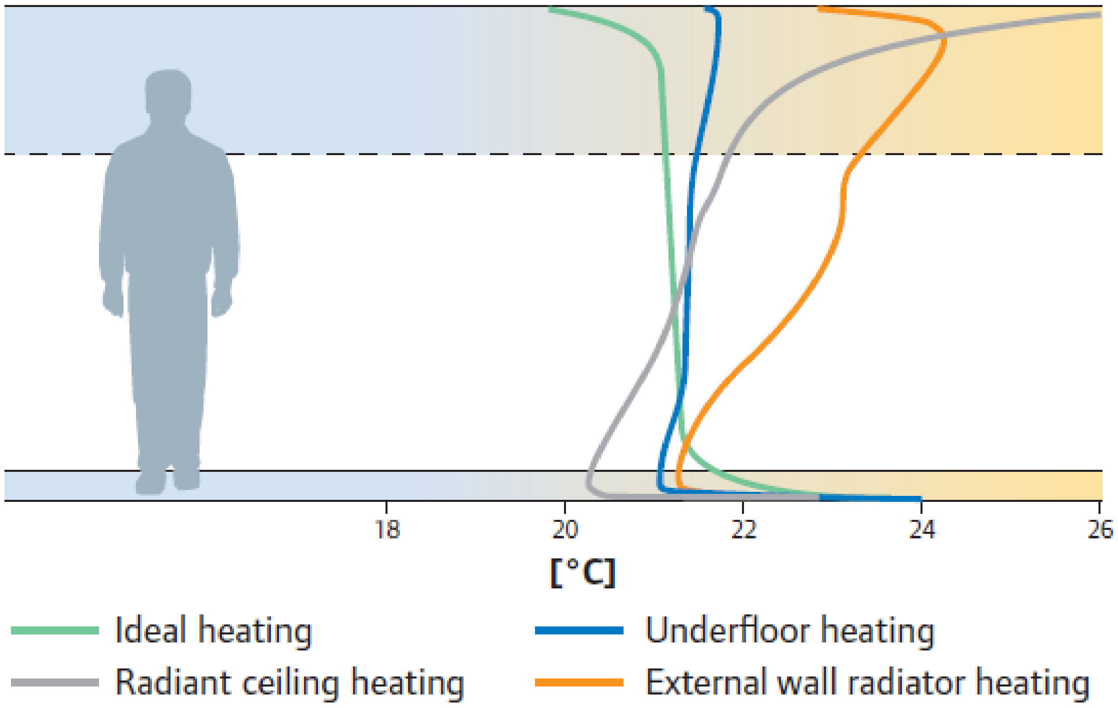
Thermal Comfort

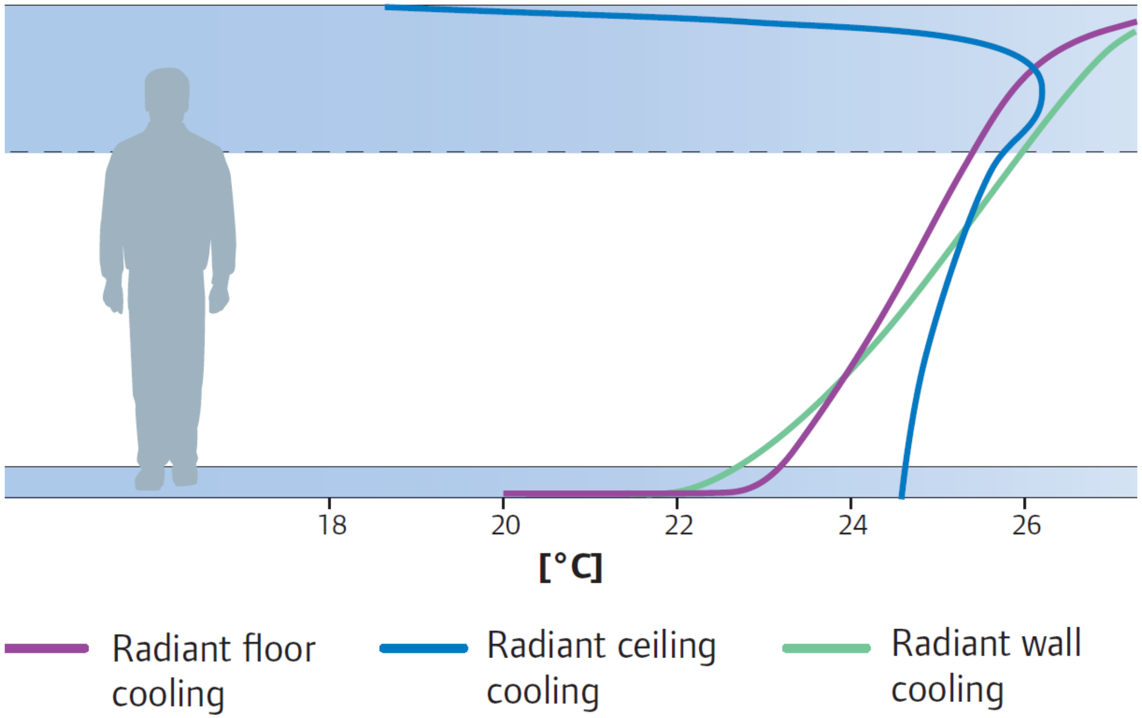
Heating Mode



- People feel most comfortable with their feet a little warmer than their heads
- Underfloor heating is the heating method that comes closet to producing an ideal room temperature distribution.

Thermal Comfort

Cooling Mode



- Cooling from the floor will only condition the area where people moving
- The cold surface of the floor cooling systems provides stratifaction of air
- Shortwave radiation absorption of direct solar radiation

Building a sustainable future together…

Comfortable Indoor Environment

Objectionable Zero Airflow

Radiant system

Air Cooling/Heating System

Radiant systems are low convective systems and will not create any problems with draught.

Building a sustainable future together...

Comfortable Indoor Environment

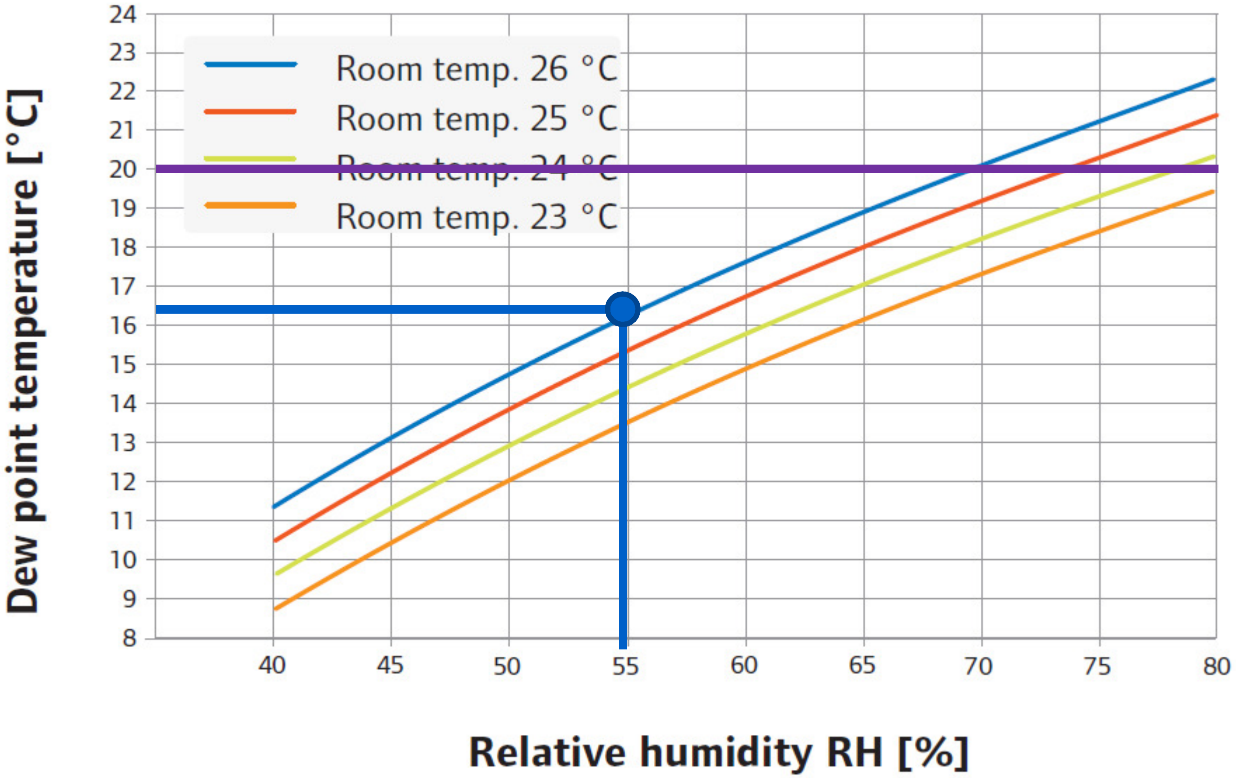
Hygienic Aspect Condensation

A/C has low outlet air temperature.

This can occur condensation around the outlets (for room temperature 26°C and humidity 55% the condensation temperature is ~15°C).

With radiant cooling the surface temperature is kept above the condensation temperature (floor temperature ~20°C, ceiling temperature ~18-19°C).

Preventing of Condensation



In order to secure that there is no condensation on the surface of the emitter in the room the supply water temperature should be controlled so that the surface temperatures of the emitter always is above dew point.

In the diagram, the dew point temperatures can be found under different levels of relative humidity (RH).

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Comfortable Indoor Environment

Indoor Air Quality

No Germ

No Mold

No Dust

Radiant System

Germ

Mold

Dust

Conventional System

Comfortable Indoor Environment

Quiet Indoor Environment

✓ Less than 30 dB

✗ Above 45 dB

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Volume Saving

✓

✗

A ø 20 mm pipe can transfer as much energy as a 1000 cm² air duct.

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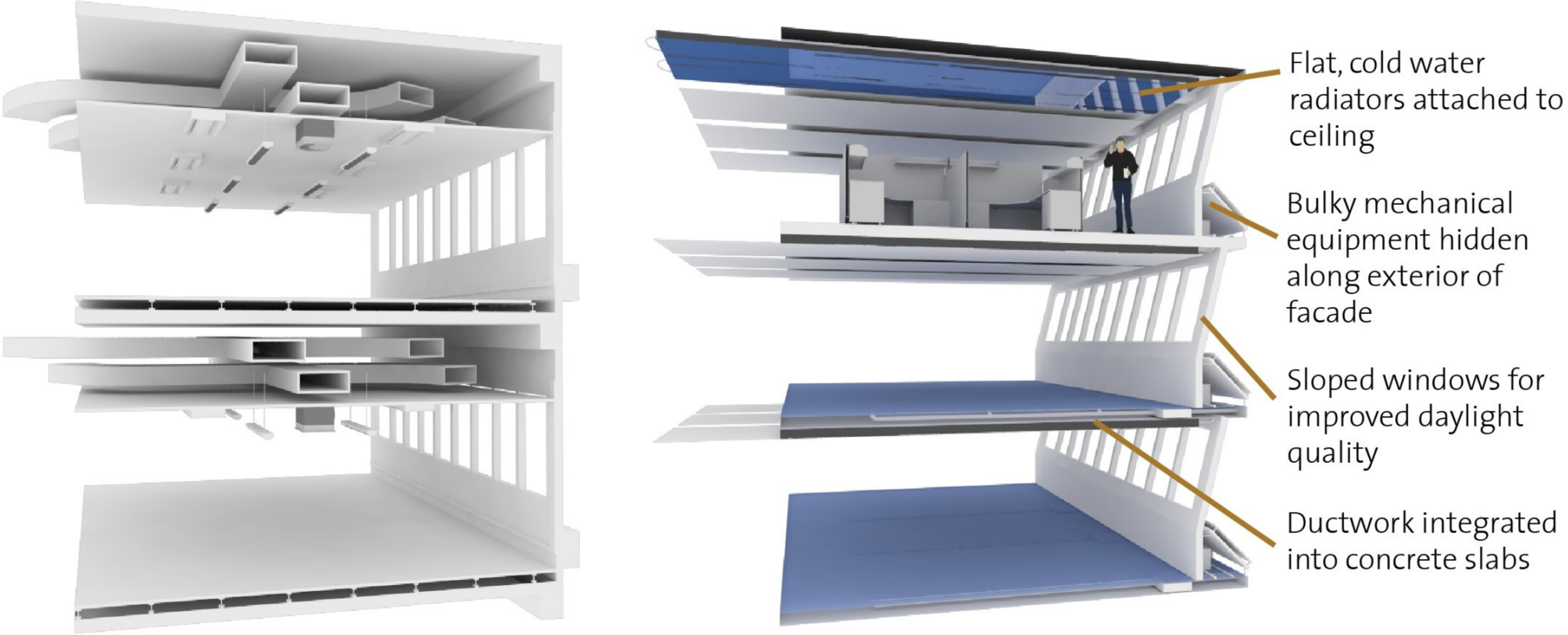
Building Height Saving



Conventional building

‘3for2’ building

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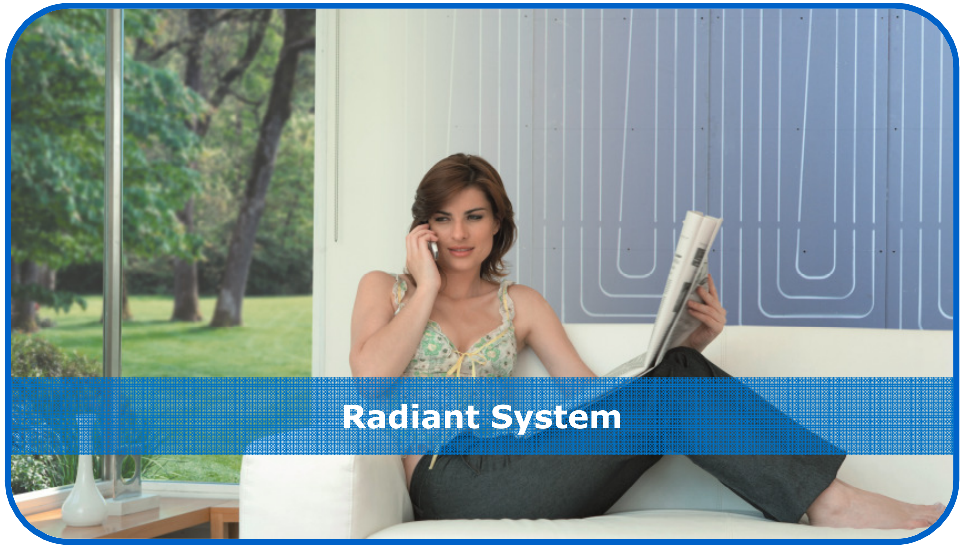
Architectural Efficiency

✓



Radiant System

✗

Conventional System

- There is more usable floor and wall space, and there are no ugly heating grilles or bulky radiators to detract from the appearance of the room.
- Uponor Radiant systems are ideal for advanced interior design.

Building a sustainable future together...

Maintenance Free

✗ **An A/C system has to be maintained**

- Fans
- Filters
- Outlets
- Ducts…

✓ **A radiant cooling system works practically maintenance free as the pipes are embedded in concrete and the water runs in a closed system**

Building a sustainable future together…

Energy Saving

Source

The Uponor radiant system is adaptable to a variety of energy sources: geothermal, wood, gas, oil, electricity or solar power.

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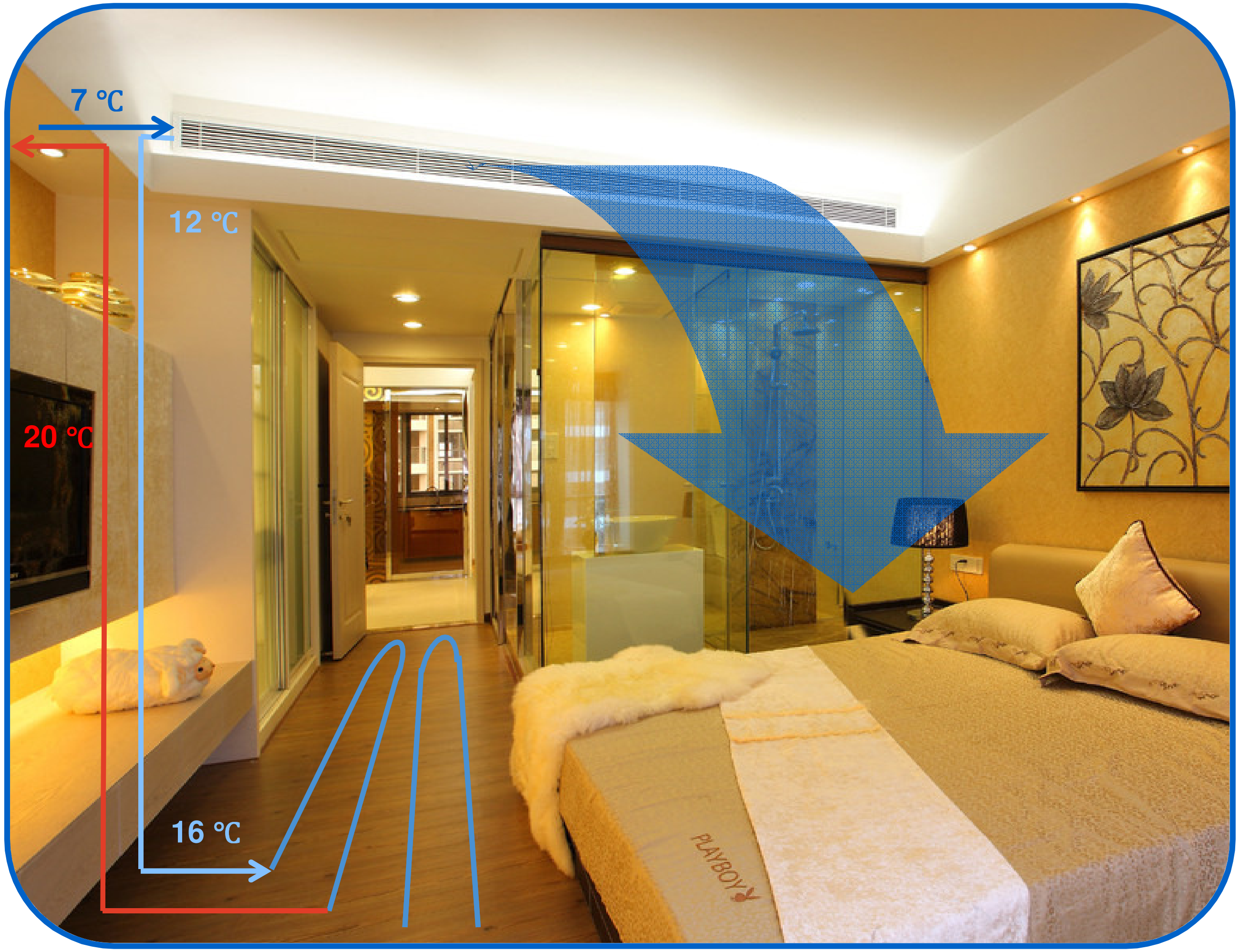
Energy Saving

Reducing AC Size

- **Conventional air-conditioning (AC with AHU/FCUs)**

Energy Saving

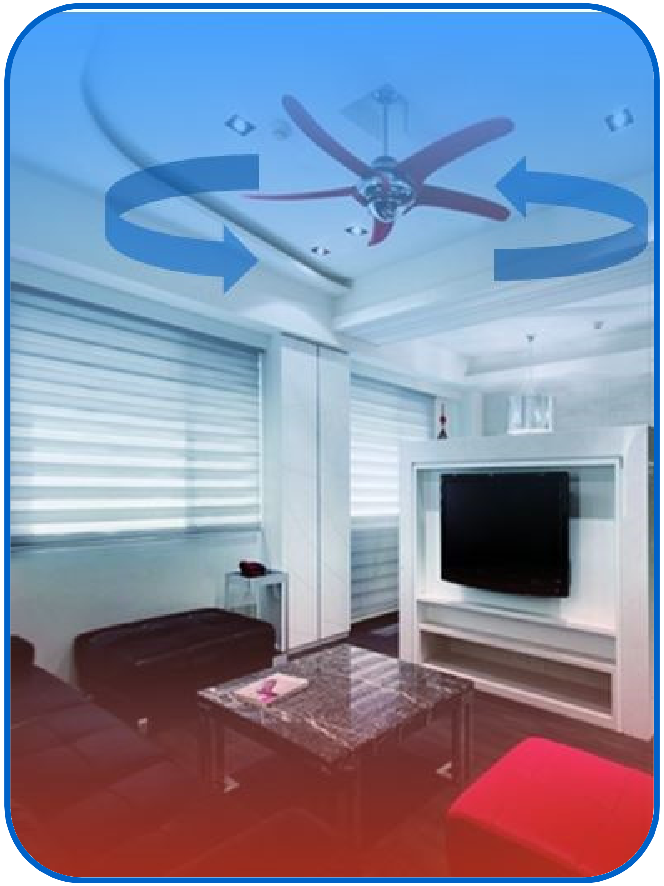
Reducing AC Size

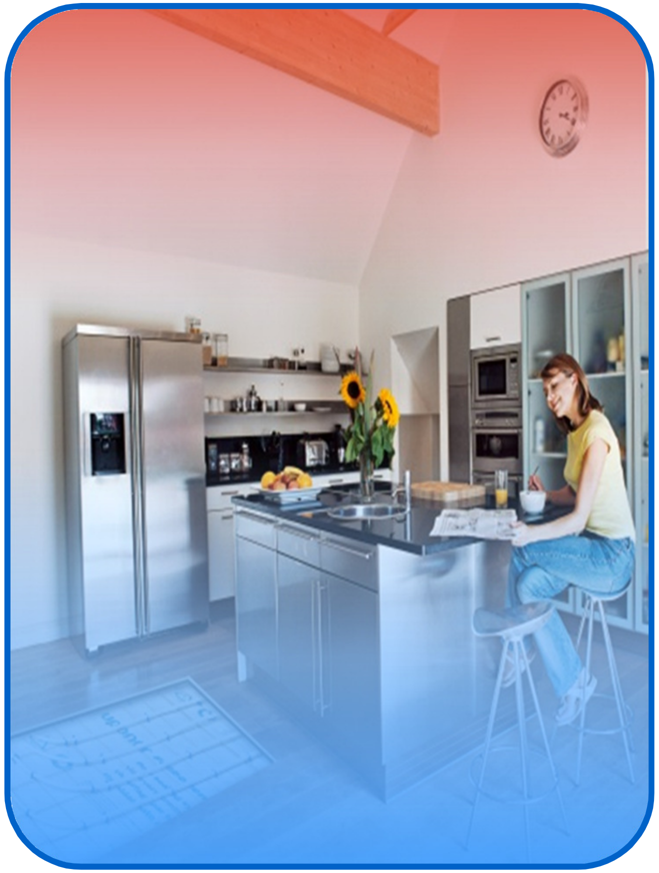


- **Additional installation of a radiant underfloor cooling system (AC+UFC)**
- **Downgrading of ducts and FCUs due to the reduced air-flow rate**

Energy Saving

High Ceiling





An A/C system changes all air volume in a room. For people it is important to create a comfort temperature in a zone up to ~ 2.5 m above the floor.

With a floor cooling system this can be realized without high air change rates.

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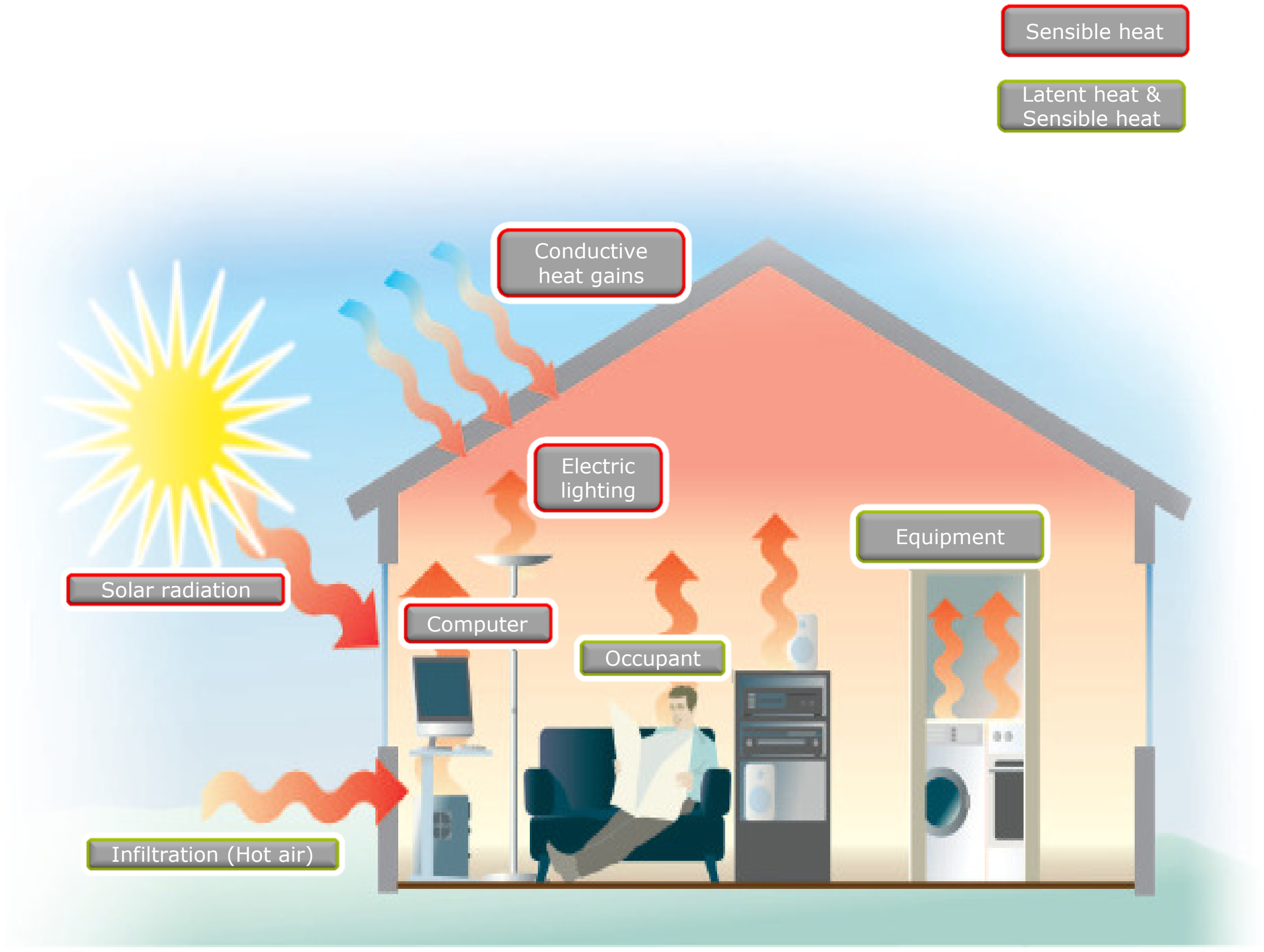
Cooling Load



Factors influencing the sensible cooling load

- Windows or doors
- Direct and indirect sunshine through windows, skylights or glass doors heating up the room
- Exterior walls
- Partitions (that separate spaces of different temperatures)
- Ceilings under an attic
- Roofs
- Floors over an open crawl space
- Air infiltration through cracks in the building, doors, and windows
- People in the building
- Equipment and appliances operated in the summer
- Lights

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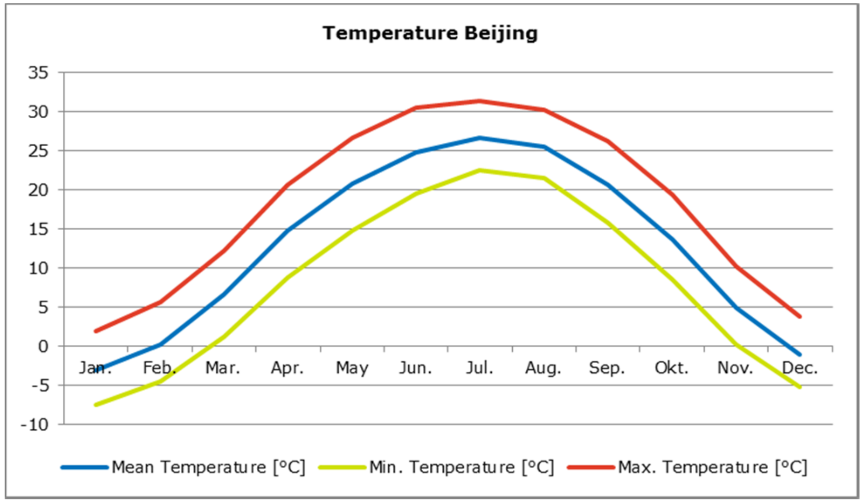
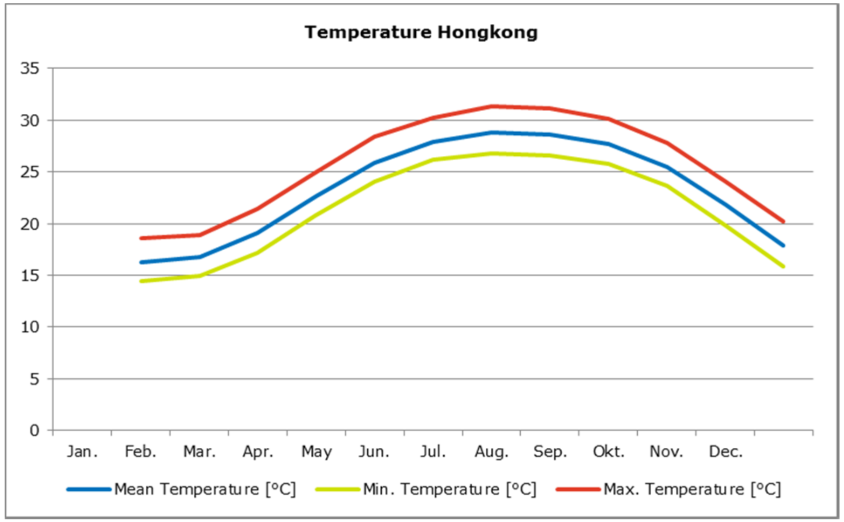
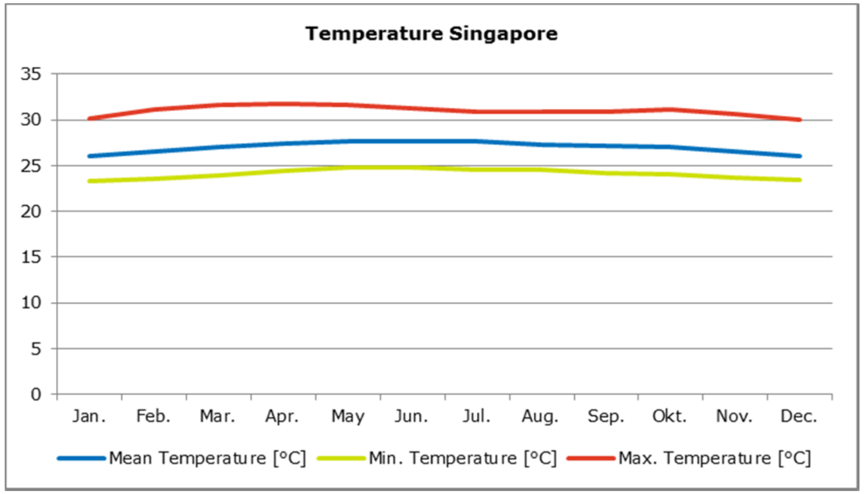
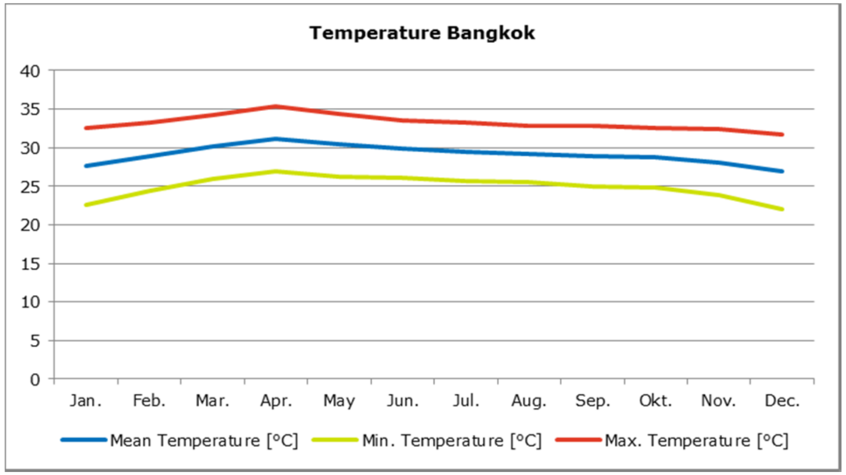
Seasonal Cooling & Heating


Temperature Beijing


Temperature Hongkong


Temperature Singapore


Temperature Bangkok

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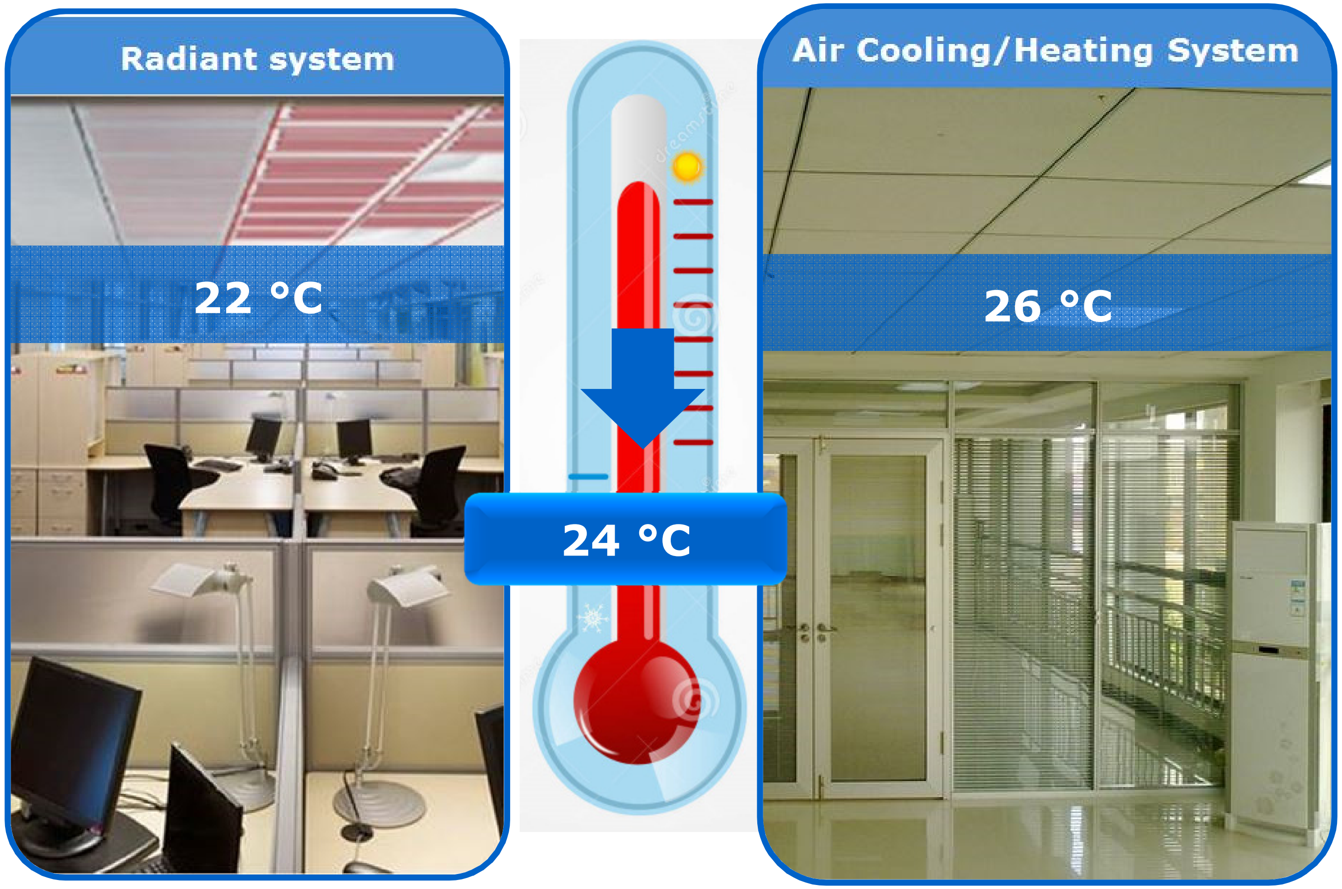
Energy Saving

Temperature Setting



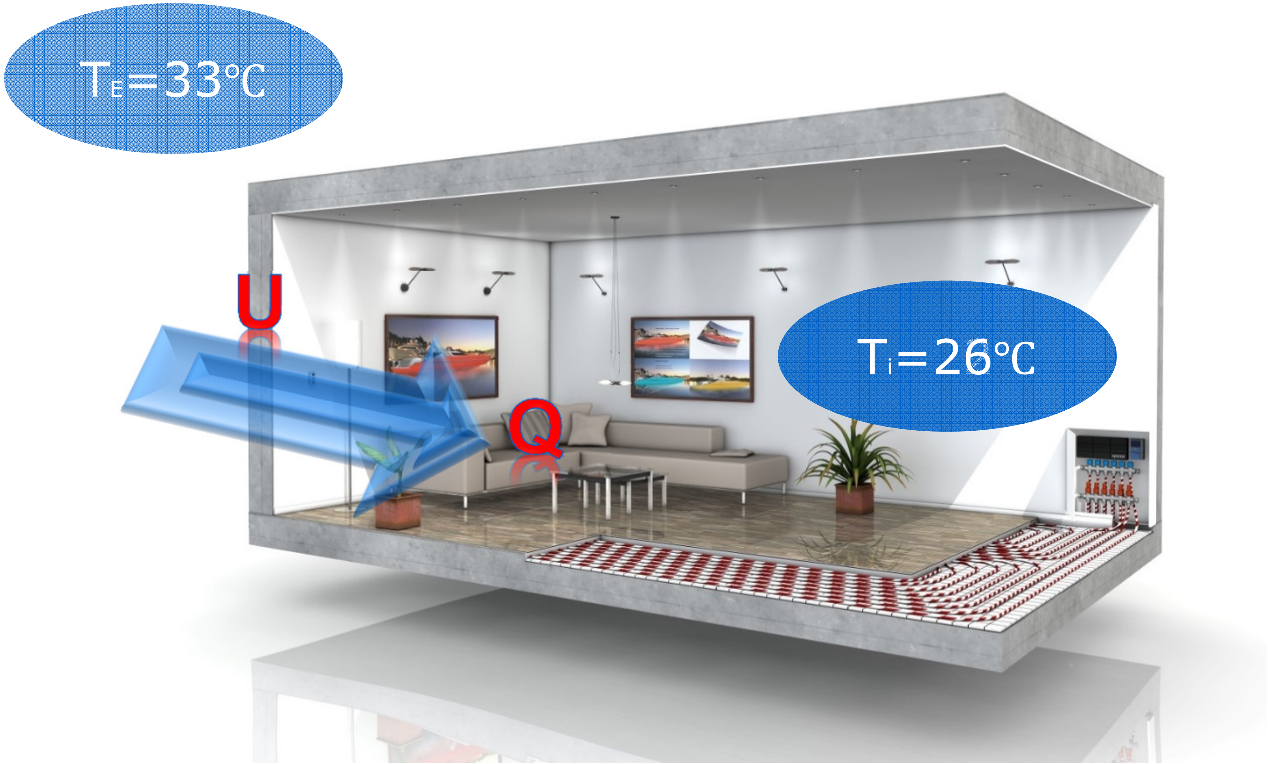
Energy saving due to lower setting temperature

heating: 6~7%; cooling: 8~10%

- **Temperature set point 1~2 °C lower compared to existing forced convection.**
- **Lower heating set points & higher cooling set points result to same physical feeling.**

Energy Saving

Conductive Cooling Load



$$Q = U \times (T_E - T_i)$$

Reduced conductive cooling load by 36%

Energy Saving

Medium Capacity

1L of **water** can transfer the same amount of energy than **3.5 m³** of **air**, or a ¾ ″ pipe can transfer as much energy as a 14 ″ round duct.

To remove 1 kW sensible heat from a room an A/C ducting system needs ~ 35-45 times more electrical energy for fans than a radiant cooling system for circulation pump.

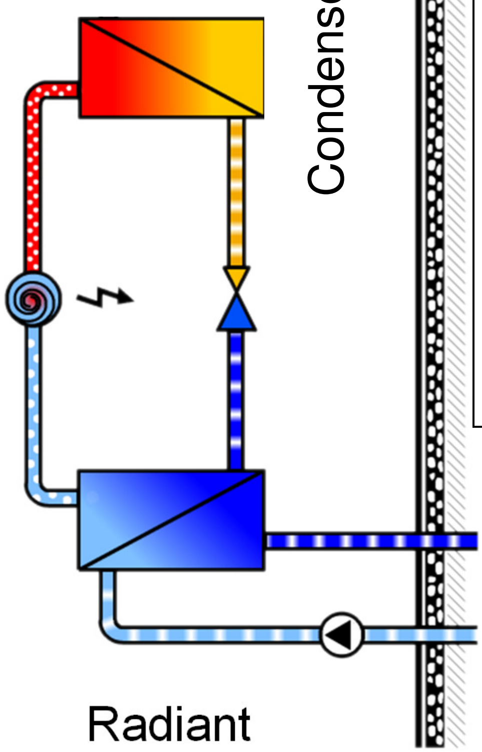
Radiant cooling can significant reduce the electricity consumption for cooling.

Building a sustainable future together...

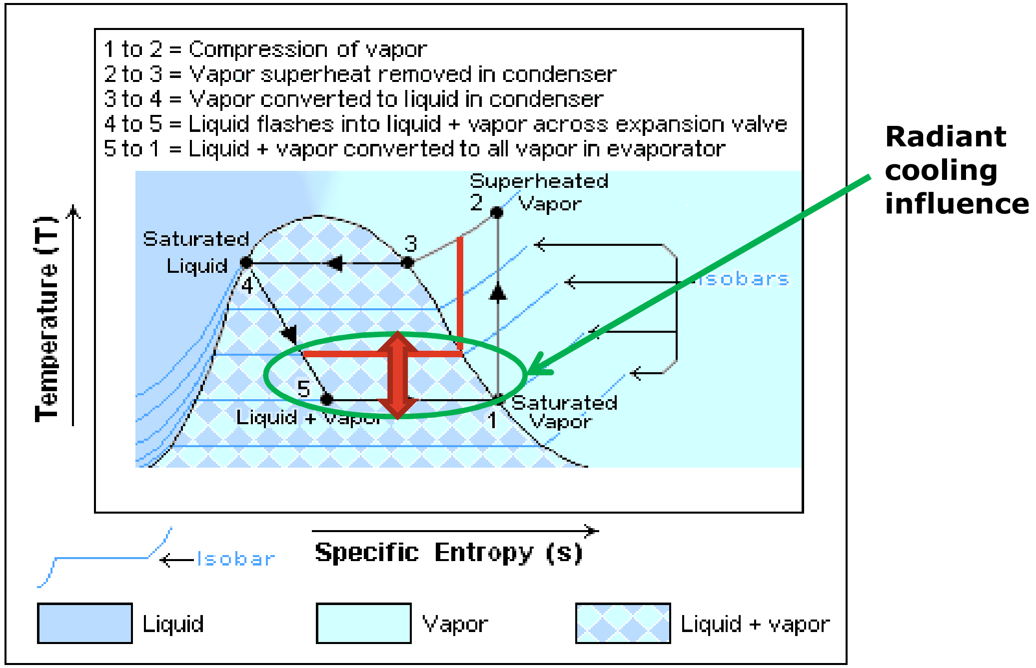
Compression Chiller

Compressor

Condenser



Radiant system



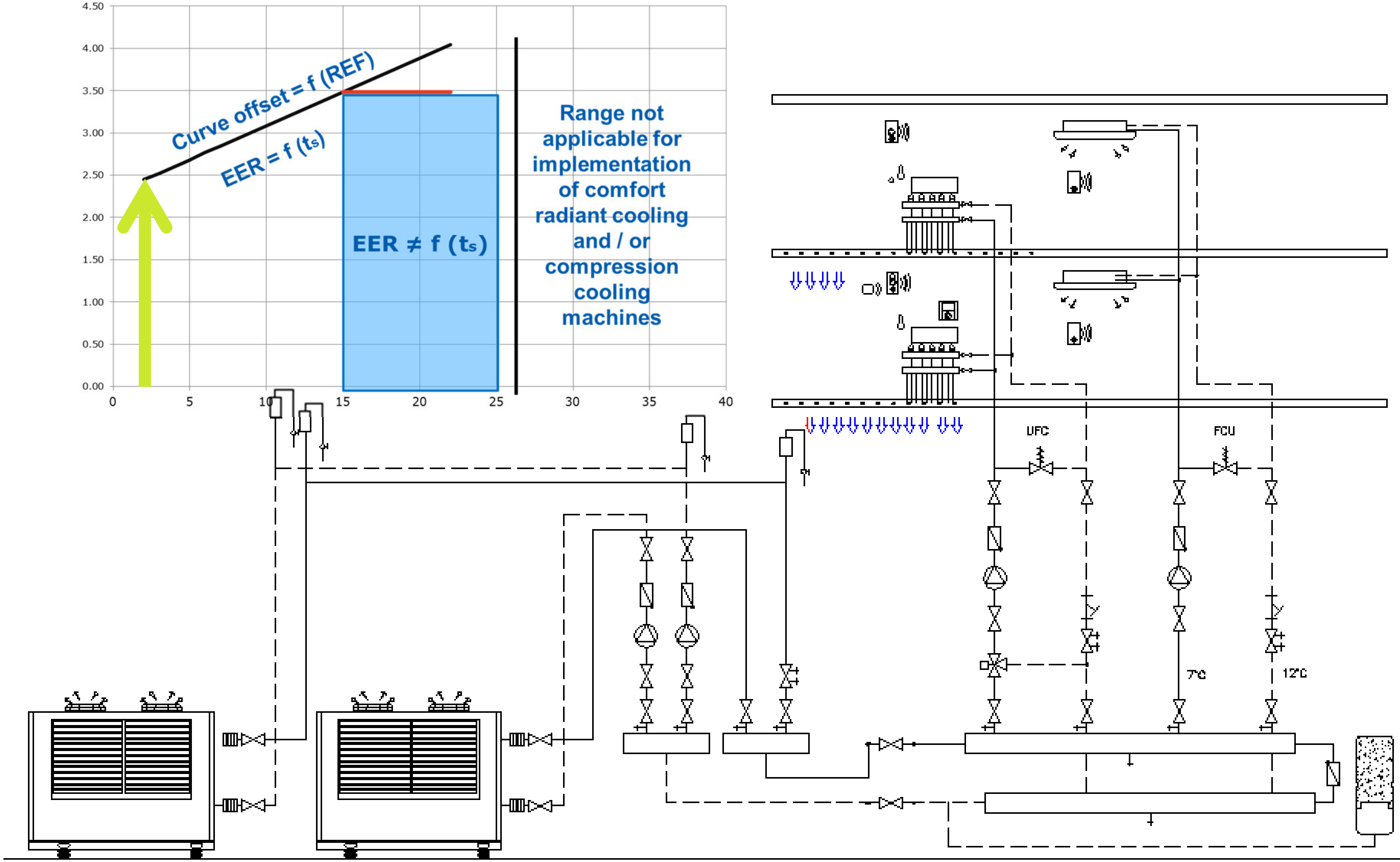
1 to 2 = Compression of vapor
2 to 3 = Vapor superheat removed in condenser
3 to 4 = Vapor converted to liquid in condenser
4 to 5 = Liquid flashes into liquid + vapor across expansion valve
5 to 1 = Liquid + vapor converted to all vapor in evaporator

*Wikipedia

Description	Unit
Return water temperature	°C
Temperature difference	°K
Water flow	m^3/h
Flow type	Constant ??

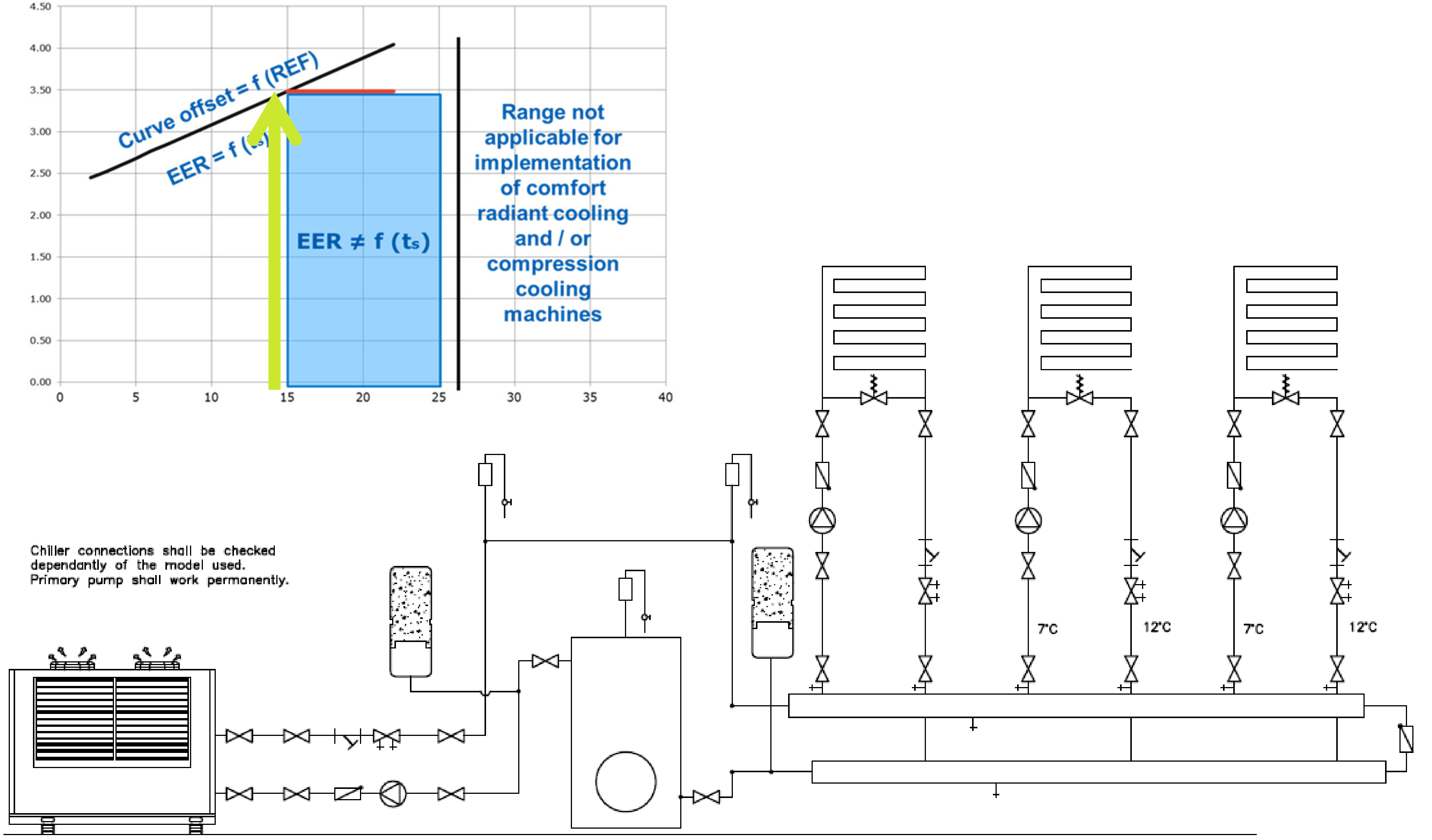
- Compressor Copeland, Evaporator Danfoss, Condenser Güntner

Common source together
FCU (DOAS) & Radiant system



Range not applicable for implementation of comfort radiant cooling and / or compression cooling machines

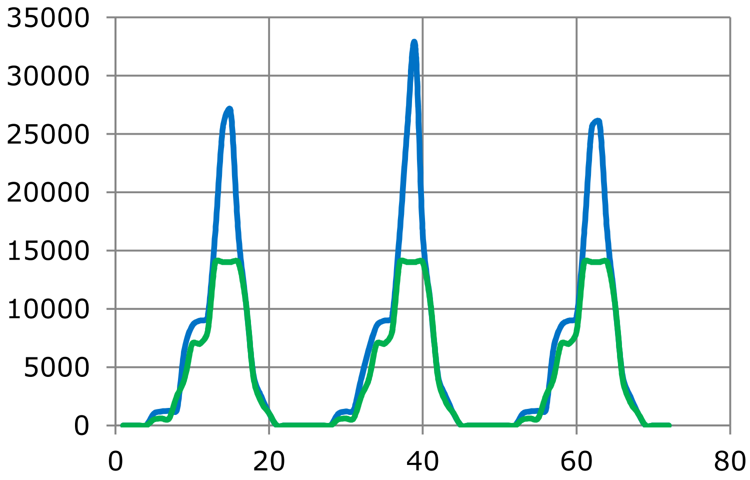
Dedicated Radiant chiller

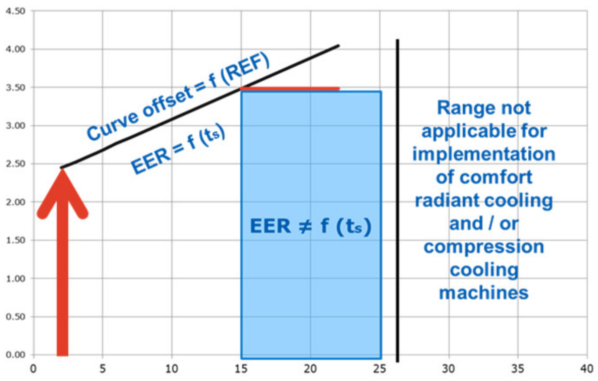


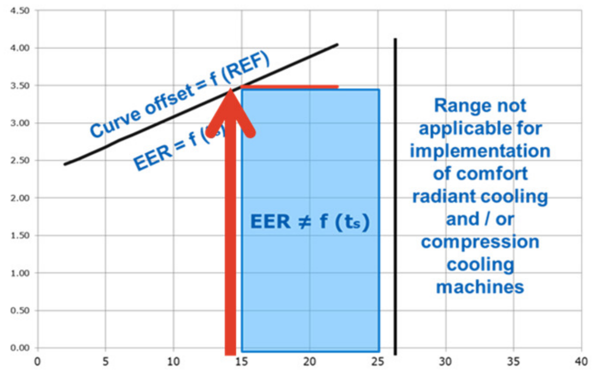
Chiller connections shall be checked dependantly of the model used.
Primary pump shall work permanently.

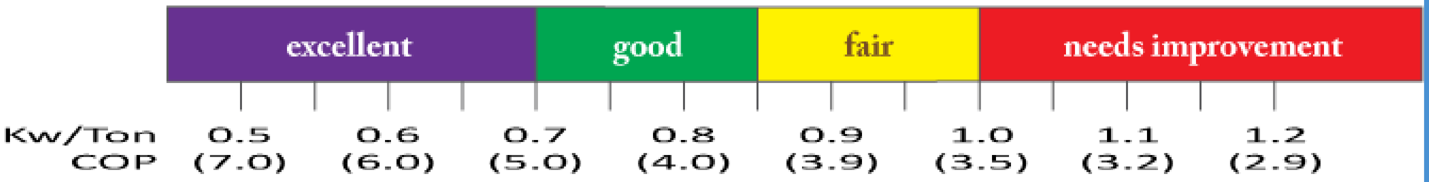
COP Increase

	Evaporat.	Condens.	EER
°K	°C	°C	/
7/12	**2**	**55**	**2,47**
13/16	8	55	2.97
14/18	9	55	3.07
16/20	**11**	**55**	**3.27**





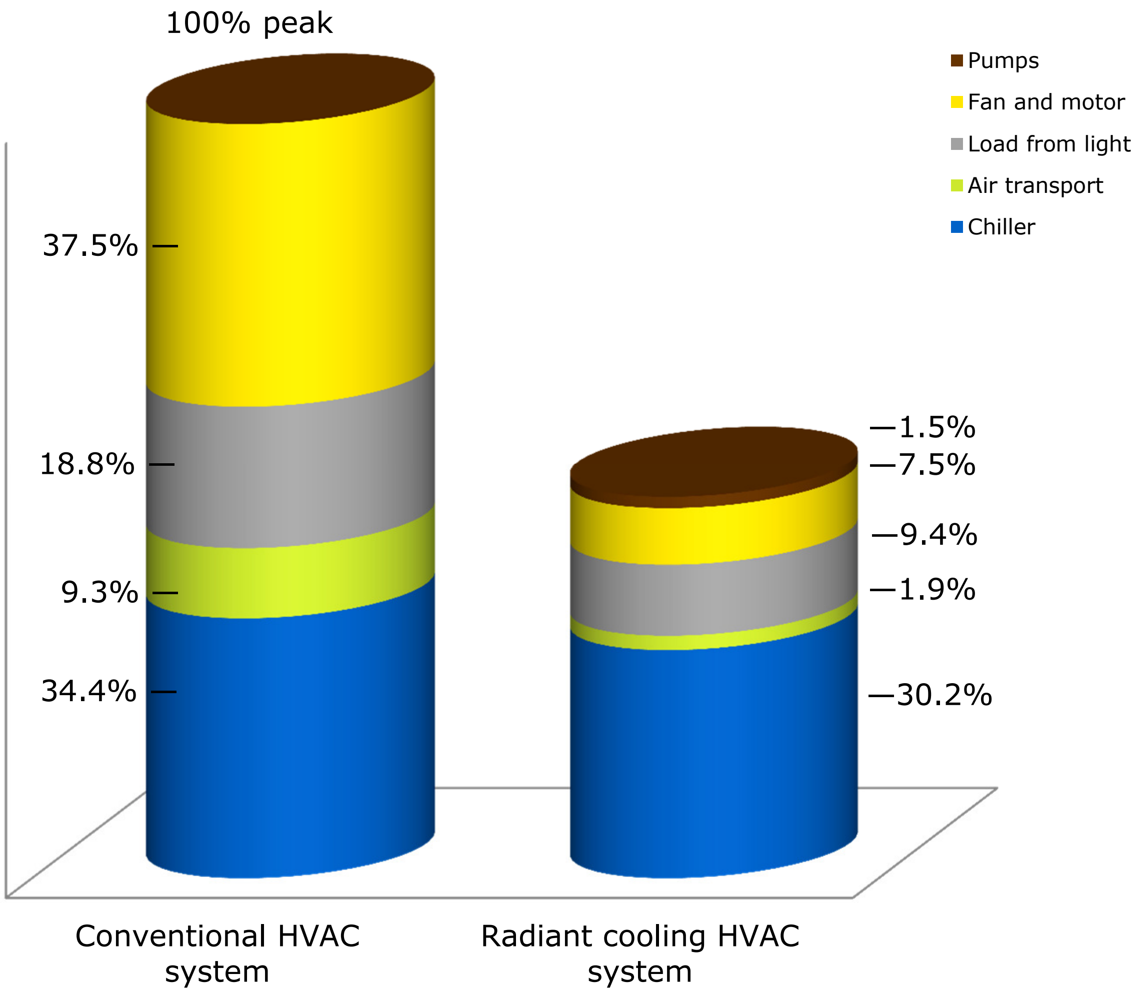




Annual Average Chiller Plant Efficiency Kw/Ton (COP)

- **Difference of the EER for theoretical refrigerant cycle for (FCU vs. Radiant) is in this case approximately 30%**
- **Theoretically, the higher temperature we are using for cooling, EER should be higher**
- **Based on previous each degree of higher temperature in cooling is bringing 3.5% of increase of EER (theoretical)**

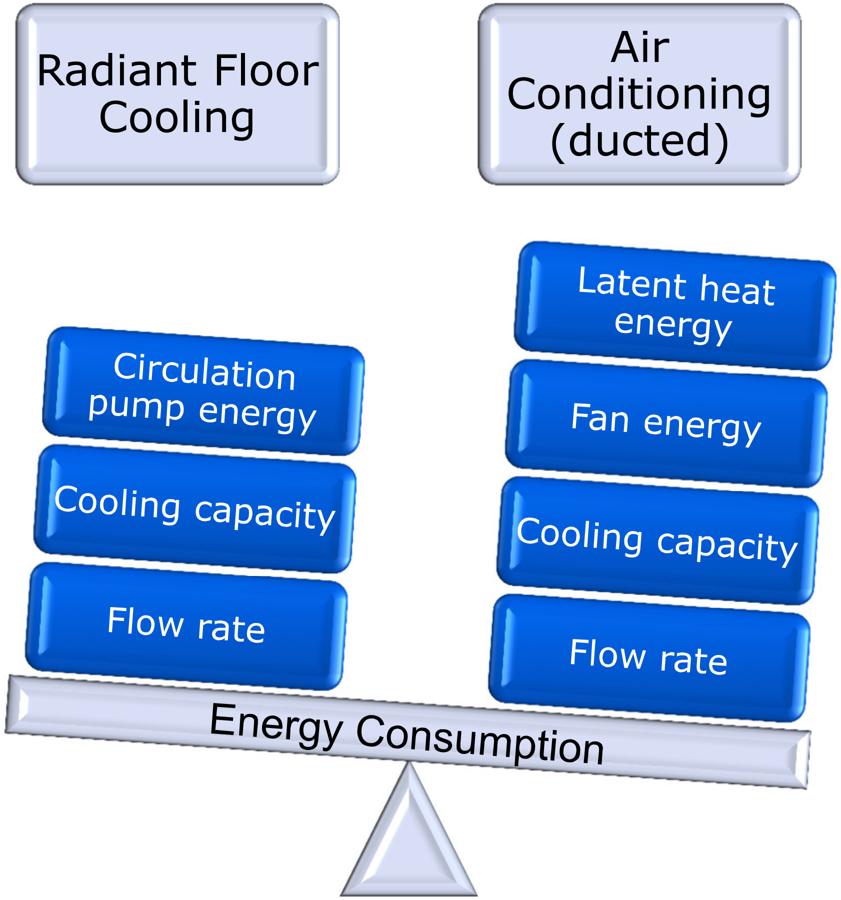
Energy Saving



Pumping fluids as opposed to moving air can reduce the point-to-point transfer costs by as much as 95% on a BTU-to-BTY basis.

Energy Saving

Example



Radiant Floor Cooling:

(typical case with 40 W/m², dT=3K)

- Cooling capacity 40 W
- Mass flow water 11kg/h
- Circulation pump energy 0.12 W
- Total energy demand 40.12 W

Air Conditioning (ducted)

(supply 18°C/60% RH, exhaust 26°C/50% RH)

- Cooling capacity 40 W
- Mass flow air 15 m³/h
- Fan energy 5.6 W
- Latent heat energy 35 W
- Total energy demand 80.6 W

Energy Savings: 40.5 W/m²

(without COP corrections)

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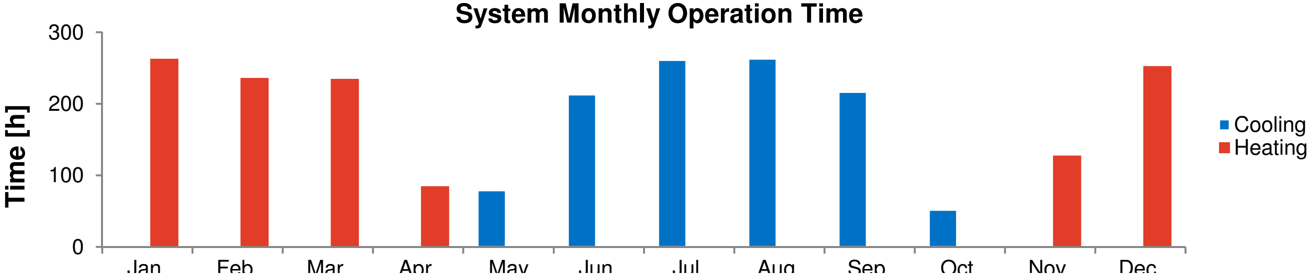
Economic Performance Comparison



Location: Shanghai

Building Type: Office

Conditioned Area: 2000 m²

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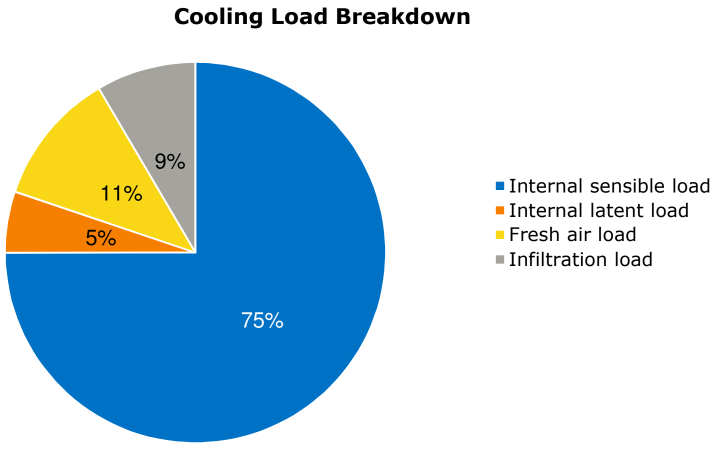
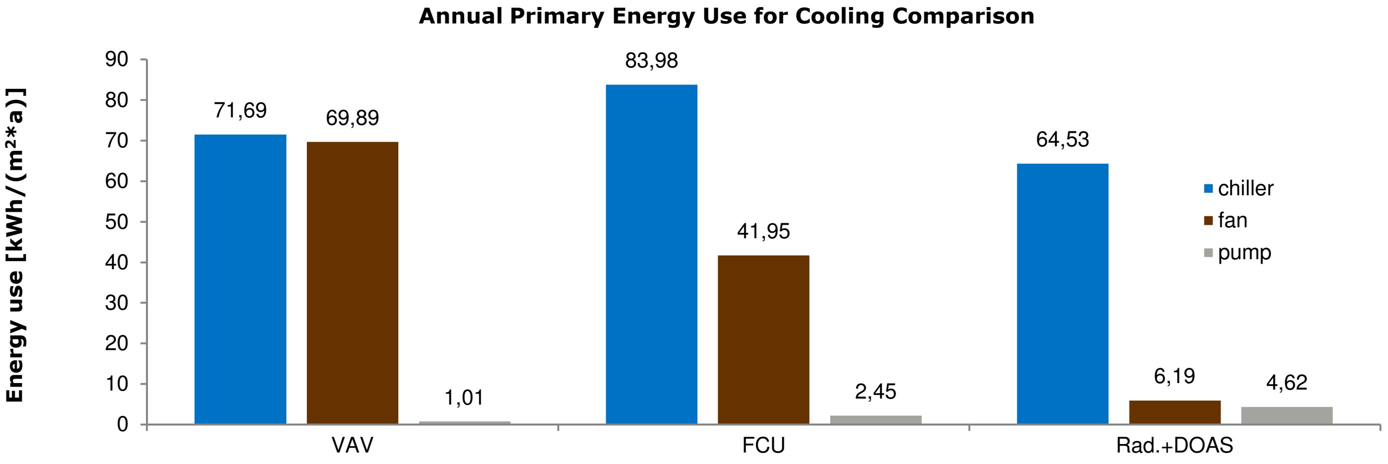
Economic Performance Comparison

Cooling

Cooling		Convec.	Radi.
Design indoor temperature	*°C*	22.0	24.0
Design indoor humidity	*%*	60.0	55.0
Average specific demand	*W/m²*	130.0	
Radiant system type		**Underfloor**	
Design outdoor temperature	*°C*	32.0	
Design outdoor humidity	*%*	83.0	
Local atmospheric pressure	*Pa*	100530	





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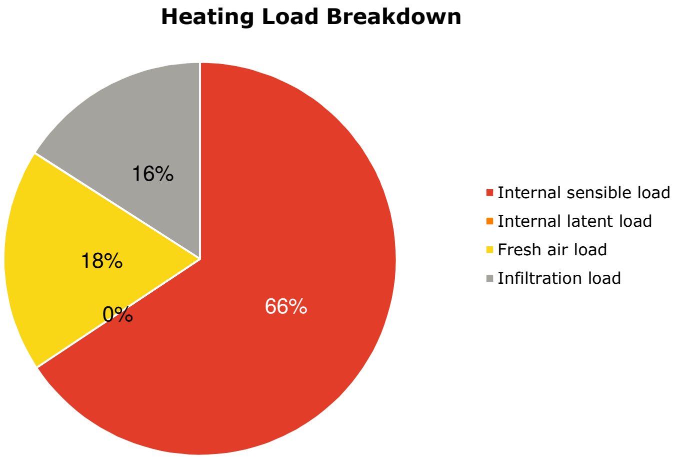
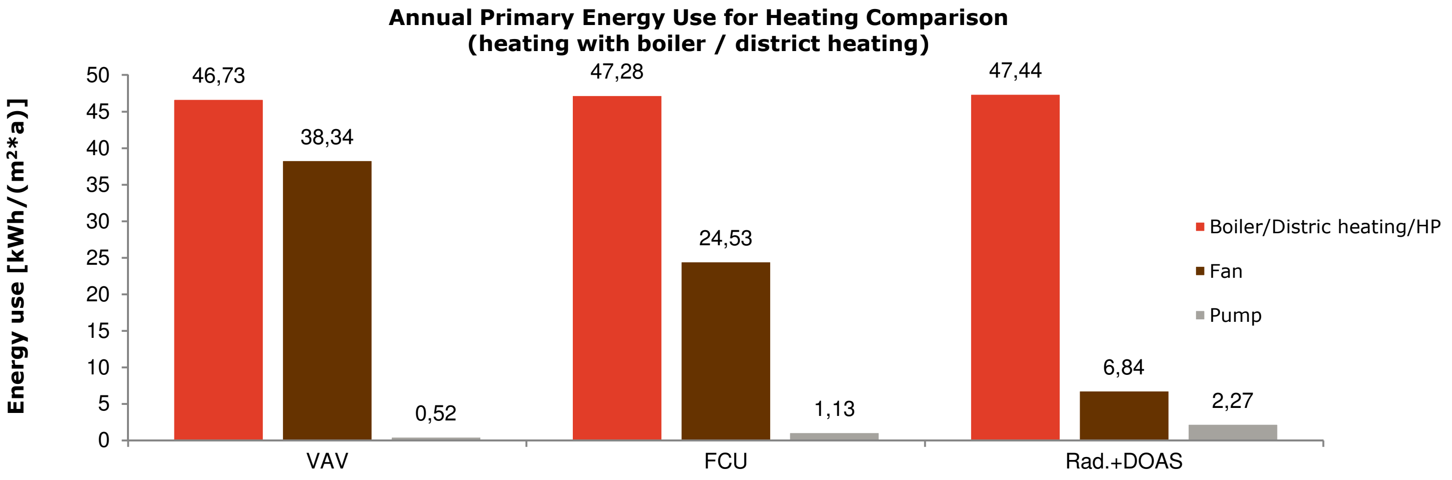
Economic Performance Comparison

Heating

Cooling		**Convec.**	**Radi.**
Design indoor temperature	*°C*	22.0	20.0
Design indoor humidity	*%*	60.0	60.0
Average specific demand	*W/m²*	40.0	
Radiant system type		**Underfloor**	
Design outdoor temperature	*°C*	-2.0	
Design outdoor humidity	*%*	75.0	
Local atmospheric pressure	*Pa*	102510	


Heating Load Breakdown


Annual Primary Energy Use for Heating Comparison (heating with boiler / district heating)

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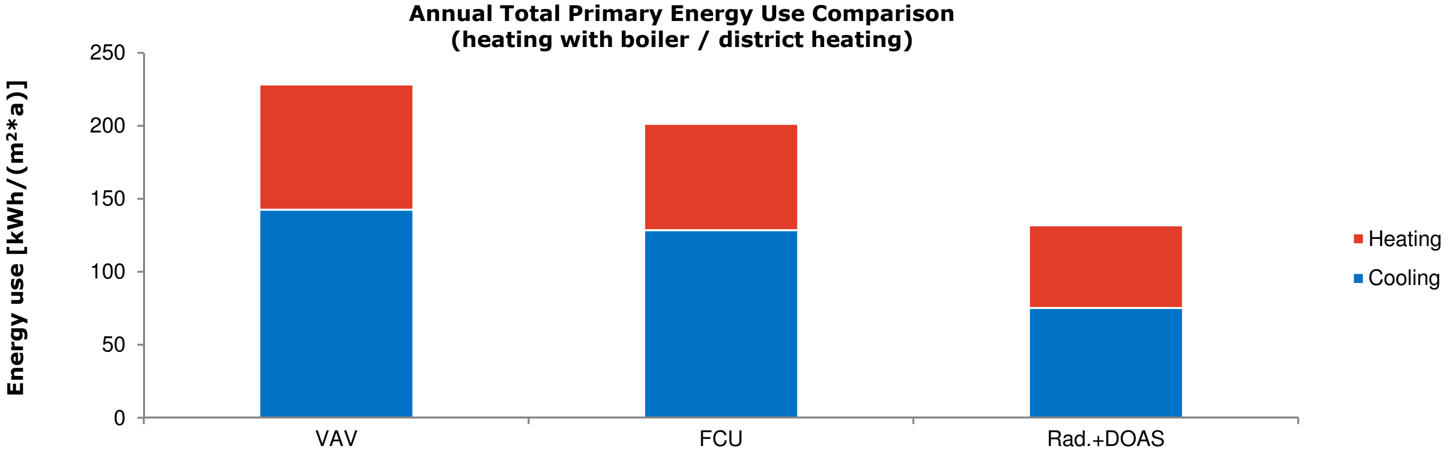
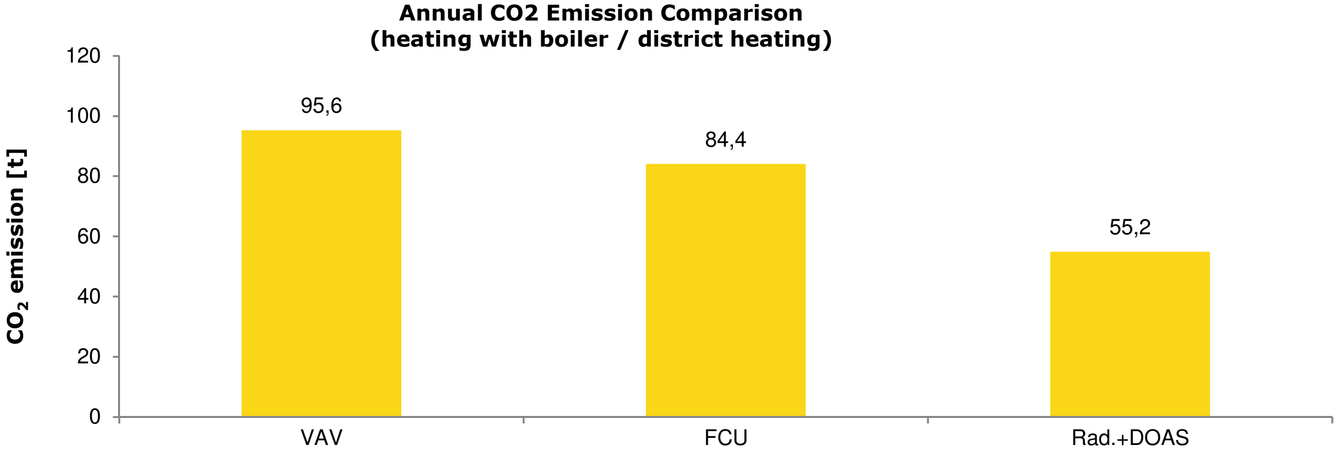
Economic Performance Comparison





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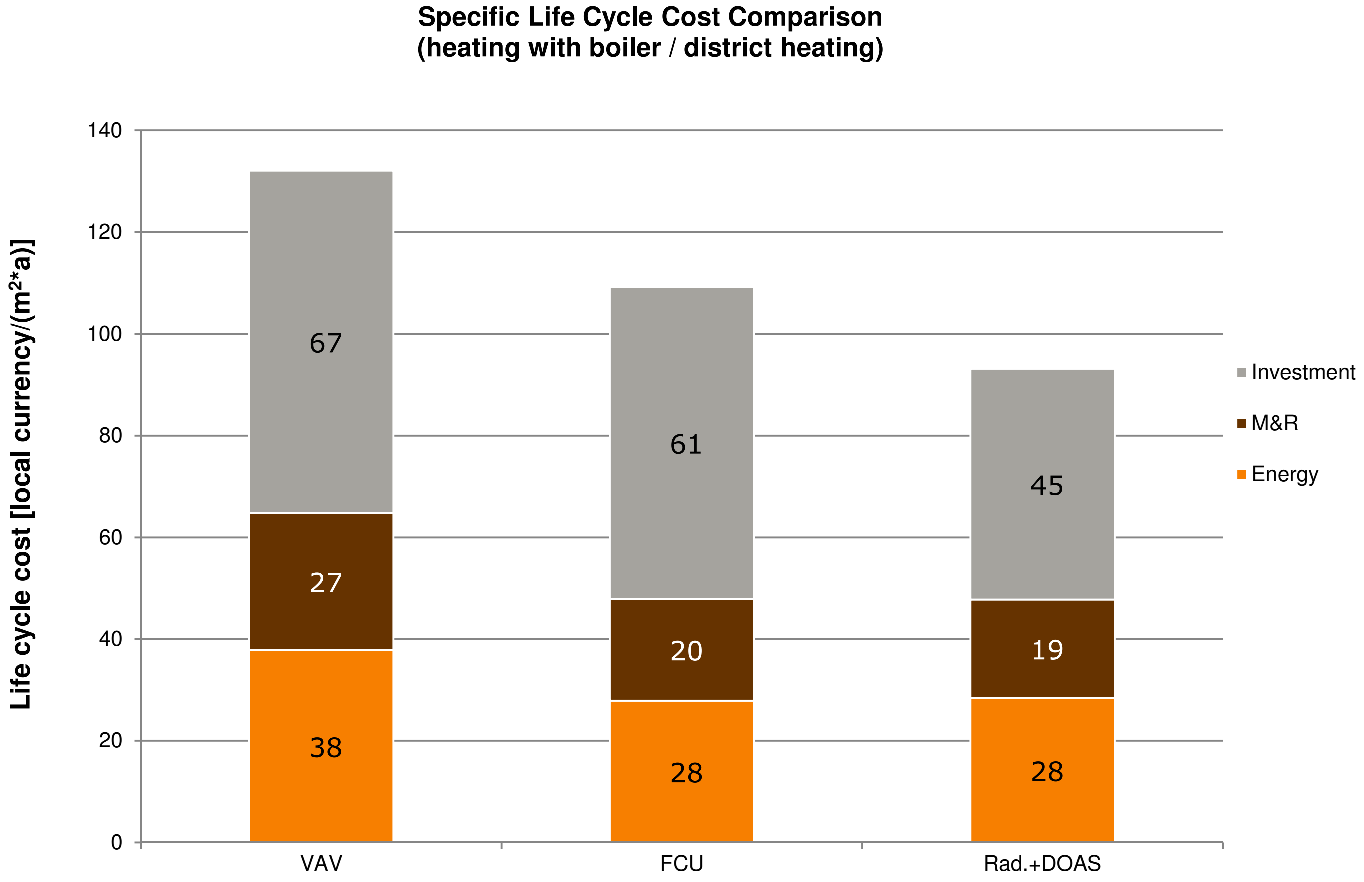
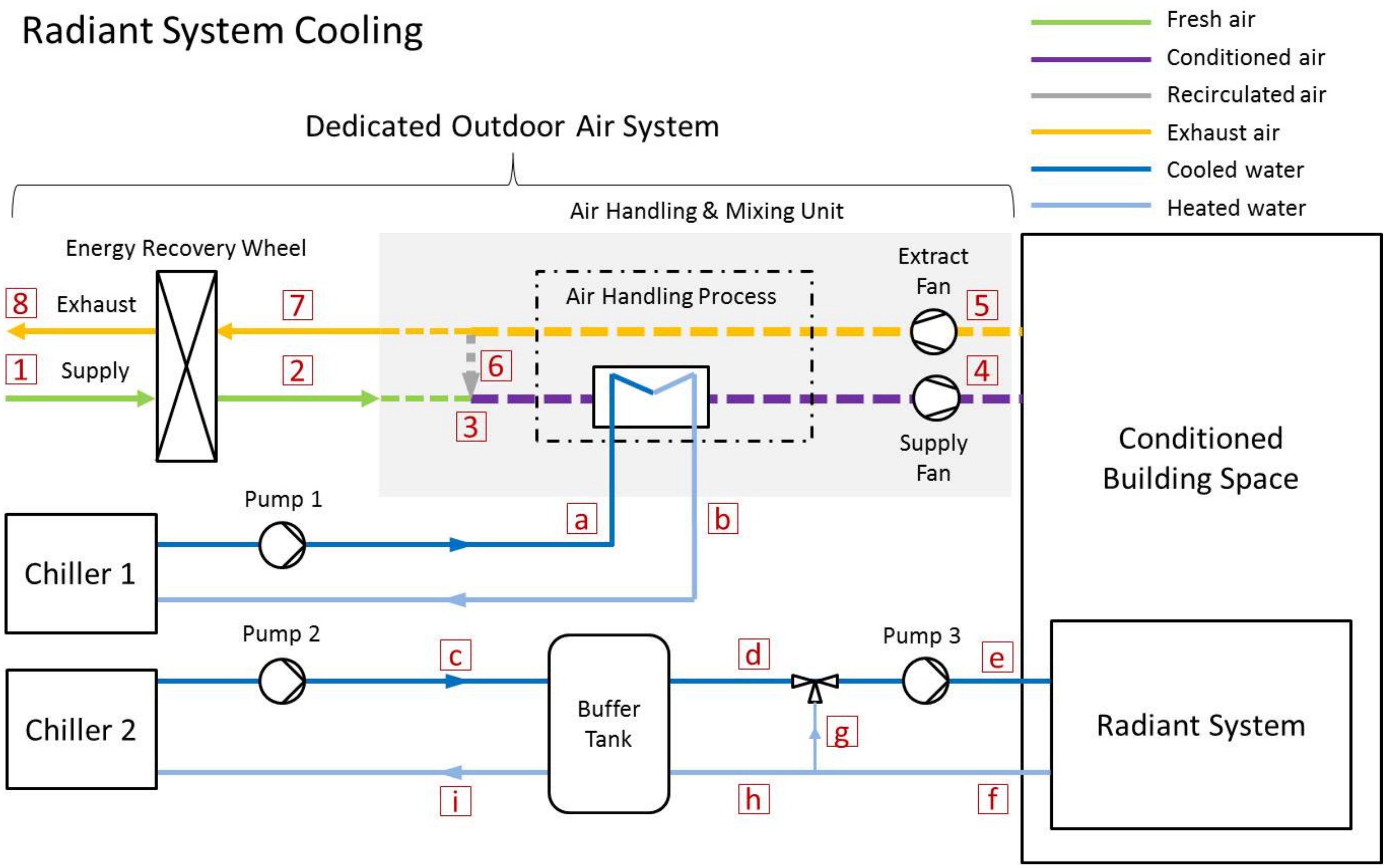
Economic Performance Comparison



	RoI in 20 years	Payback period Δ
Radiant and DOAS vs.VAV	137,55 %	0
Radiant and DOAS vs.FCU	57,11	0

Radiant System + DOAS



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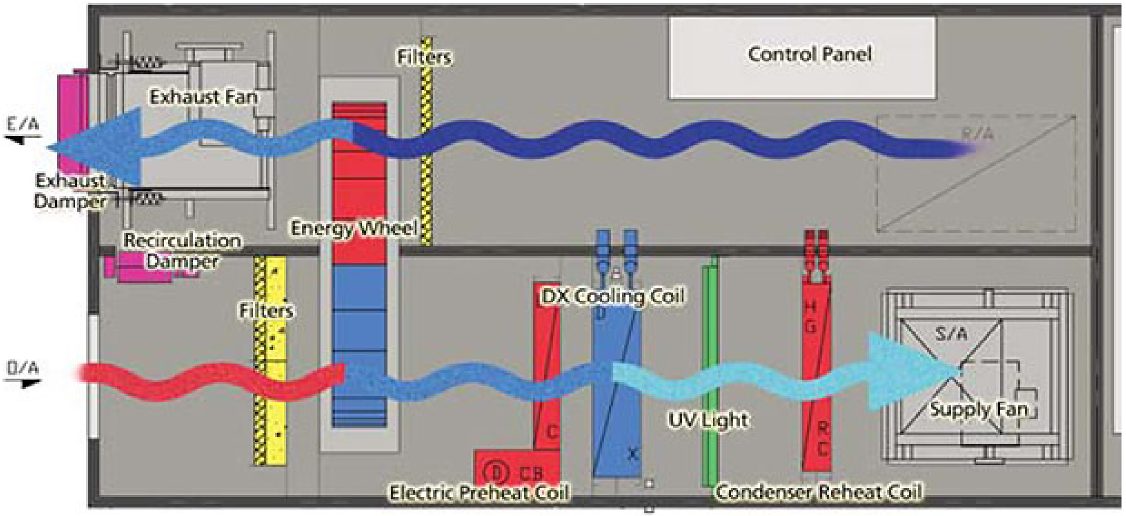
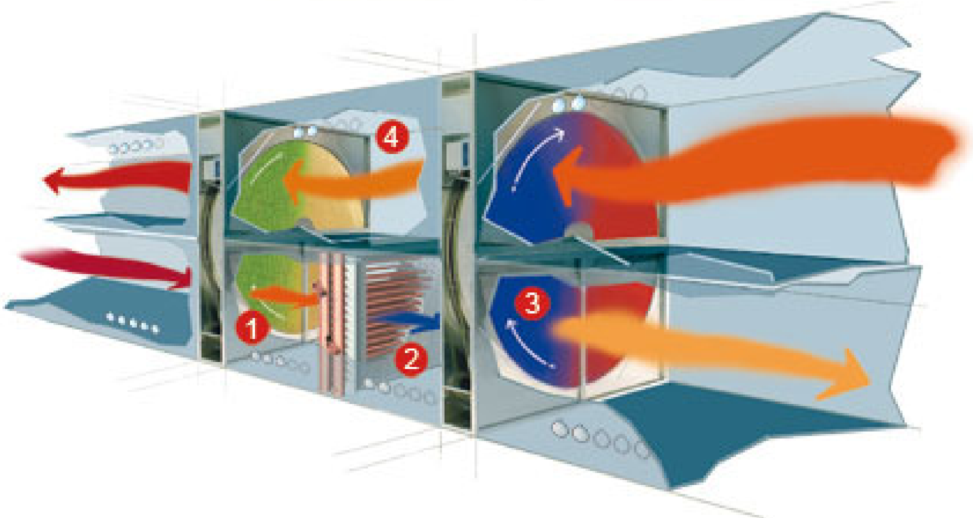
DOAS

Dedicated **O**utdoor **A**ir **S**ystem

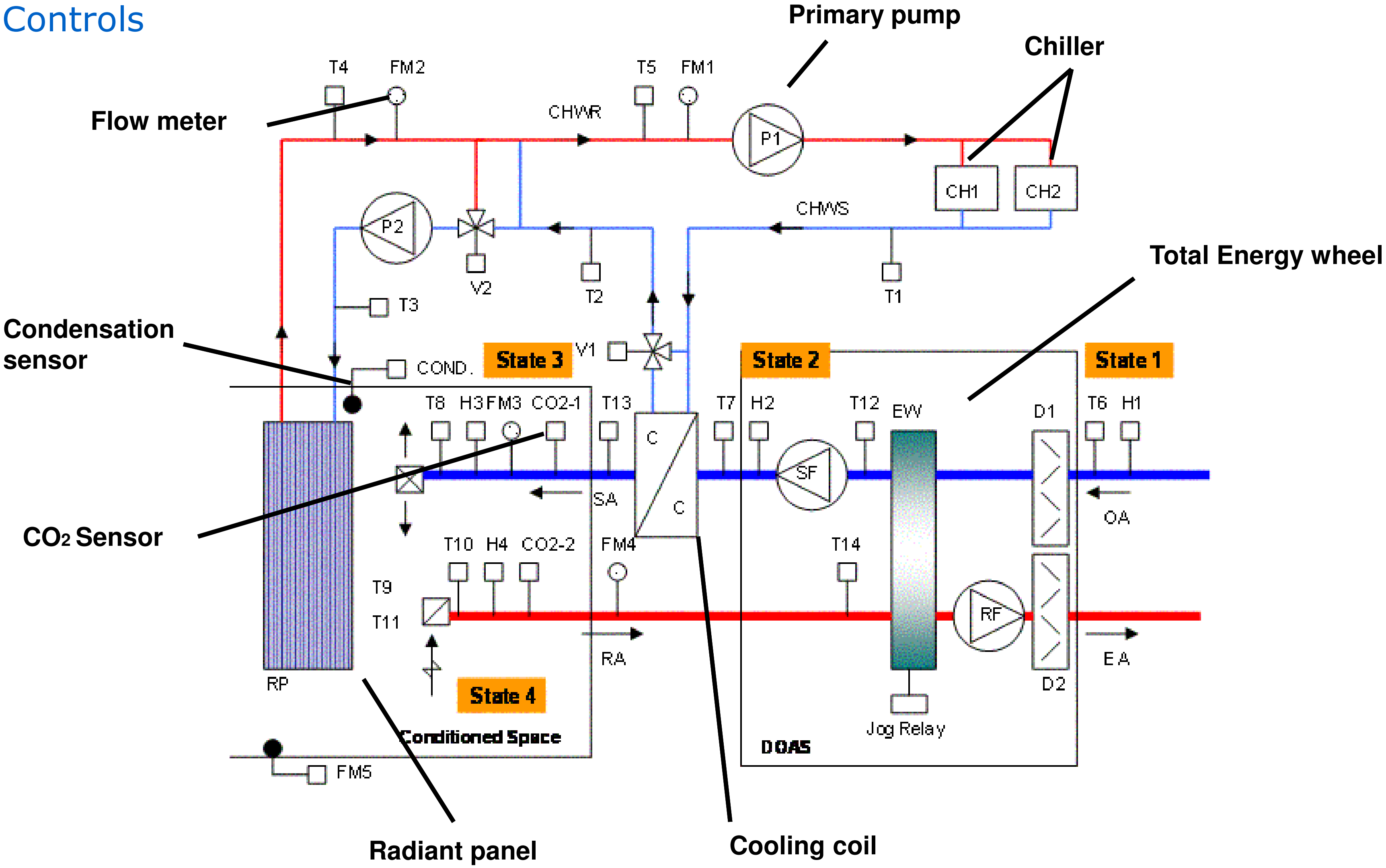




A dedicated outdoor air system (DOAS) is a type of heating, ventilation and air-conditioning (HVAC) system. The DOAS unit provides the ventilation air control but the system also requires a parallel sensible cooling system to handle the other building loads.

DOAS

Controls



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Your Benefits at a Glance:

Comfortable	Acts directly on the body without the intermediate stage of first warming/cooling the room air.
Low Acoustic Level	Runs quietly there are no irritating or disturbing background noises
Clean and Healthy	Hardly raising any dusts, it is the perfect heating system for people suffering from allergies.
Complete Design Freedom	There is more usable floor and wall space.
Adaptable Easy to Install	The Uponor underfloor heating and cooling system is adaptable to a variety of energy sources and easy to install.
Energy Efficient with Low Maintenance Costs	Underfloor heating and cooling reduces energy consumption by up to 12% and thus helps to save costs.
Energy-saving and Environmental Friendly	The lower/higher temperatures on the supply side allow the use of more environment-friendly heating/cooling system elements.

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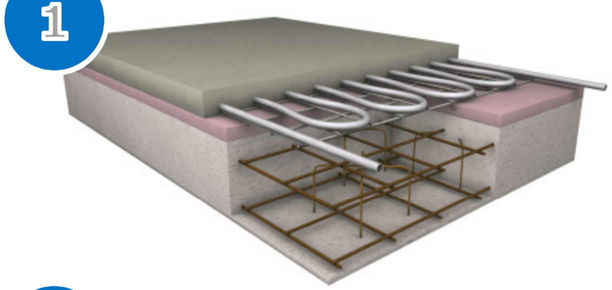
Applications

1


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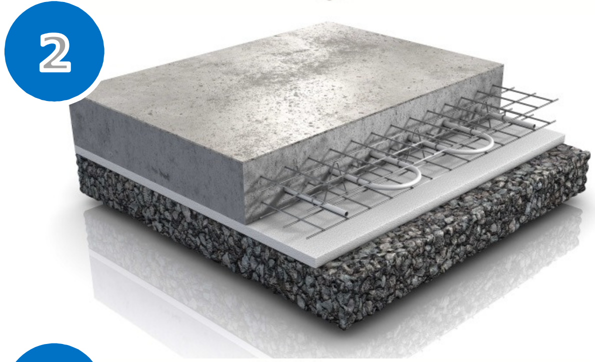

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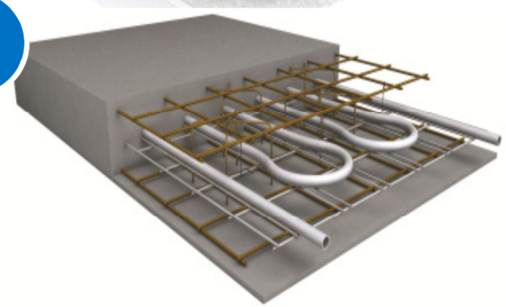

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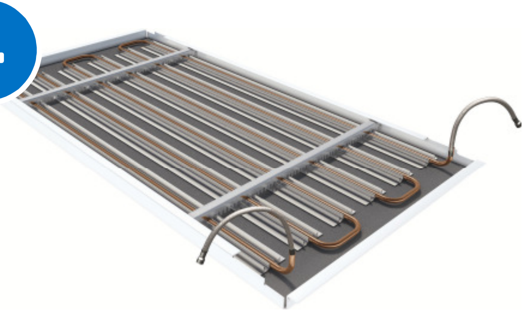

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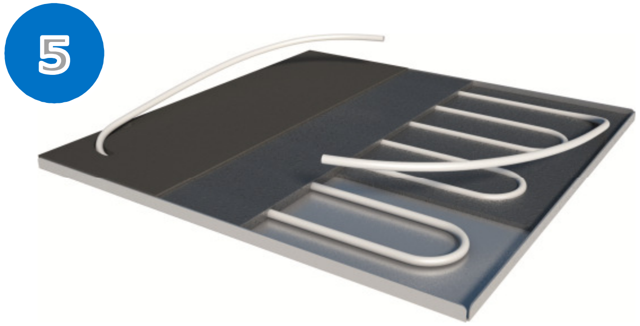

6


1. **Classic**
2. **Magna**
3. **TABS**
4. **Spectra**
5. **Comfort**
6. **Renovis**

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Service, Support and Success

Advantages for installers and specifies:

- One product specification for one system
- Fast installation, lower labor costs and earlier completion of the building
- Your ideas can be released with the wide range of items
- Tried and tested systems help to reliably realize your ideas
- Cheap systems often lead to leakages. Thus high costs for renovation and consequential damages arise for tiles, marble and bathroom accessories

Advantages for contractors and construction companies:

- Once installed, tight and safe with a service life of at least 50 years
- Reduction of total project costs through reduced maintenance costs
- No renovation costs because of corroded and/or blocked pipes
- Long term reliability increases the resale value
- 10 years warranty stands for high product quality

uponor

simply more

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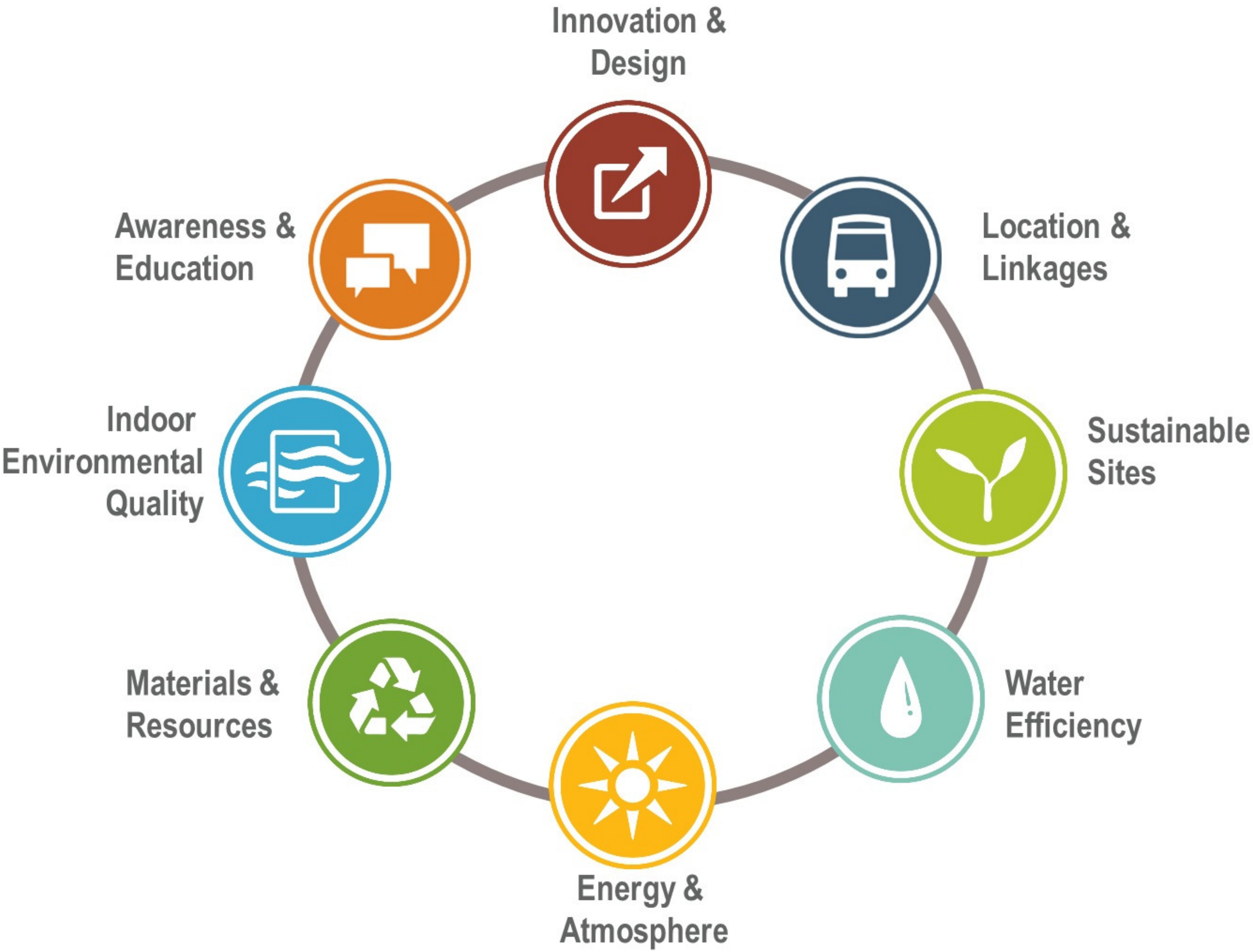
uponor

simply more



Innovation & Design

Location & Linkages

Sustainable Sites

Water Efficiency

Energy & Atmosphere

Materials & Resources

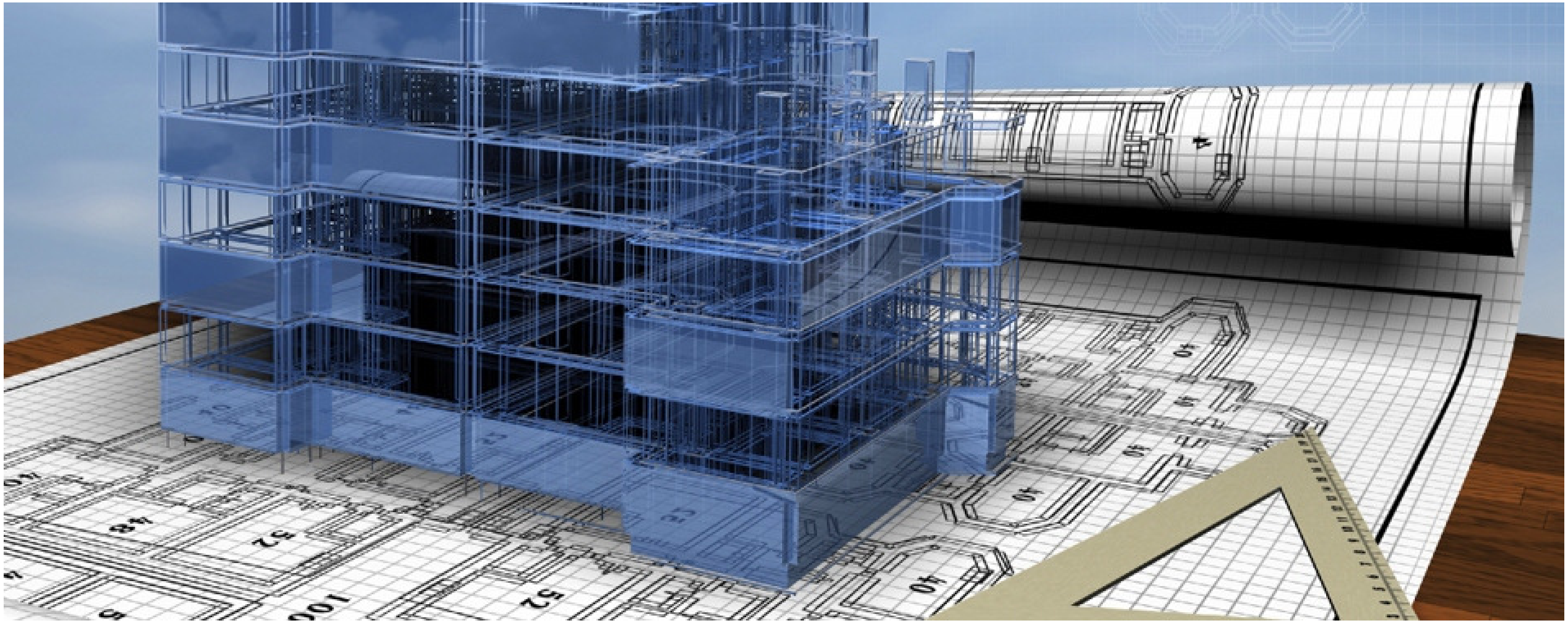
Indoor Environmental Quality

Awareness & Education

Sustainability Summary

Section	Credit	Description	Possible Points	Association System
(SS) Sustainable Sites	6.1	Stormwater Design Quality Control	1	Uponor AquaPEX Reclaimed Water Tubing
(WE) Water Efficiency	2	Innovative Wastewater Technologies	2	Uponor AquaPEX Reclaimed Water Tubing
(WE) Water Efficiency	3	Water Use Reduction	2-4	Uponor D'MAND Hot Water Delivery System
(EA) Energy and Atmosphere	Prereq 2	Minimum Energy Performance	Required	Uponor Radiant Heating and Cooling Systems
(EA) Energy and Atmosphere	Prereq 3	Fundamental Refrigerant Management	Required	Uponor Radiant Heating and Cooling Systems
(EA) Energy and Atmosphere	1	Optimized Energy Performance	1-19	Uponor Radiant Heating and Cooling Systems
(EA) Energy and Atmosphere	2	On-site Renewable Energy	1-7	Uponor Radiant Heating and Cooling Systems
(EA) Energy and Atmosphere	4	Enhance Refrigerant Management	2	Uponor Radiant Heating and Cooling Systems
(EQ) Indoor Environment Quality	4.1	Low Emitting Adhesives and Sealants	1	Uponor Radiant Heating and Cooling Sytems
(EQ) Indoor Environment Quality	6.2	Controllability of Systems, Thermal Comfort	1	Uponor Radiant Heating and Cooling Sytems
(EQ) Indoor Environment Quality	7.1	Thermal Comfort Design	1	Uponor Radiant Heating and Cooling Sytems
(EQ) Indoor Environment Quality	7.2	Thermal Comfort Verification	1	Uponor Radiant Heating and Cooling Sytems
(ID Innovative and Design	1	Innovation in Design	1-5	Various Uponor Plumbing Heating/ Cooling and Fire Safety Systems

Design Build Improves Constructability



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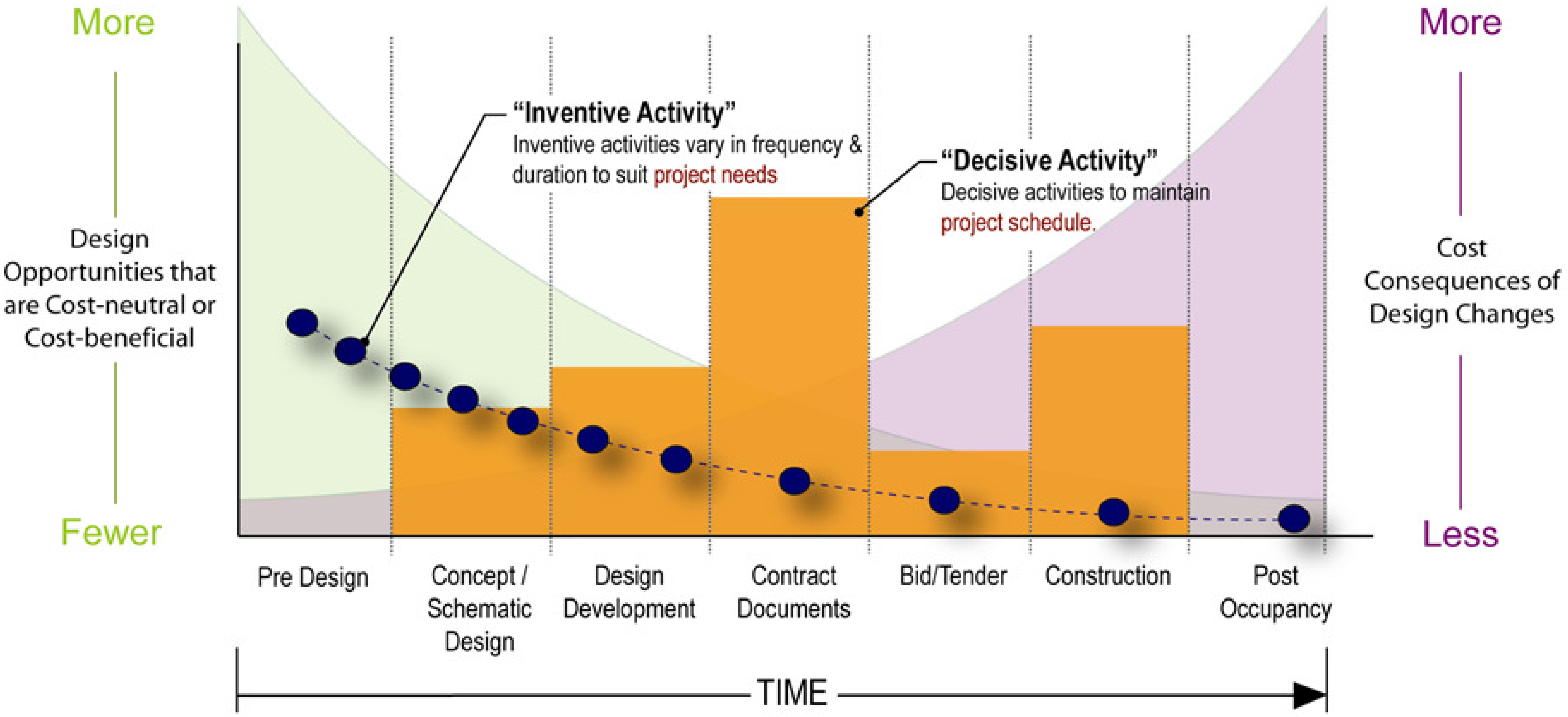
Design Build Cuts Costs



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uponor

simply more