Lecture 2 –
Thermal considerations in the building and the city

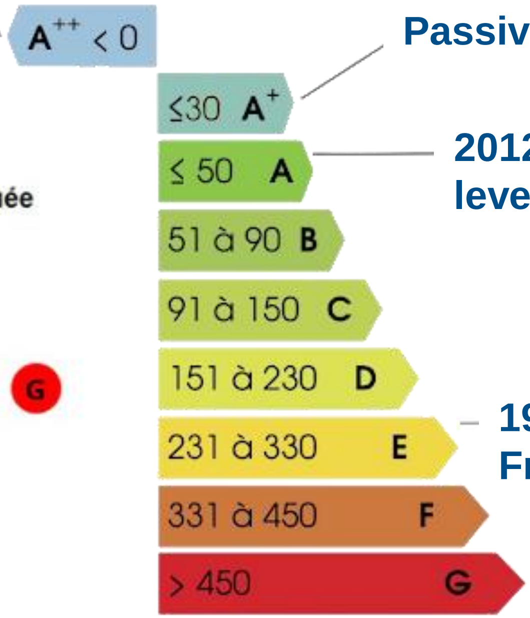
Magistère de Physique Fondamentale
Université Paris-Saclay
2019-2020

Energy consumption

Evolution of the energy consumption in French dwellings as a function of the construction year

Energy performance diagnosis (DPE)

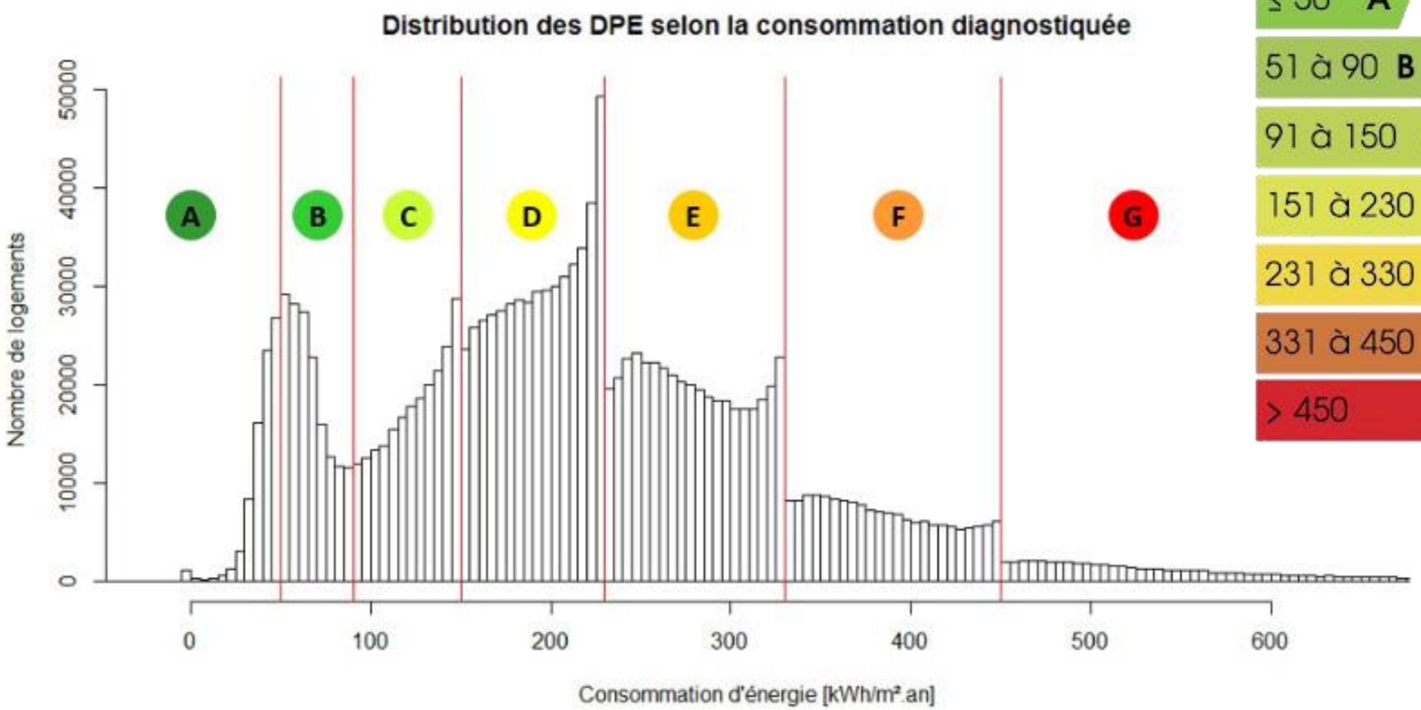
BEPOS
Positive energy homes



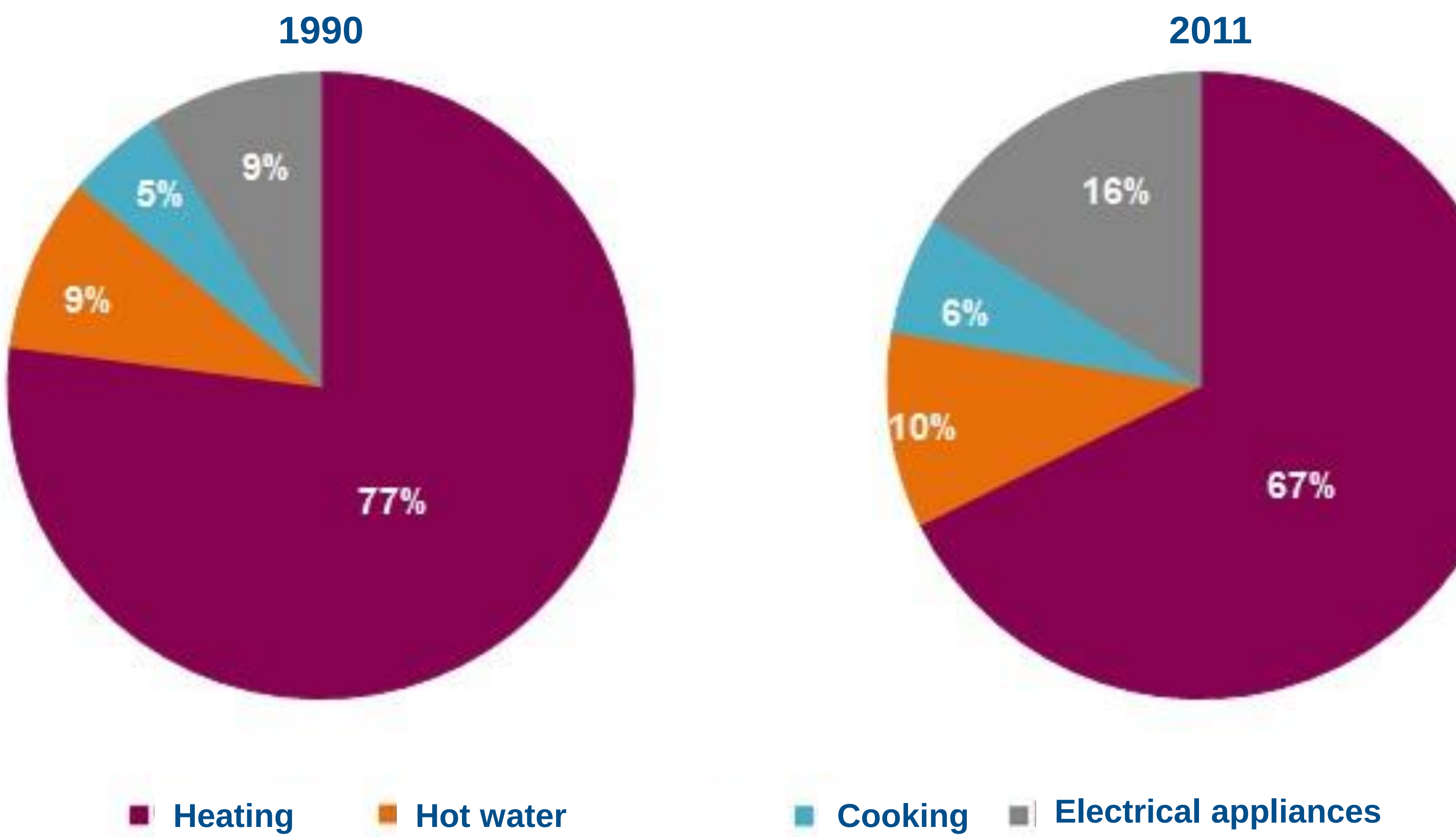
Passive house

2012 Regulation level

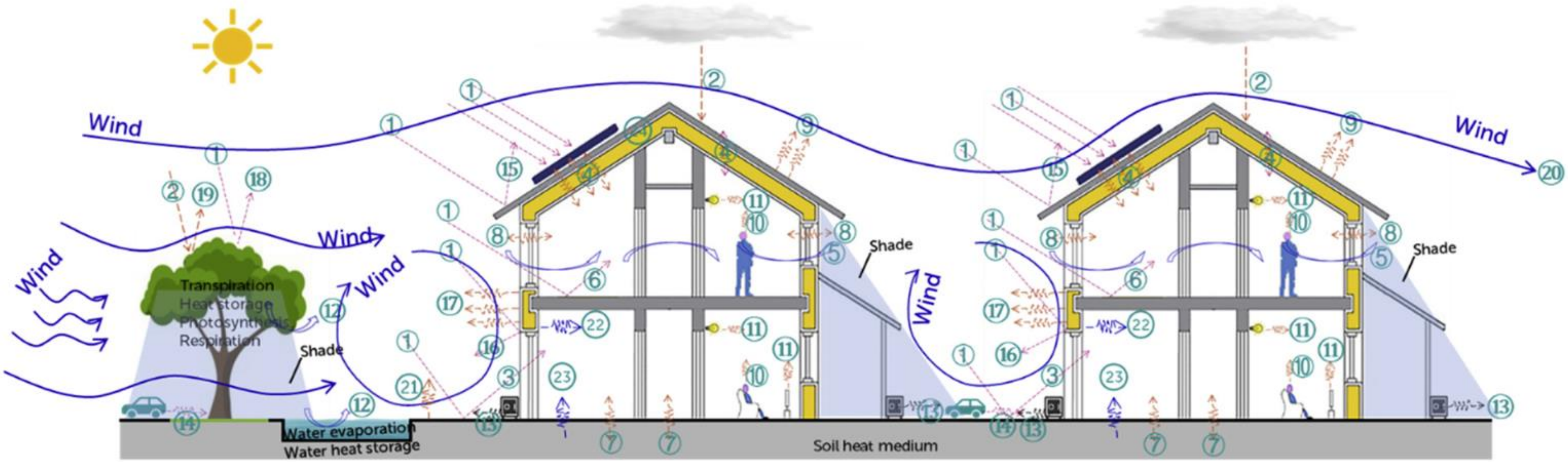
1970 houses French average



Energy demand



Thermal exchanges in a building



1. Direct solar radiation
2. Diffuse solar radiation
3. Ground reflected solar radiation
4. Envelope heat conduction
5. Building natural ventilation heat transfer
6. Window solar radiation
7. Indoor-earth heat conduction
8. Window heat conduction
9. Roof long-wave heat emittance
10. Occupants heat contribution
11. Waste heat from electric lights and appliances
12. Evaporative cooling
13. Waste heat from AC units
14. Waste heat from vehicles
15. Roof reflected solar radiation
16. Façade reflected solar radiation
17. Façade long-wave heat emittance
18. Tree reflected solar radiation
19. Tree long-wave heat emittance
20. Urban ventilation heat transfer
21. Ground long-wave heat emittance
22. Cool source from AC units
23. Cool source from the earth
24. Heat stored in materials

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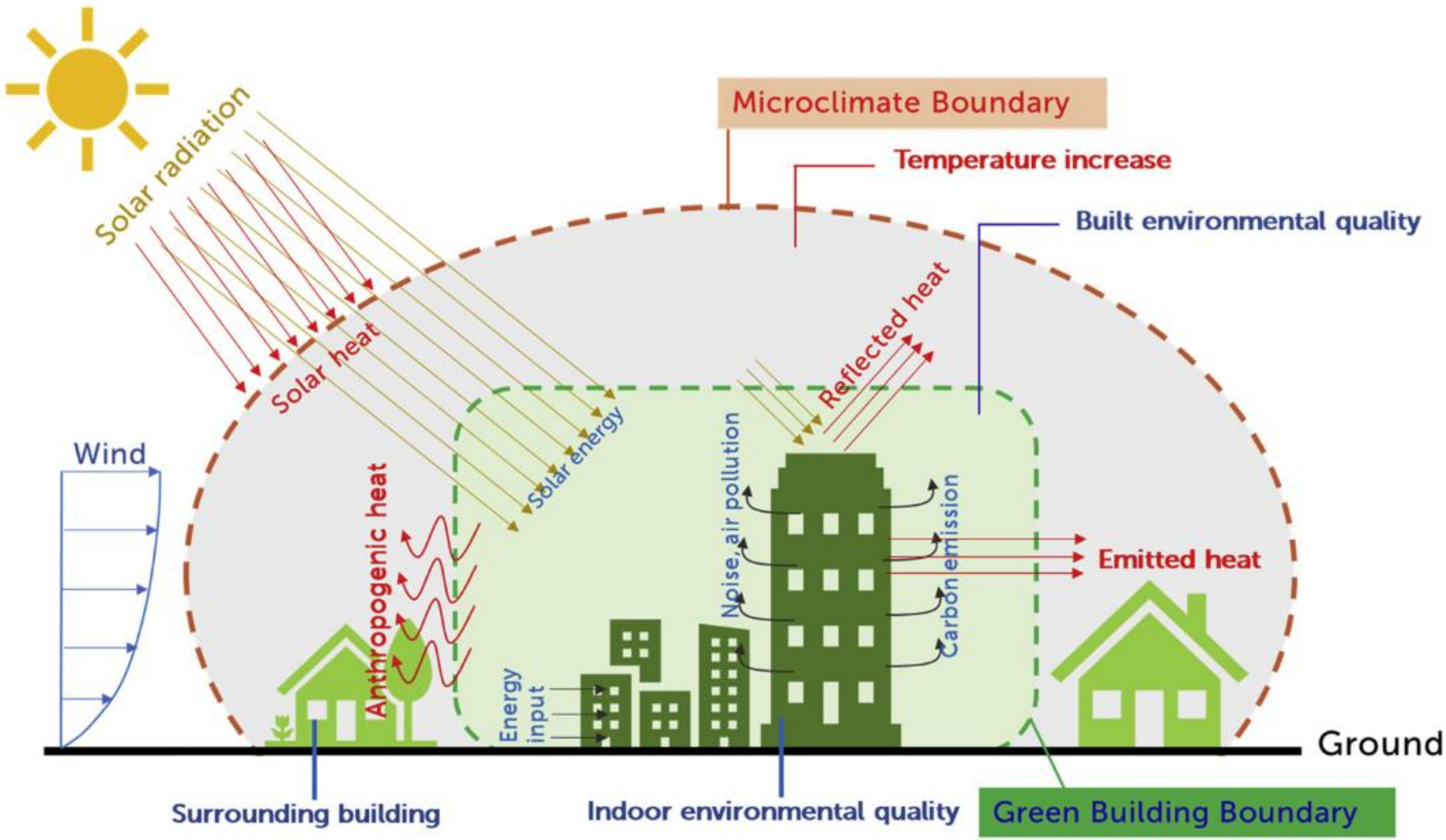
Thermal exchanges in the city



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1. THERMAL TRANSFERS – GENERAL OVERVIEW

1. Convection
2. Radiation
3. Conduction

Newton's law :

$$\Phi = hA(T_s - T_\infty)$$

Typical values of the convective heat transfer	
Process	h $(\mathrm{W/m^2 \cdot K})$
Free convection	
Gases	2 - 20
Liquids	50 - 1000
Forced convection	
Gases	25 - 300
Liquids	100 - 40,000
Convection with phase change	
Boiling or condensation	2500 - 100,000

Forced convection

Figure 2. In the summer, ceiling fans should rotate counterclockwise to mix warm air and force a cool breeze downwards, creating a downdraft.[8]

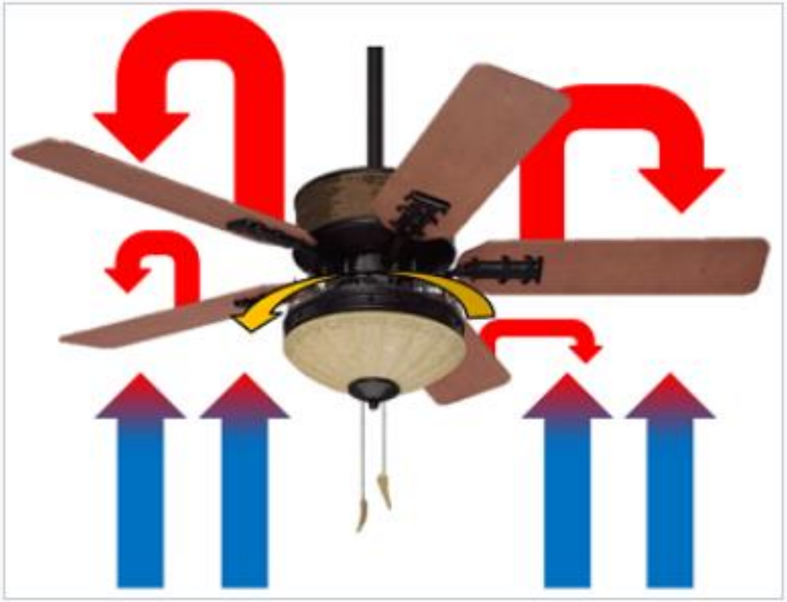
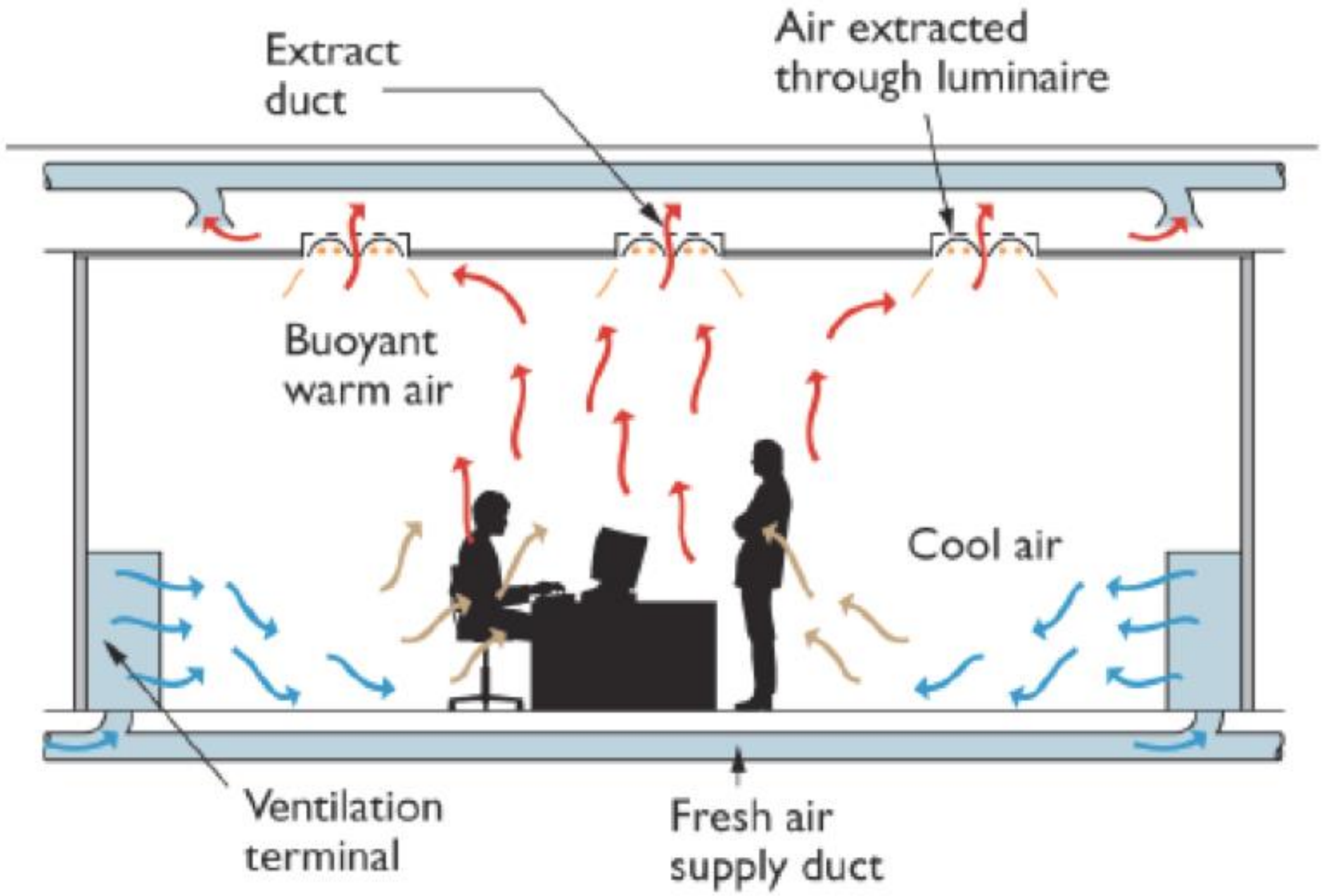


Figure 3. In the winter, ceiling fans should rotate clockwise to pull cool air up from the room and force warm air downwards, creating an updraft.[8]

Forced convection



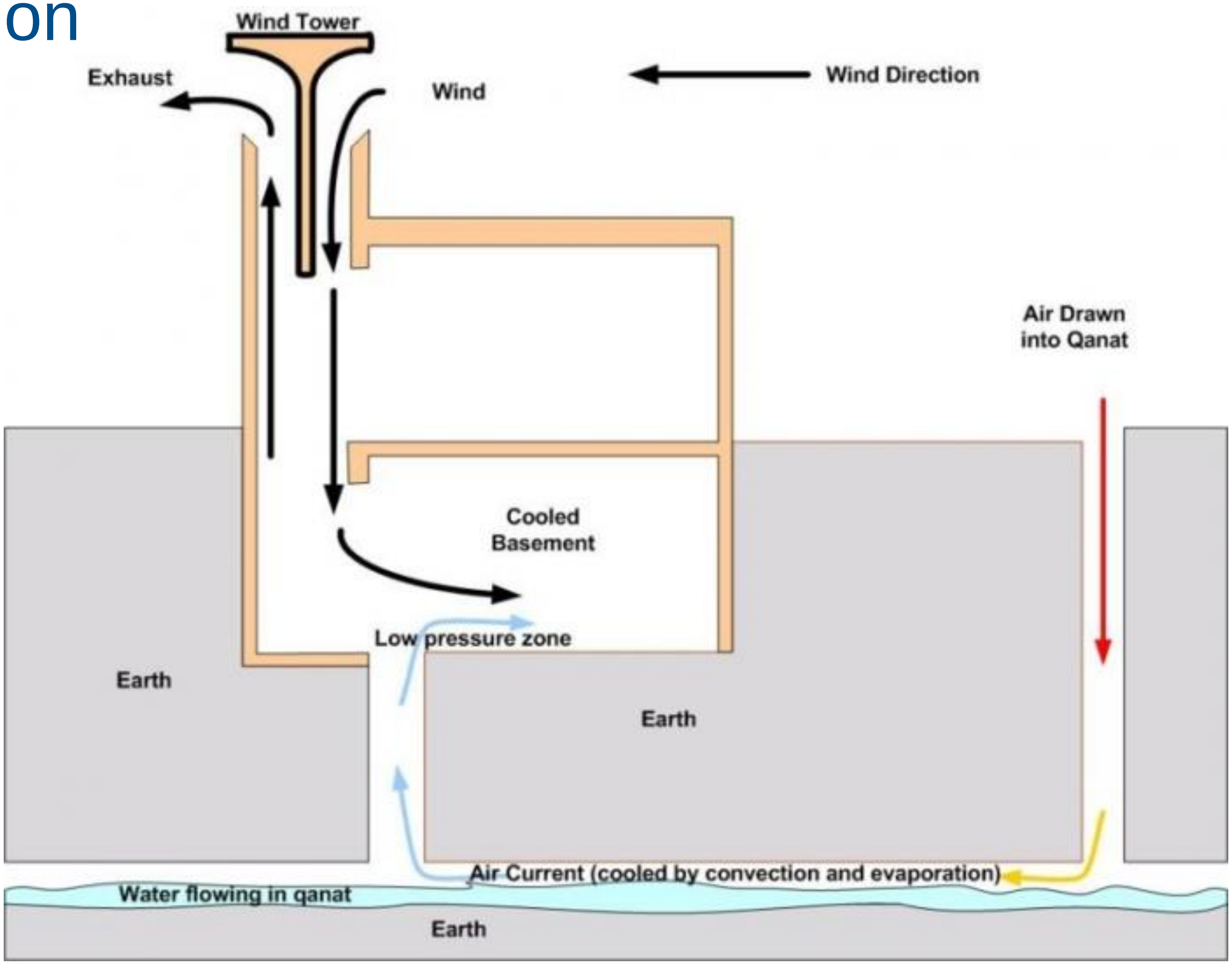
1.1. Convection

Natural convection

Windcatchers, Iran
© Erika Alatalo

Wind towers for water reservoir, Isfahan, Iran
© Eric Lafforgue

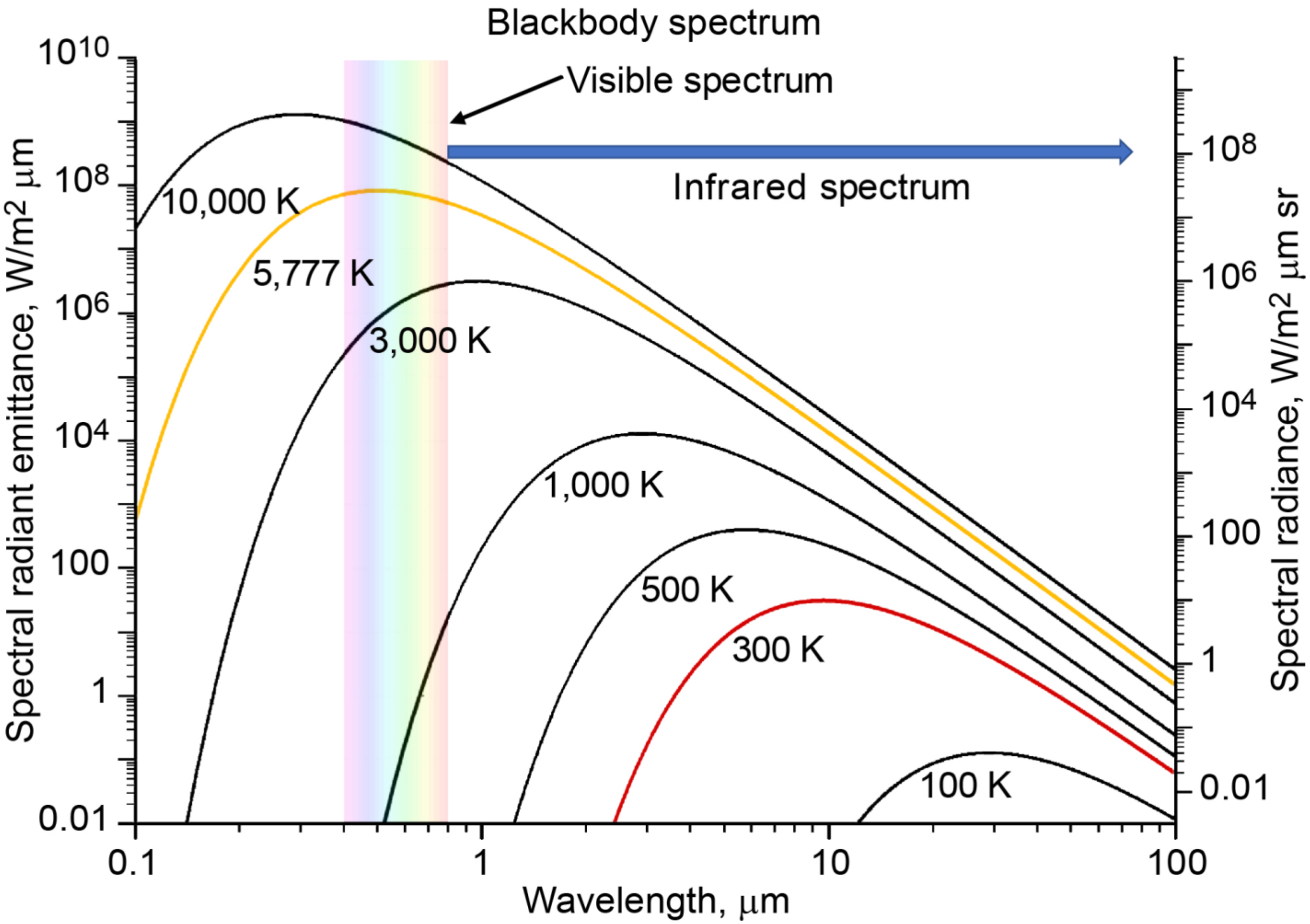
Natural convection

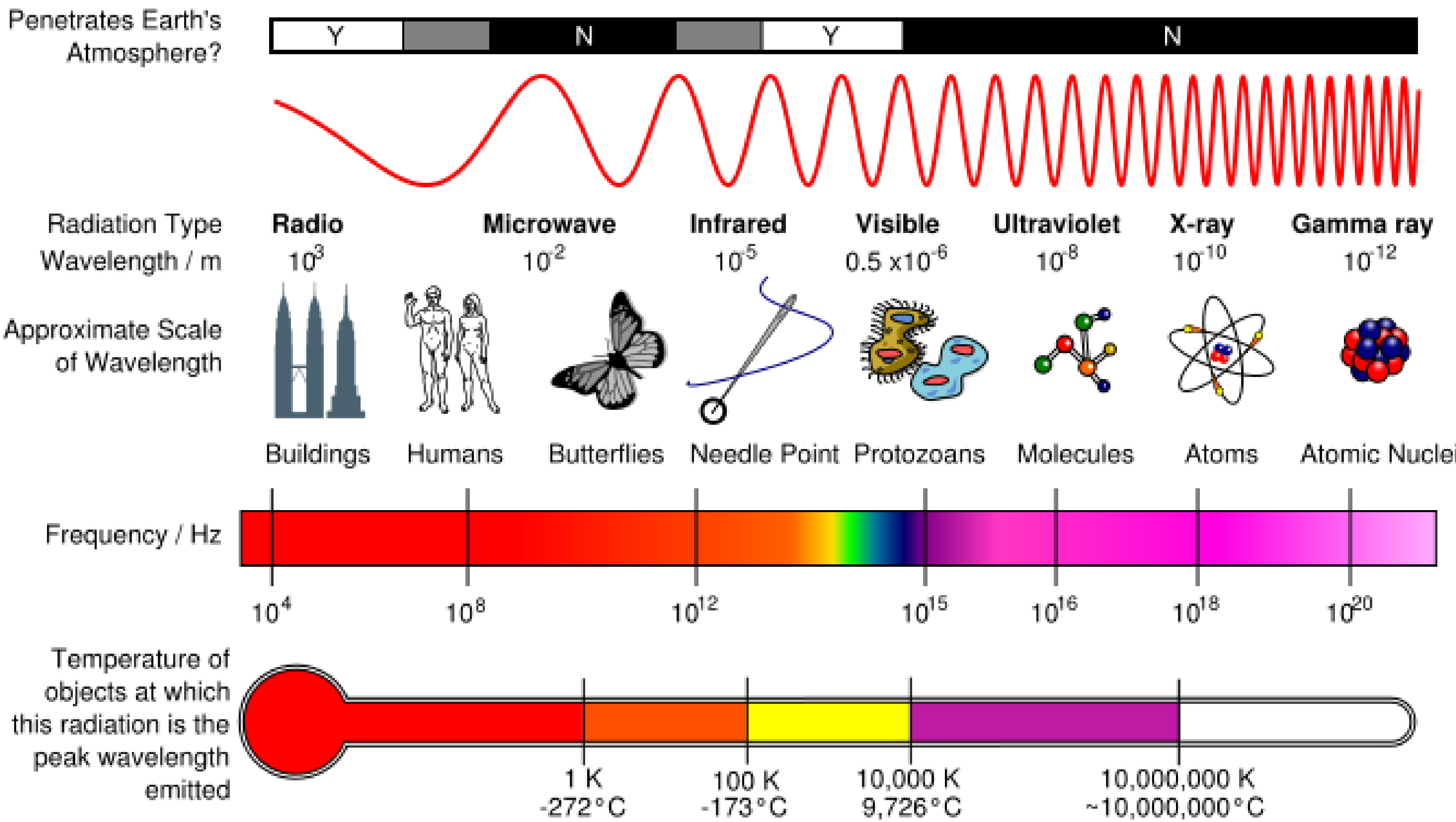


Natural convection

Natural convection

Black body radiation:



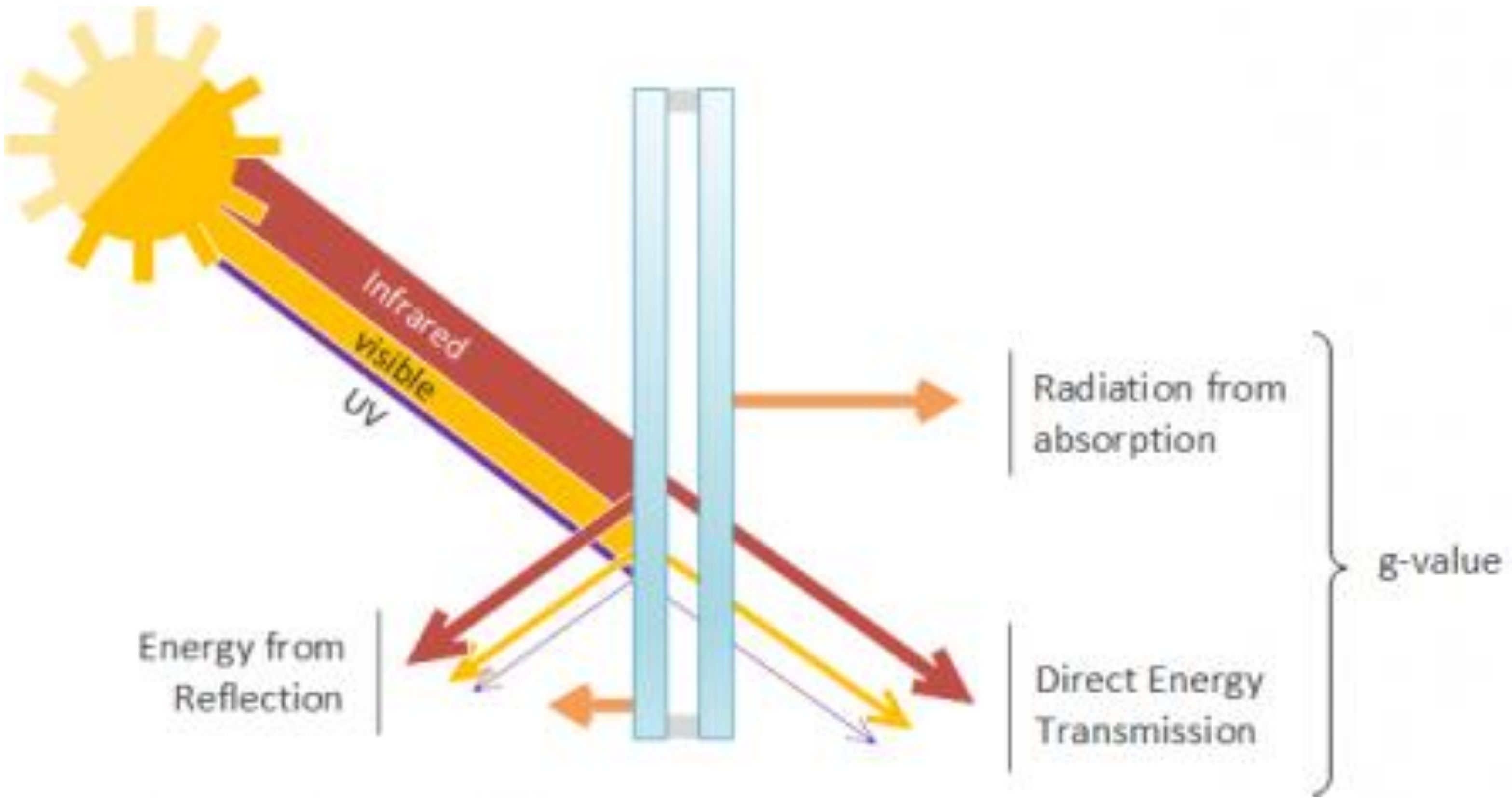

Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength / m
Radio
10^3
Microwave
10^-2
Infrared
10^-5
Visible
0.5 x10^-6
Ultraviolet
10^-8
X-ray
10^-10
Gamma ray
10^-12
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency / Hz
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of objects at which this radiation is the peak wavelength emitted
1 K
-272 °C
100 K
-173 °C
10,000 K
9,726 °C
10,000,000 K
~10,000,000 °C

Emissivity :

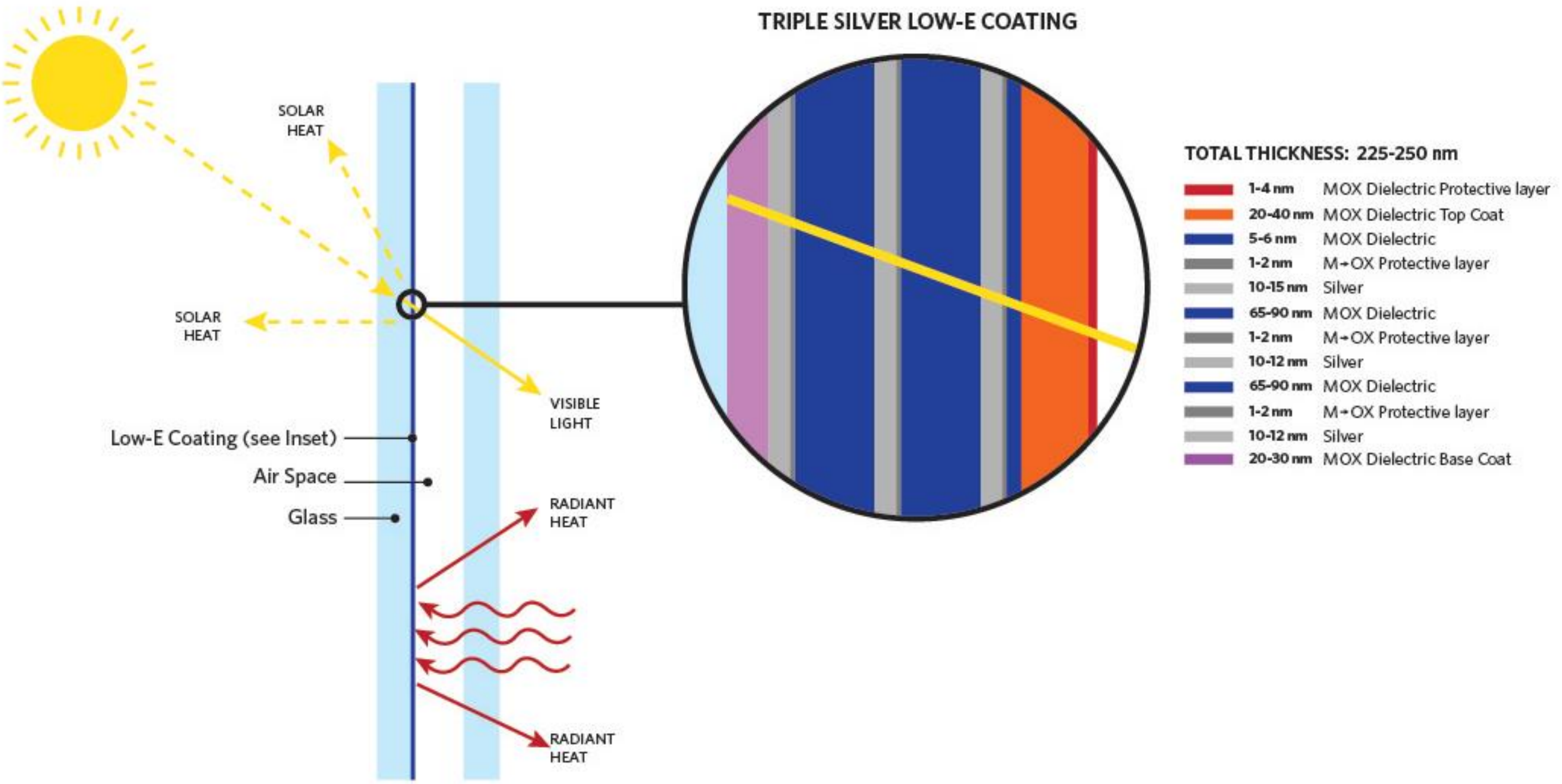
$$P = \varepsilon \sigma T^4$$

Material	Emissivity
Polished silver	0.02
Polished copper	0.03
Polished gold	0.03
Aluminum foil	0.07
Wood	0.85
Asphalt pavement	0.9
White paint	0.9
Vegetation	0.94
White paper	0.94
Water	0.95
Black paint	0.98

Low-e glass:


Infrared
visible
UV
Radiation from absorption
g-value
Energy from Reflection
Direct Energy Transmission

Low-e glass:



SOLAR HEAT
SOLAR HEAT
VISIBLE LIGHT
Low-E Coating (see Inset)
Air Space
Glass
RADIANT HEAT
RADIANT HEAT
TRIPLE SILVER LOW-E COATING
TOTAL THICKNESS: 225-250 nm
1-4 nm MOX Dielectric Protective layer
20-40 nm MOX Dielectric Top Coat
5-6 nm MOX Dielectric
1-2 nm M→OX Protective layer
10-15 nm Silver
65-90 nm MOX Dielectric
1-2 nm M→OX Protective layer
10-12 nm Silver
65-90 nm MOX Dielectric
1-2 nm M→OX Protective layer
10-12 nm Silver
20-30 nm MOX Dielectric Base Coat

Fourier's law :

$$\vec{\varphi} = -\lambda \vec{\nabla} T$$

Materials	Thermal conductivity (W/m.K)	Density (kg/m^3)
Brick Veneer	0.80	1700
Re-inforced concrete	0.50	1400
Timber	0.15	650
Single glass window	0.65	2500
External rendering	0.25	1300
Tile concrete	0.84	1900
Cast concrete slab	1.13	2200
Expanded polystyrene	0.034	24
Polyurethane rigid foam	0.023	32
Sisalation foil	0.035	25
Plasterboard	0.25	950

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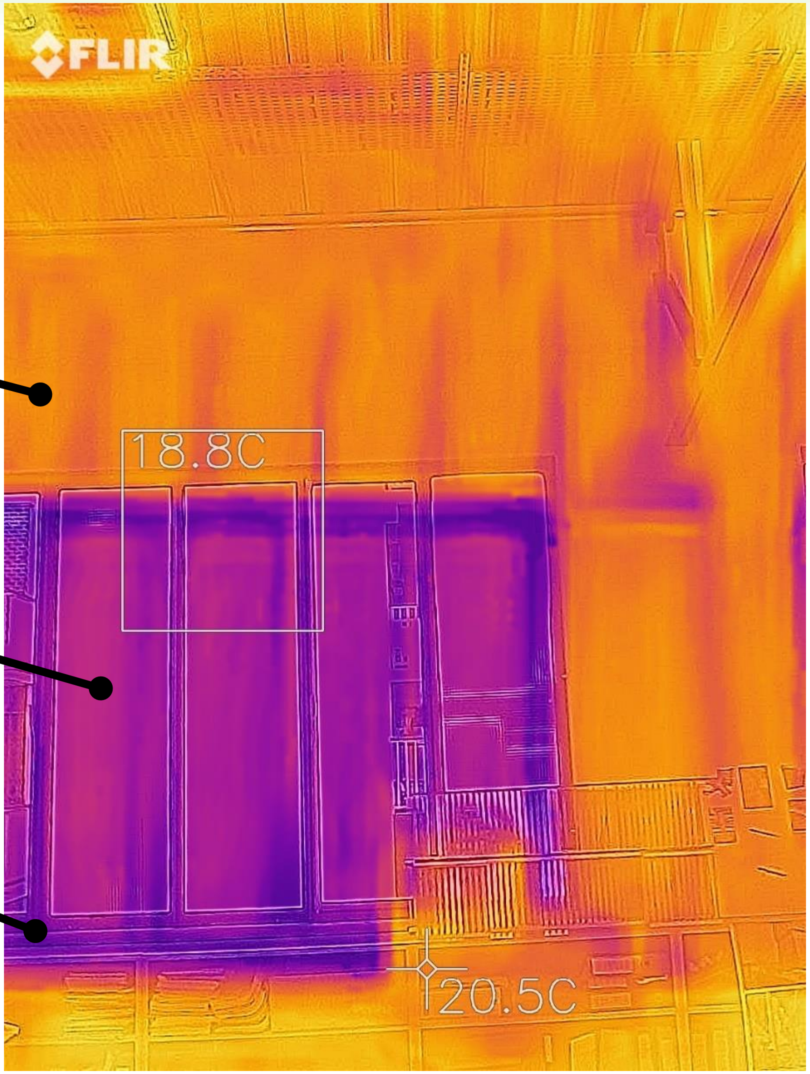
IR imagery

Insulating panels

Glazing

Metallic window carpentry

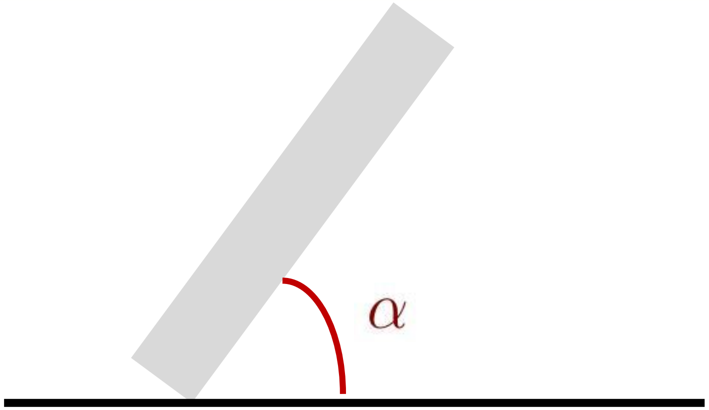


2. THERMAL TRANSFERS ON A BUILDING'S SCALE

1. Mechanisms
2. Thermal transfer map
3. Thermal inertia
4. Evaporative cooling
5. Thermal comfort

Form factor:

$$F_{se,ae} = \frac{1 - \cos\alpha}{2}$$

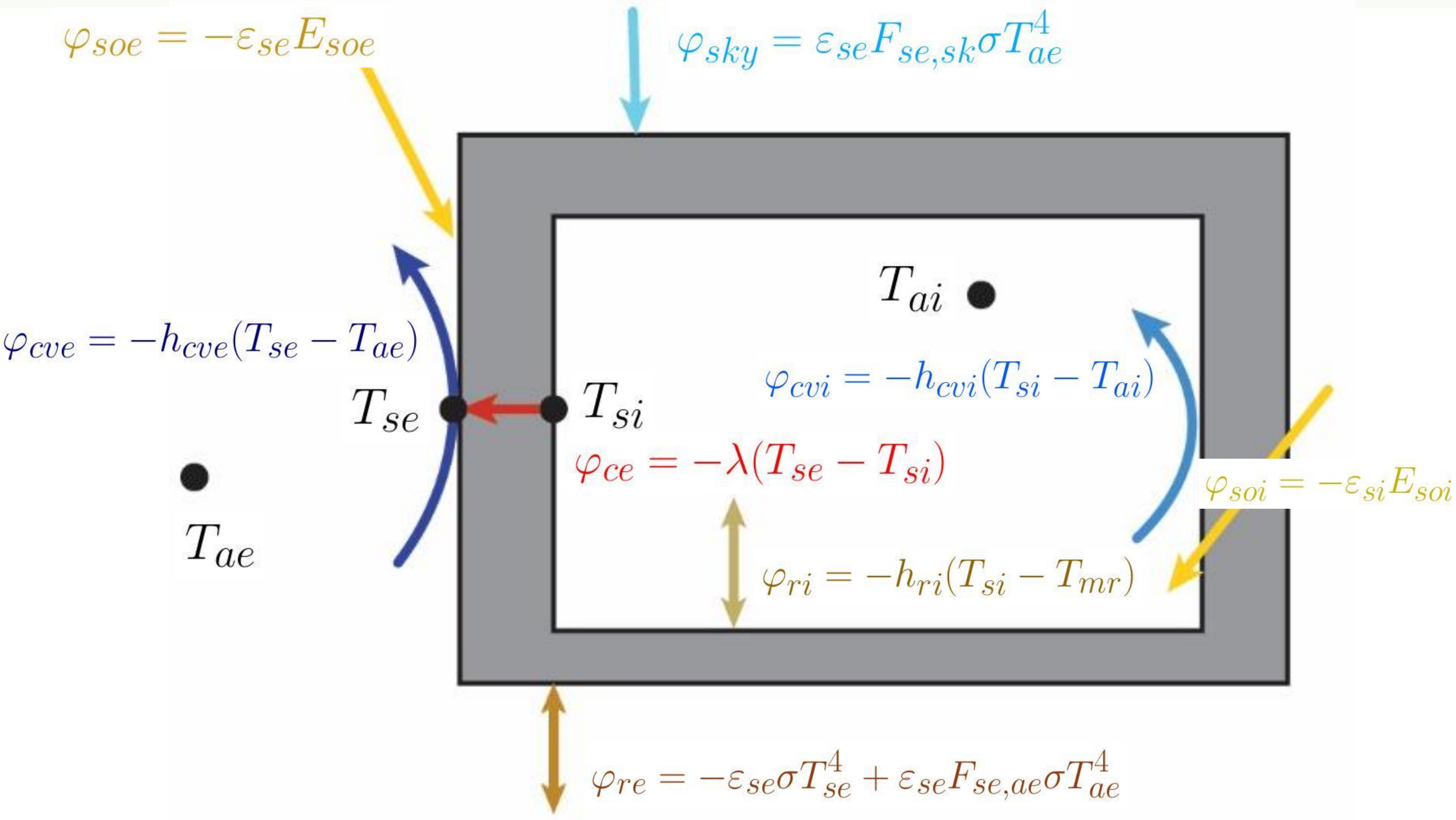


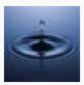
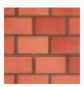
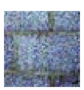
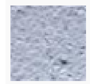
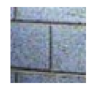
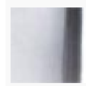
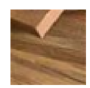
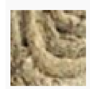
$$F_{se,sk} = \frac{1 + \cos\alpha}{2}$$

Surface	$F_{se,ae}$	$F_{se,sk}$
Vertical	0.5	0.5
Horizontal	0	1
45°	0.15	0.85

$$F_{se,sk} + F_{se,ae} = 1$$

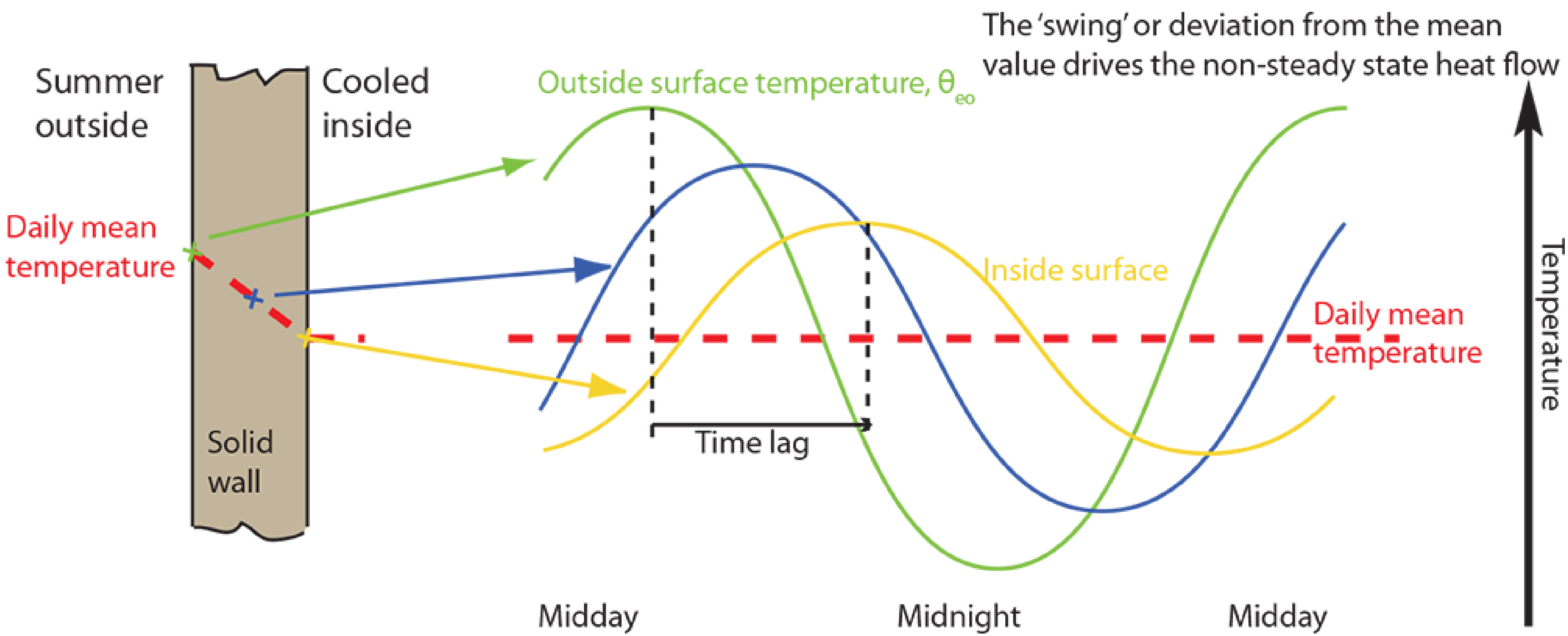
2.2 Thermal transfer maps



	Material	Specific heat capacity	Thermal conductivity	Density	Effectiveness
	water	4200	0.60	1000	high
	stone	1000	1.8	2300	high
	brick	800	0.73	1700	high
	concrete	1000	1.13	2000	high
	unfired clay bricks	1000	0.21	700	high
	dense concrete block	1000	1.63	2300	high
	gypsum plaster	1000	0.5	1300	high
	aircrete block	1000	0.15	600	medium
	steel	480	45	7800	low
	timber	1200	0.14	650	low
	mineral fibre insulation	1000	0.035	25	low
	carpet	-	0.05	-	low

Specific heat in J/kg.K, density in kg/m^3, thermal conductivity in W/m.K

2.3 Thermal inertia



2.3 Thermal inertia

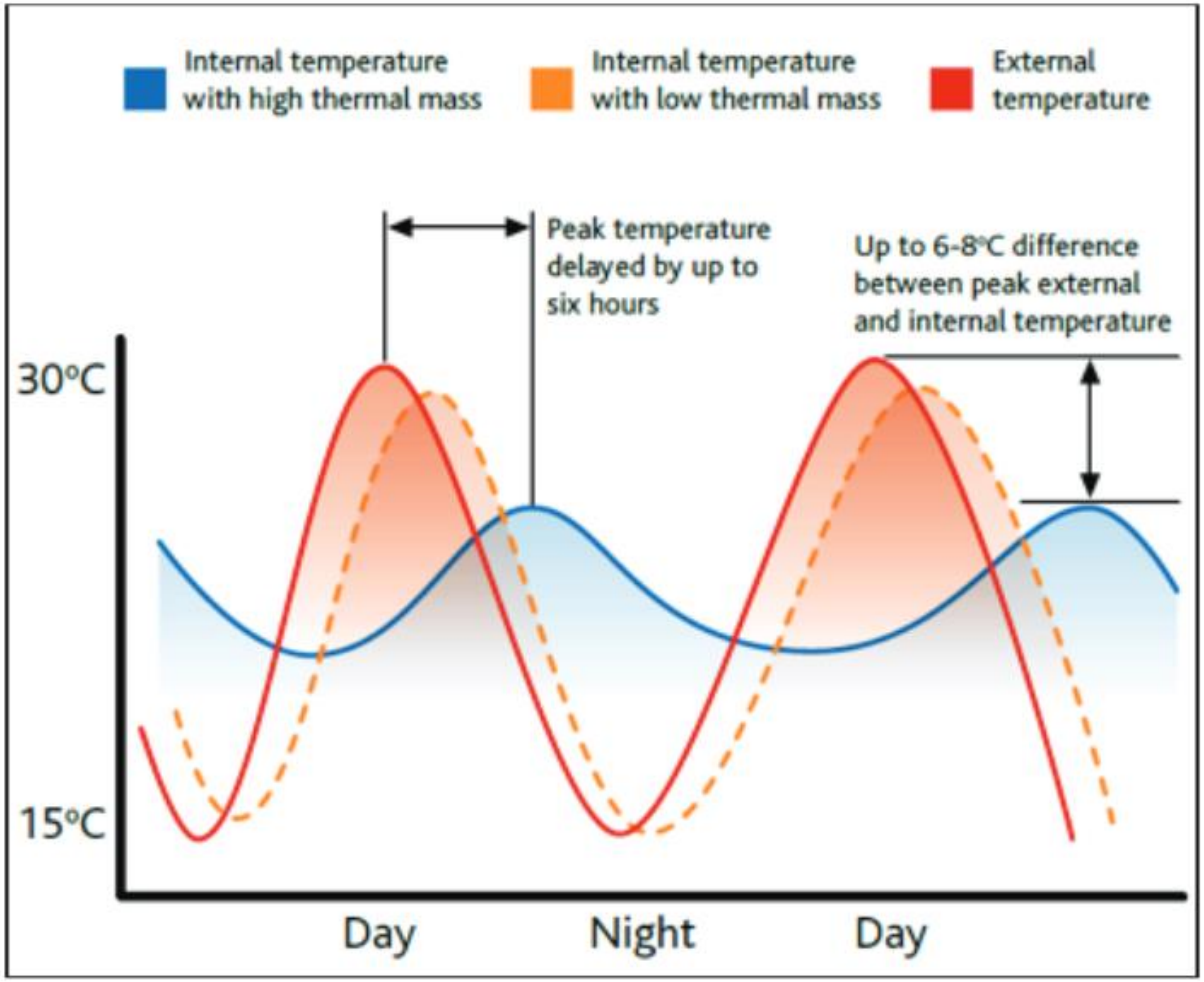
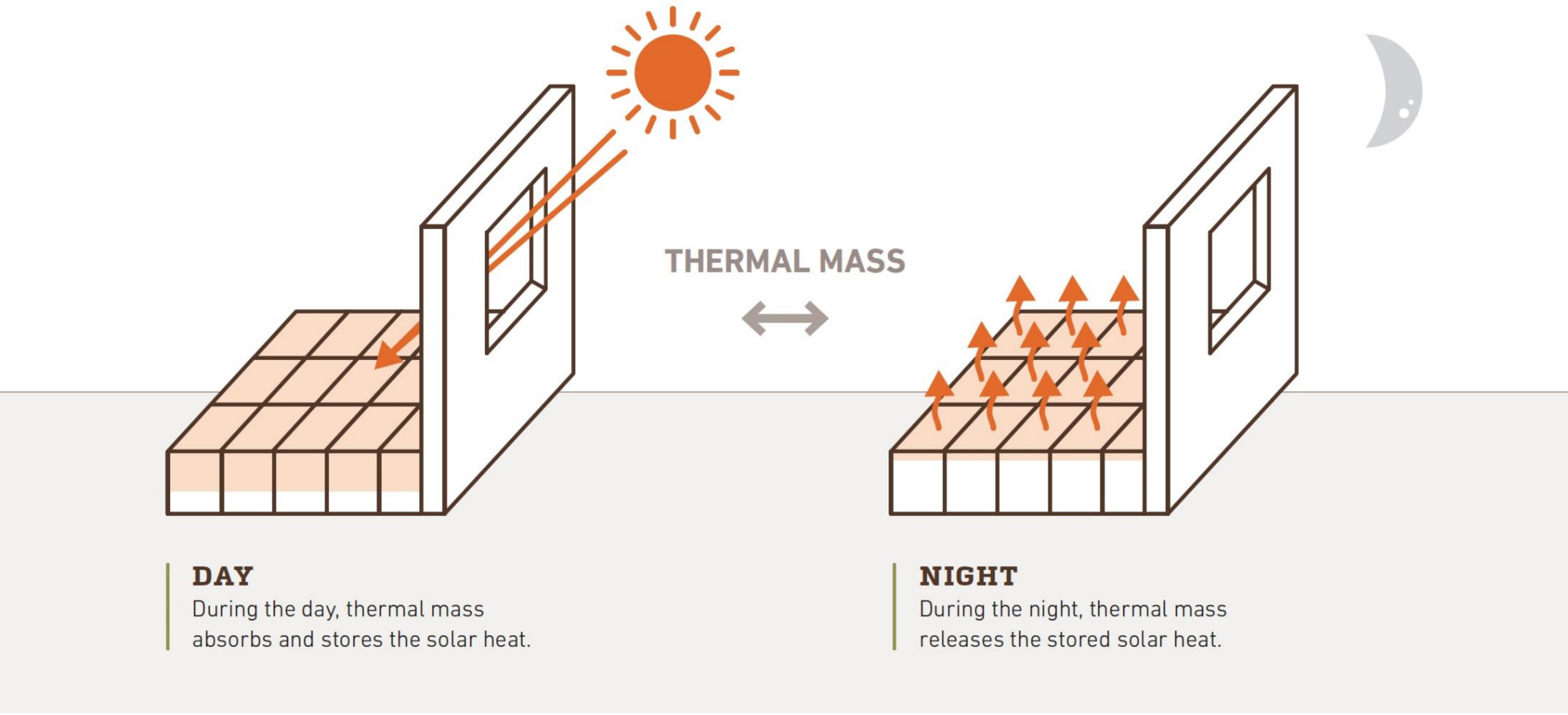


Figure 1. Stabilising effect of thermal mass on internal temperatures [1]

2.3 Thermal inertia

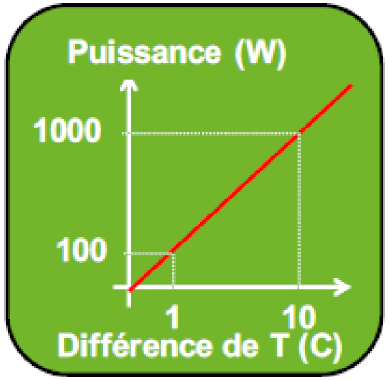


2.3 Thermal inertia

FONDATION BÂTIMENT ÉNERGIE

L'évaluation de la perte thermique

- **Coefficient de perte thermique** (infiltration et conduction) dépend de l'isolation du bâtiment et de son étanchéité à l'air
  - HLC ~ $U_{BAT}.A_{t,BAT} + ACH.\rho.C_p$ (en W/K)



- Ordres de grandeur :

Bâtiment	R [m².K/W]	U [W/m²/K]
A rénover	0,33 – 0,66	1,5 – 3
Neuf	2,0 – 5,0	0,2 – 0,5

- L'évaluation in-situ :

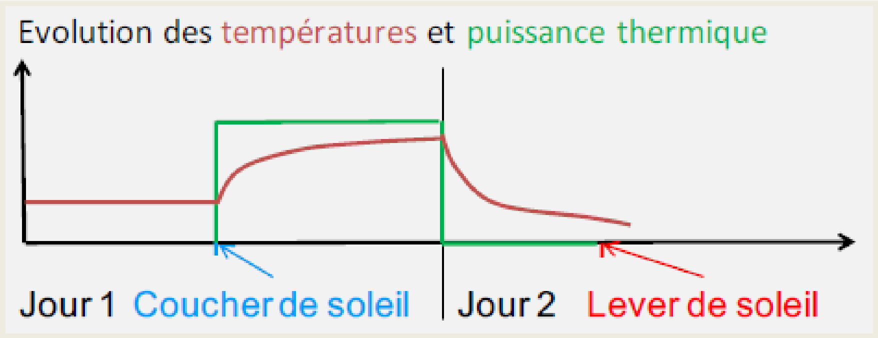
Méthode	Description	+/-
Diagnostic de Performance Energétique (DPE)	Evaluation de la consommation énergétique du logement	+: réglementaire, rapide - : dépend de l'usage
« Co-heating » [1]	2 à 3 semaines de régulation en température	+ : précise - : long, hiver, pas d'occupation

- **Pas de méthode rapide et fiable**

FONDATION BÂTIMENT ÉNERGIE

La méthode QUB/e

- Développée et brevetée par Saint-Gobain [2,3]
- Une mesure dynamique rapide



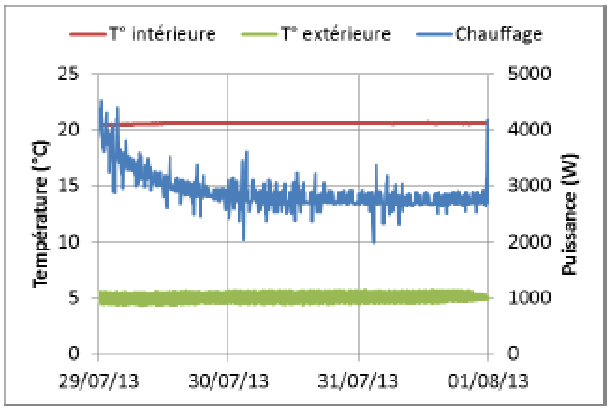
- Evolution de la température intérieure en fonction de la puissance thermique (flux thermique) dissipée et de la température extérieure
  - Pendant la nuit
  - Sans occupation

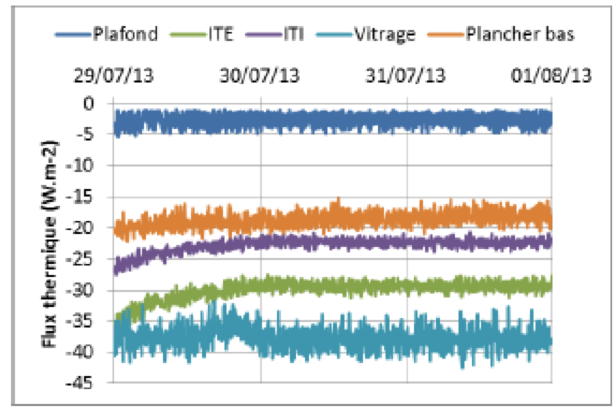
Système de chauffage Programmable Electrique

Capteurs de température et puissance (fluxmètres) Intérieur et extérieur (sur les éléments à mesurer)

Une expérience en climat contrôlé

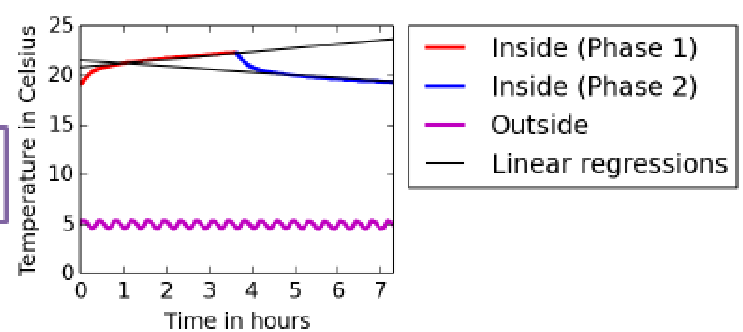
- Quelques jours en chambre climatique avec une excellente précision





⇒ QUB/e en quelques heures

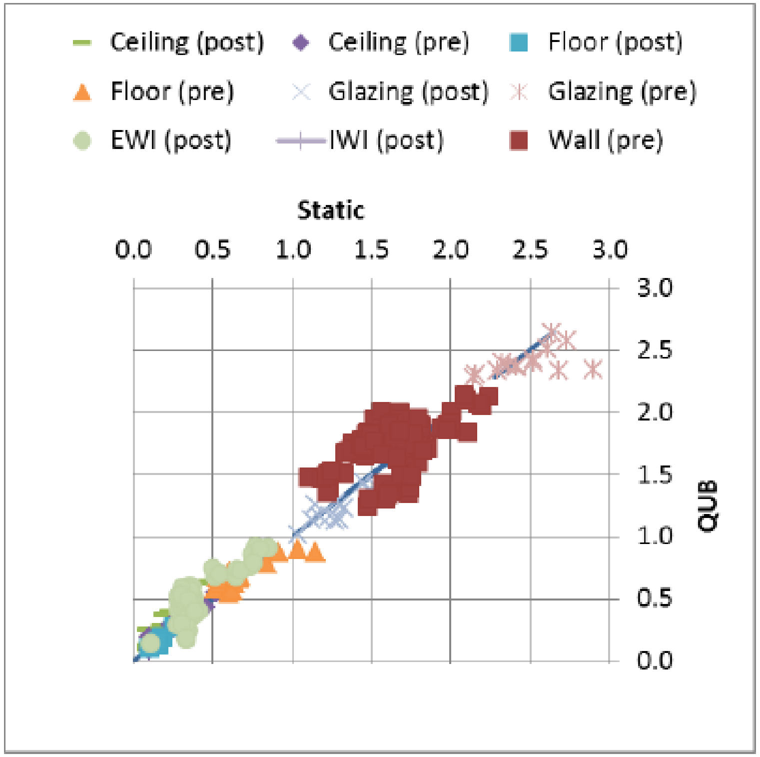
$$P_{Therm}^{(i)} = HLC(T_{IN} - T_{OUT}) + C\frac{\Delta T_{IN}}{\Delta t}$$



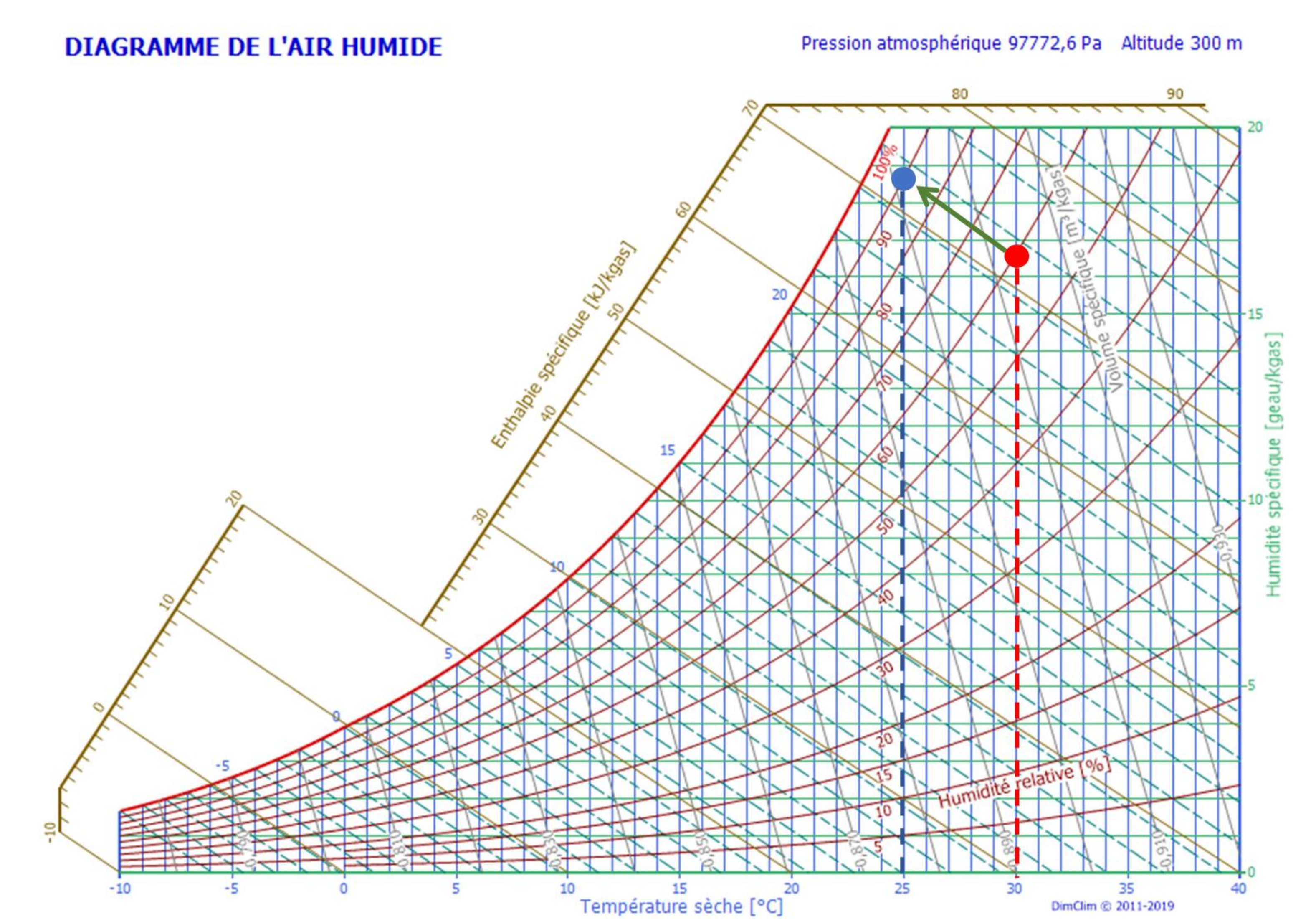
FONDATION BÂTIMENT ÉNERGIE

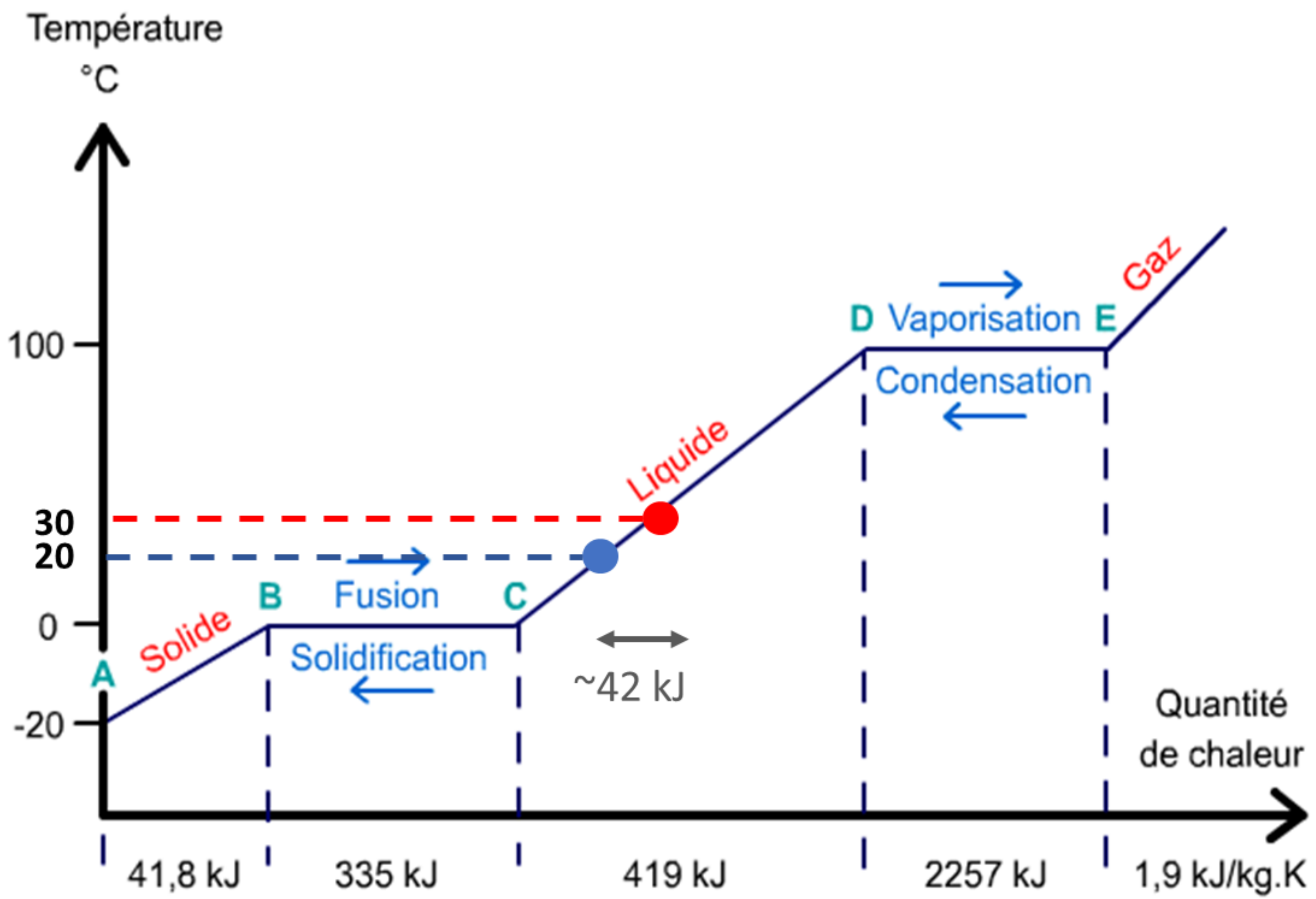
Valeur U [W/m²/K] : Statique vs QUB/e

- 6 mesures QUB/e réalisées à chaque étape
- 48 points de mesures de flux thermique
- Bonne corrélation entre les mesures QUB/e et statique
- Quel que soit l'élément mesuré (niveau d'isolation et inertie)



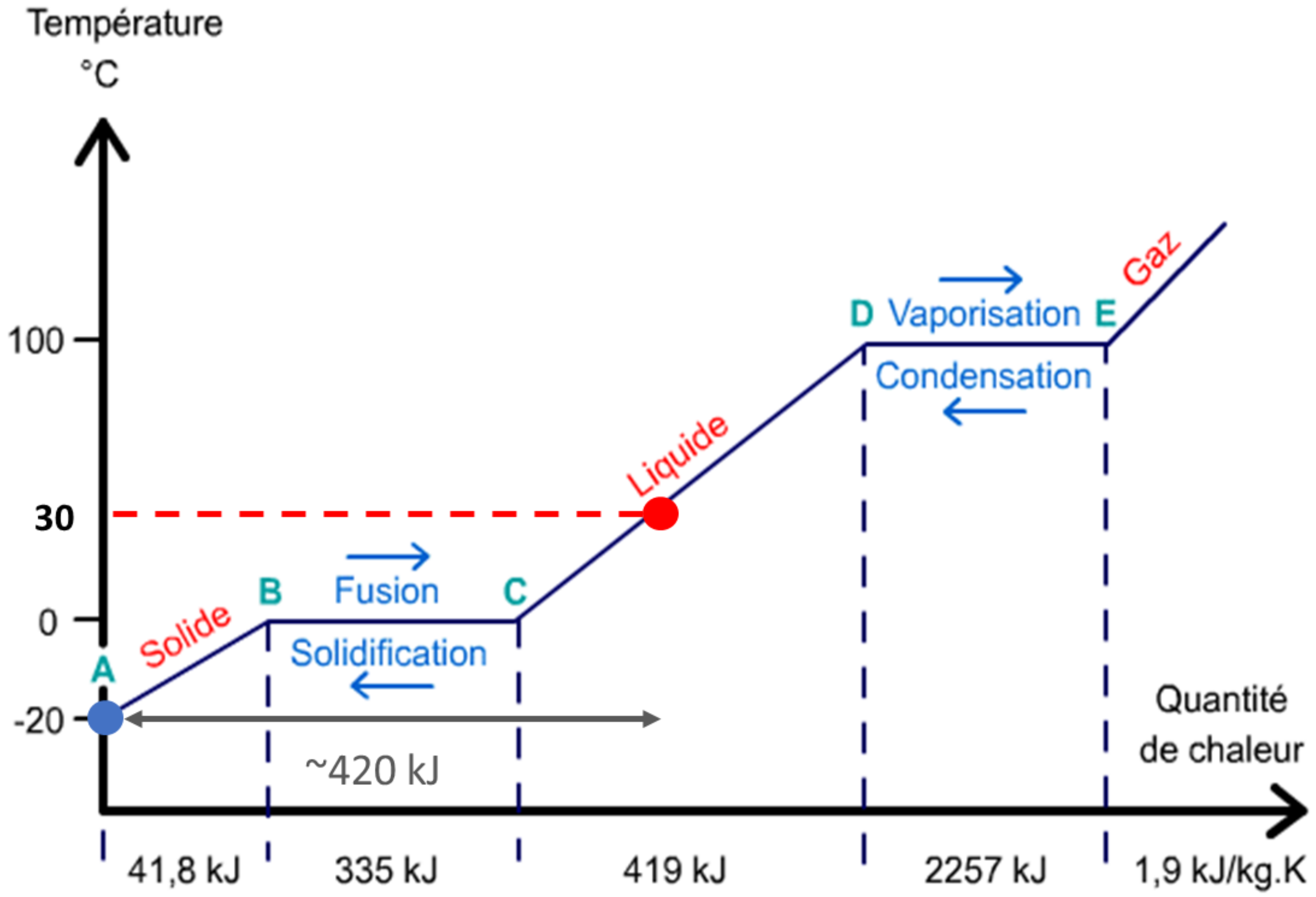
2.4 Evaporative cooling





Température
°C
100
30
20
0
-20
A
Solide
B
Fusion
C
Solidification
Liquide
~42 kJ
D
Vaporisation
E
Condensation
Gaz
Quantité
de chaleur
41,8 kJ
335 kJ
419 kJ
2257 kJ
1,9 kJ/kg.K

2.4 Evaporative cooling



2.4 Evaporative cooling

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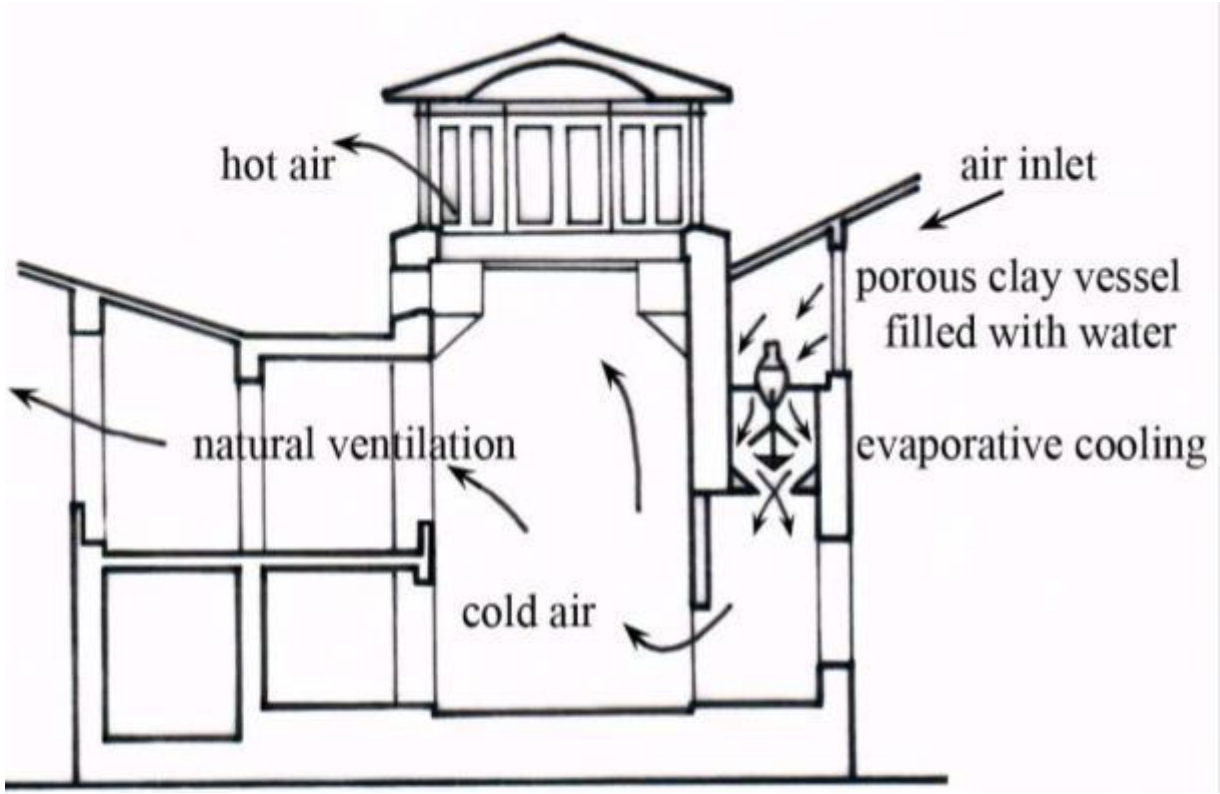
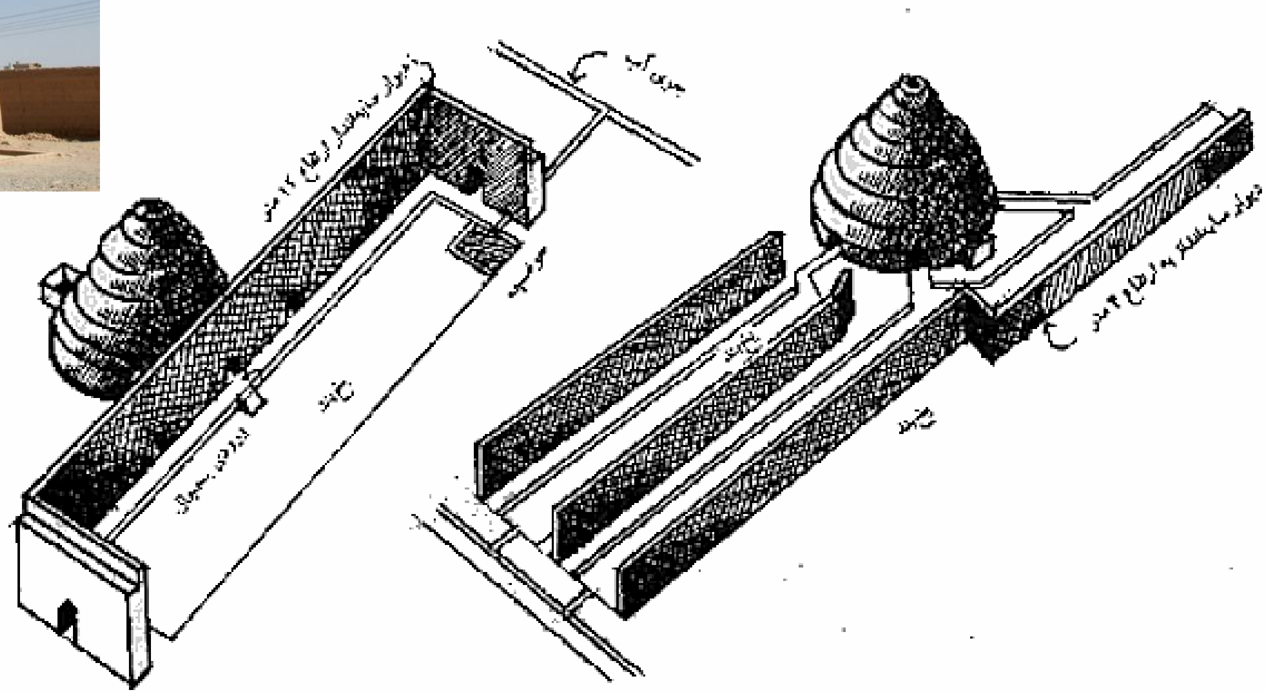


2.4 Evaporative cooling

© Slate



© Misfit’s architecture

2.4 Evaporative cooling

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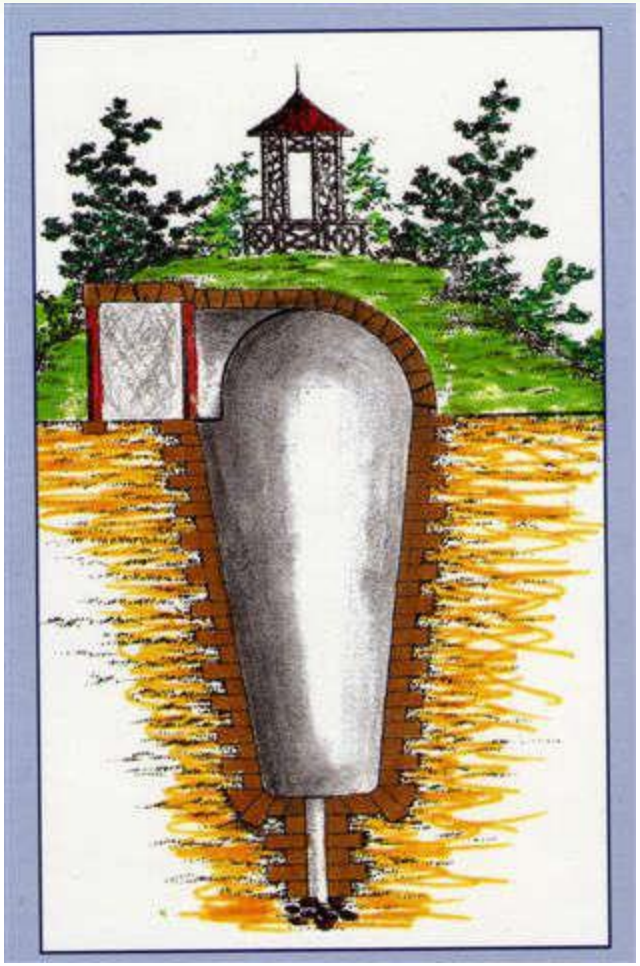

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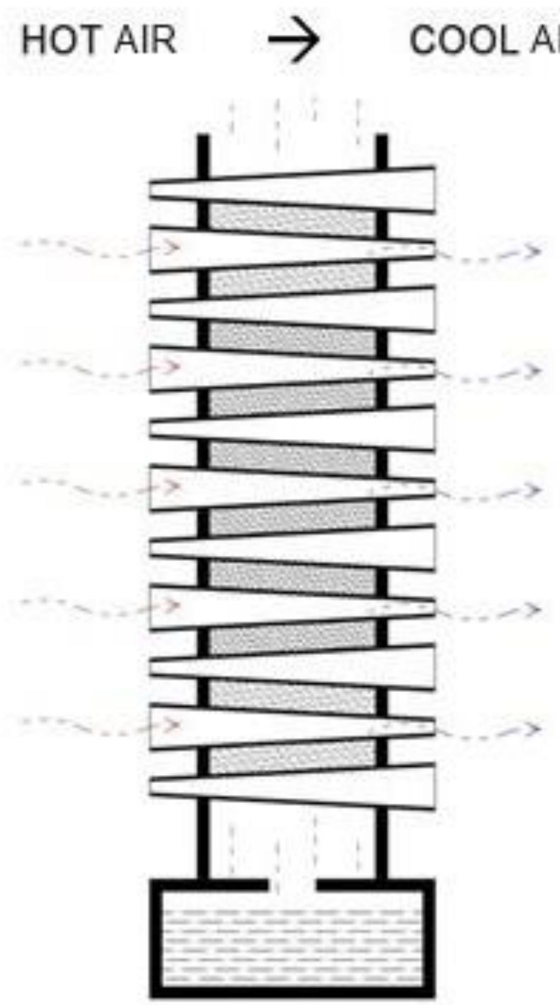
2.4 Evaporative cooling



50°C → 35°C

** Other cooling methods ? **

Applied Thermal Engineering 142 (2018) 100–109

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Applied Thermal Engineering

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Research Paper

Bose-Einstein (*B-E*) photon energy reformation for cooling and heating the premises naturally

Md. Faruque Hossain*

Green Globe Technology, 4323 Colden Street 15L, Flushing, NY 11355, USA
Department of Civil and Urban Engineering, New York University, 6 Metrotech Center, Brooklyn, NY 11201, USA

HIGHLIGHTS

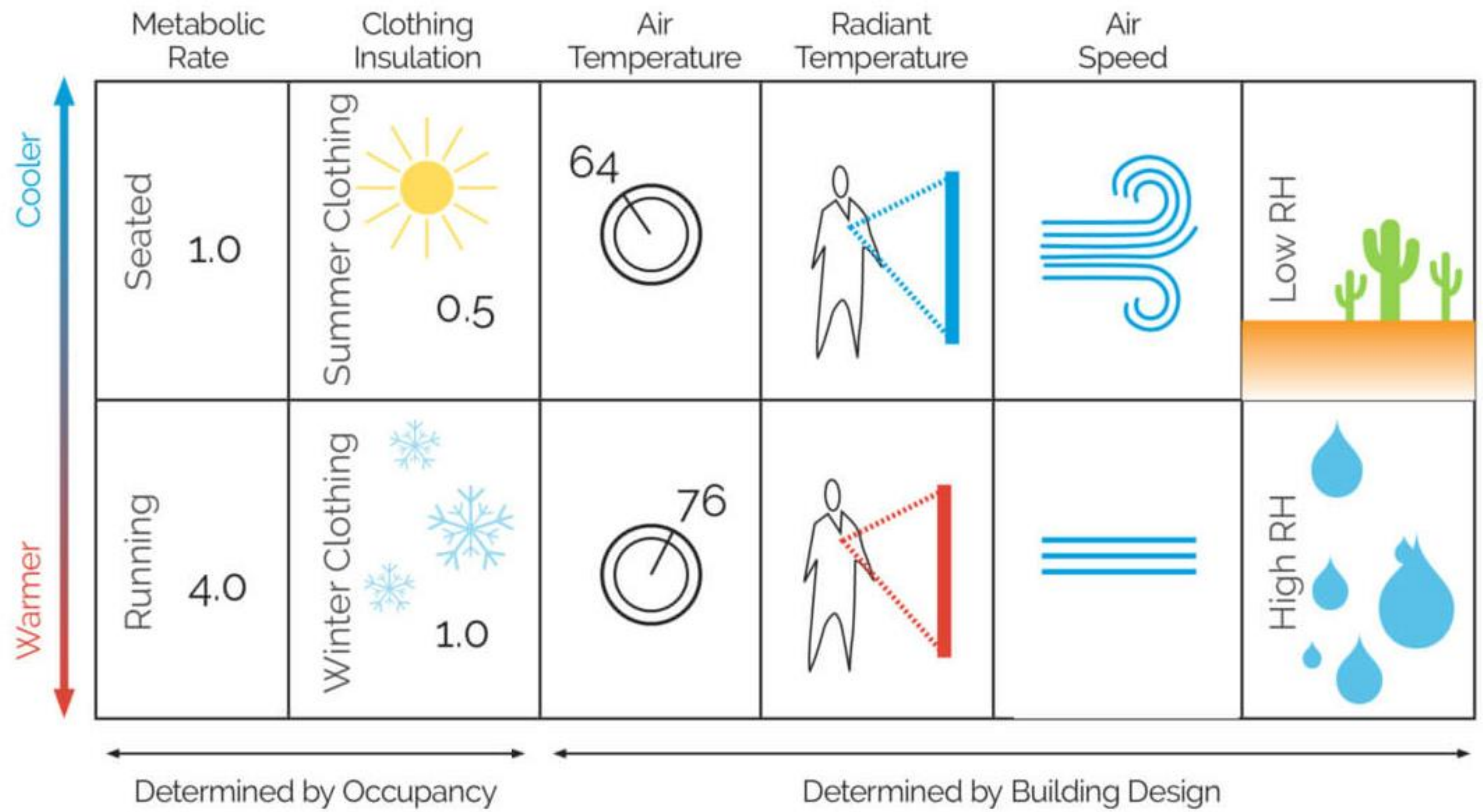
- Bose-Einstein photon mechanism has been remodeled.
- Heating and cooling photon been modeled to control the photon energy.
- Quantum field being utilized to transform photon into thermal energy.
- Photonic thermal energy being used to cool and heat the building naturally.

** Other cooling methods ? **

A B S T R A C T

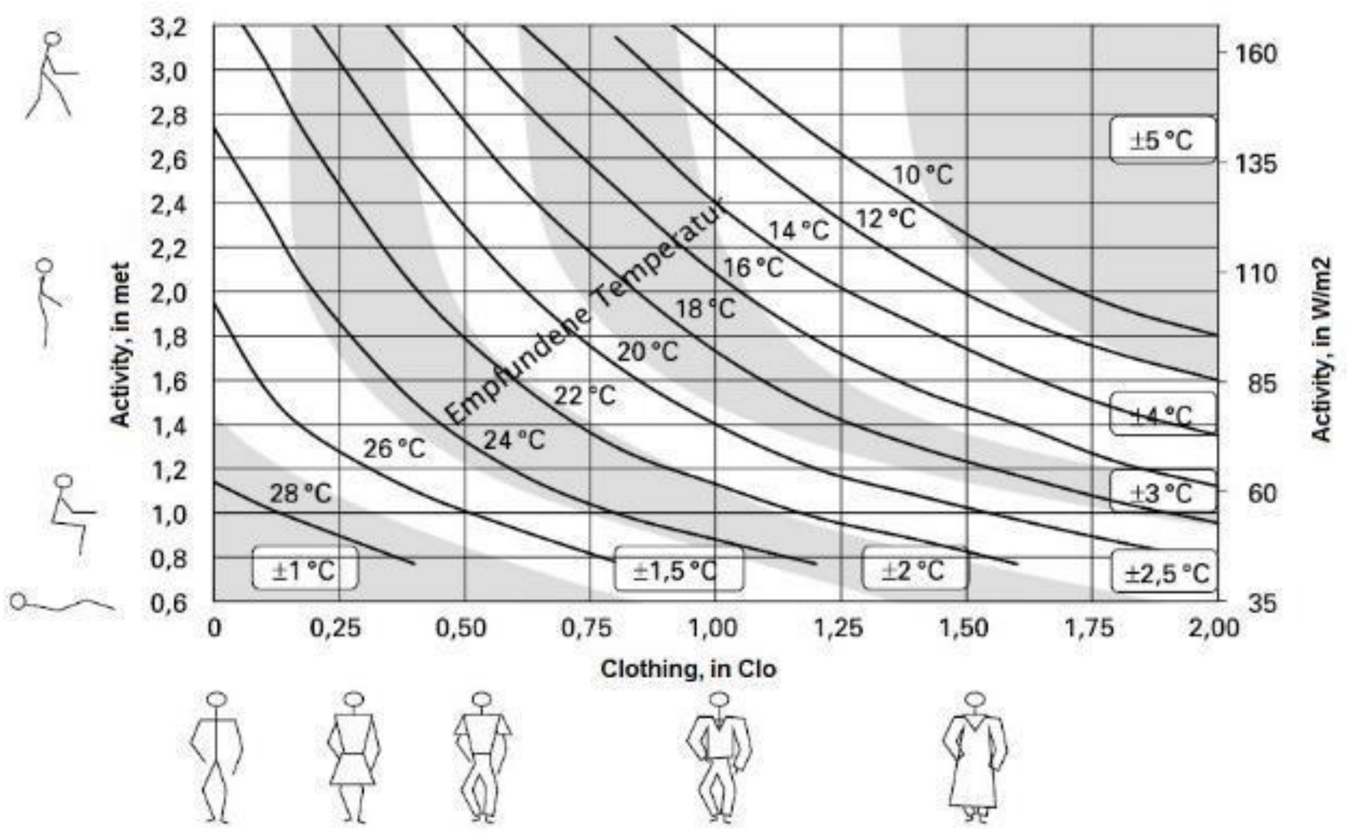
Conventional heating and cooling systems consume fossil fuels and release toxic gases into the environment, so sustainable heating and cooling systems are urgently needed. To mitigate this perplexity, photon particles are being decoded by the Bose–Einstein (*B-E*) photon distribution mechanism in the Helium assisted glazing wall to cool the building naturally by inducing photonic band-gap of cooling state photons. This cooling-state photon denoted, as the *Hossain Cooling Photon* (HcP^-). Once need this HcP^- can be transformed into a thermal state photon, denoted as the *Hossain Thermal Photon* (HtP^-) formed by Higgs Bosons ($H \rightarrow \gamma\gamma^-$) electromagnetic quantum field utilizing by two diode thermal semiconductor. Because the $H \rightarrow \gamma\gamma^-$ quantum field is initiated by an extremely short-range weak force that enforces the electrically charged HcP^- quantum get excited to transform it into an HtP^-. The formation of HcP^- and the transformation of HtP^- are being demonstrated by a series of mathematical tests that confirms the viability of the decoded photons (HcP^- and HtP^-) are actively feasible into the glazing wall to cool and heat the premises naturally.

Parameters that influence subjective perception:



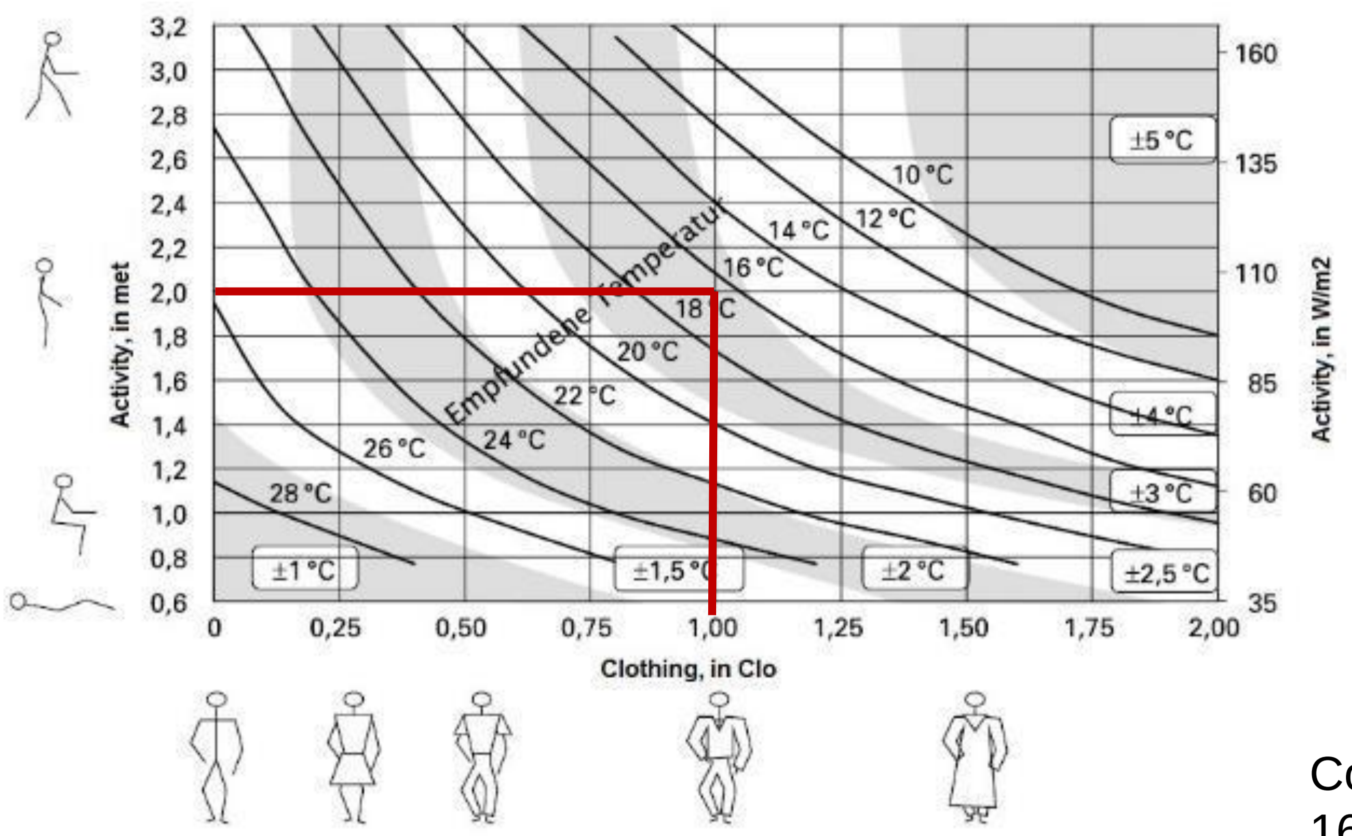
© Payette

Optimum operative temperature:



MET = Metabolic Equivalent of Task
1met = 4.184 kJ/kg.h

Optimum operative temperature:

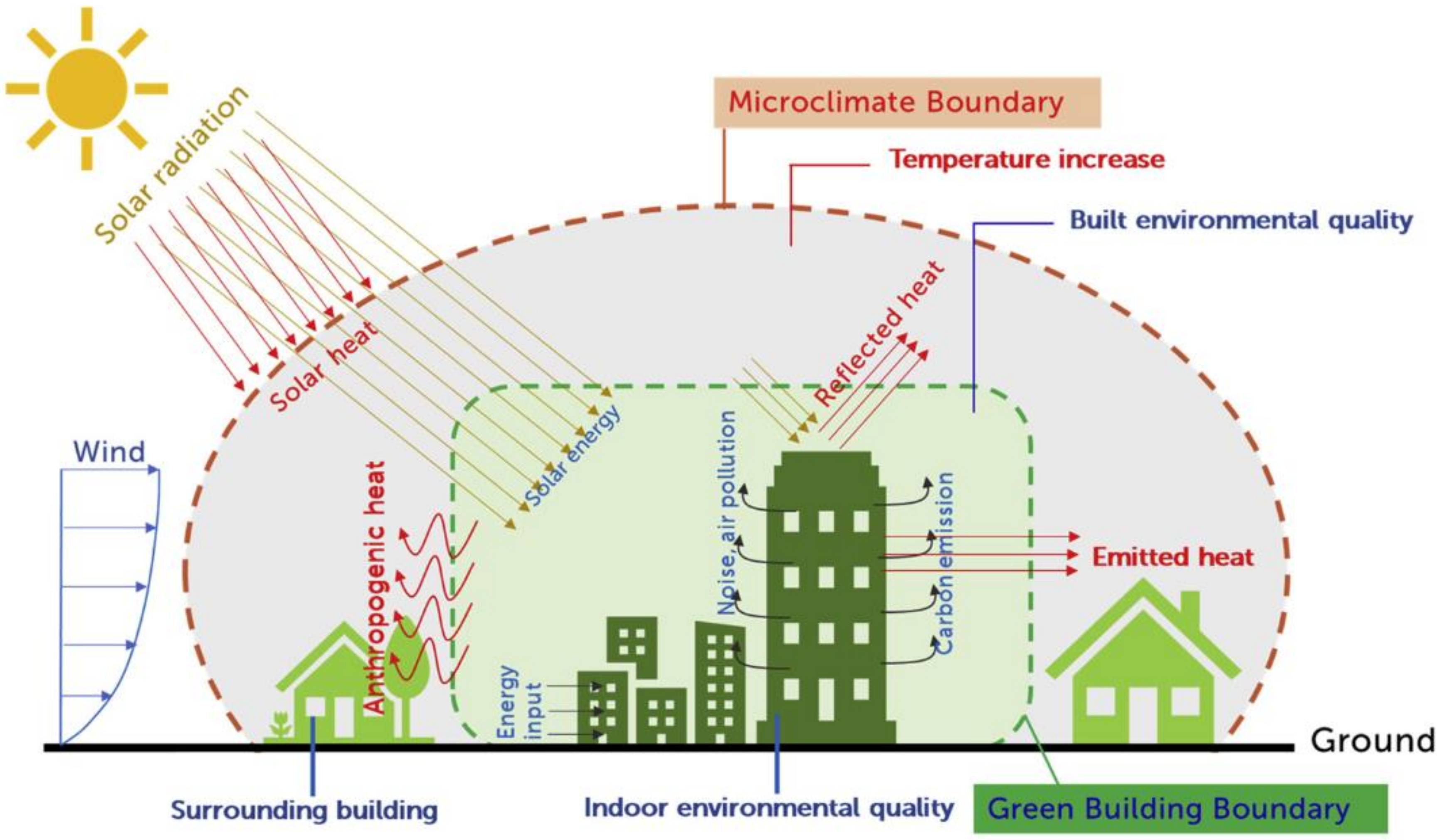


Comfort temperature = 16.5°C +\- 3°C

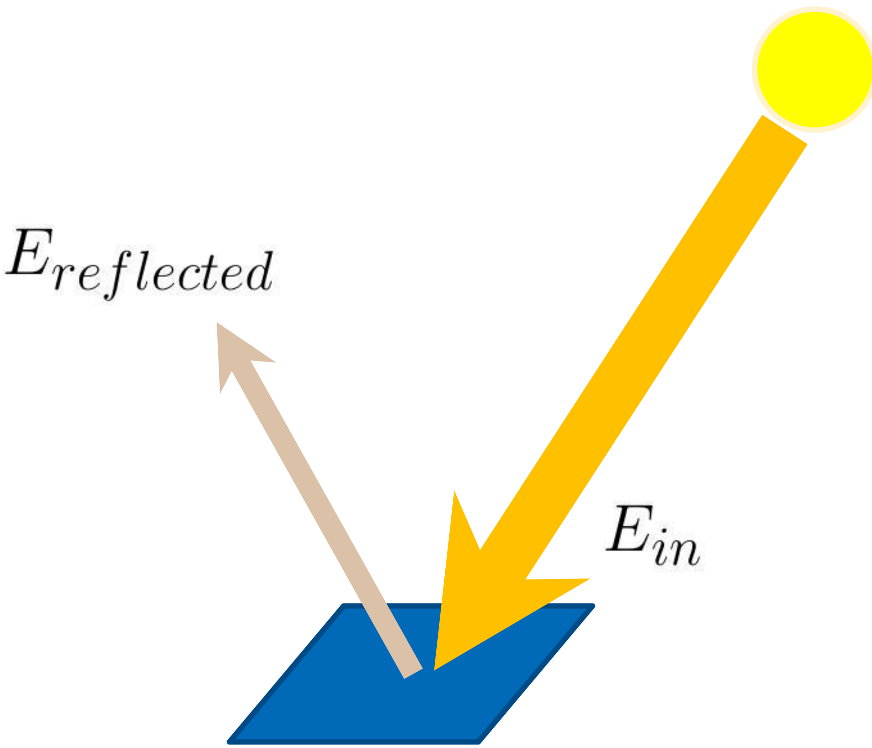
3. THERMAL TRANSFERS AT THE CITY'S SCALE

1. Phenomena to be taken into account
2. Urban Heat Island effect

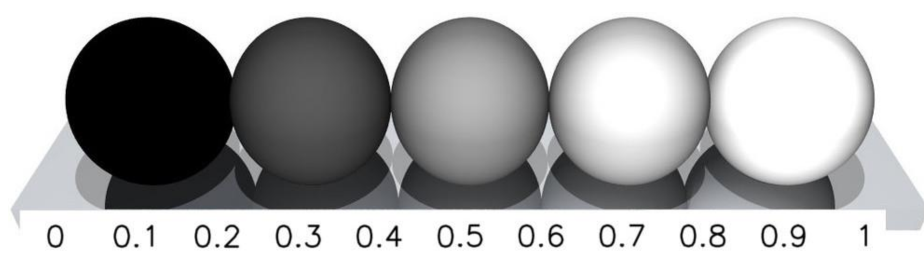
3.1 Phenomena to be taken into account



3.1 Phenomena to be taken into account



$$albedo = \frac{E_{reflected}}{E_{in}}$$



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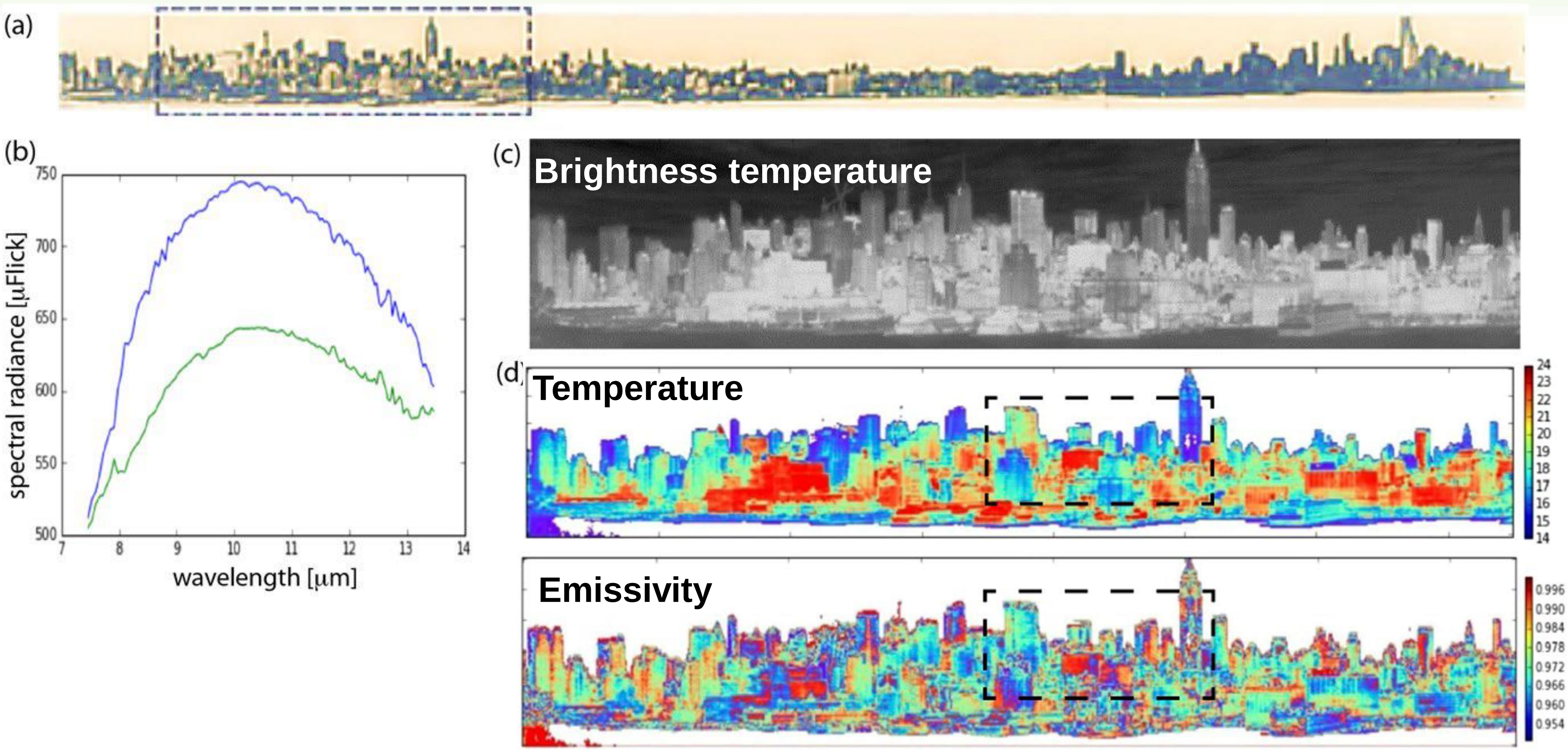
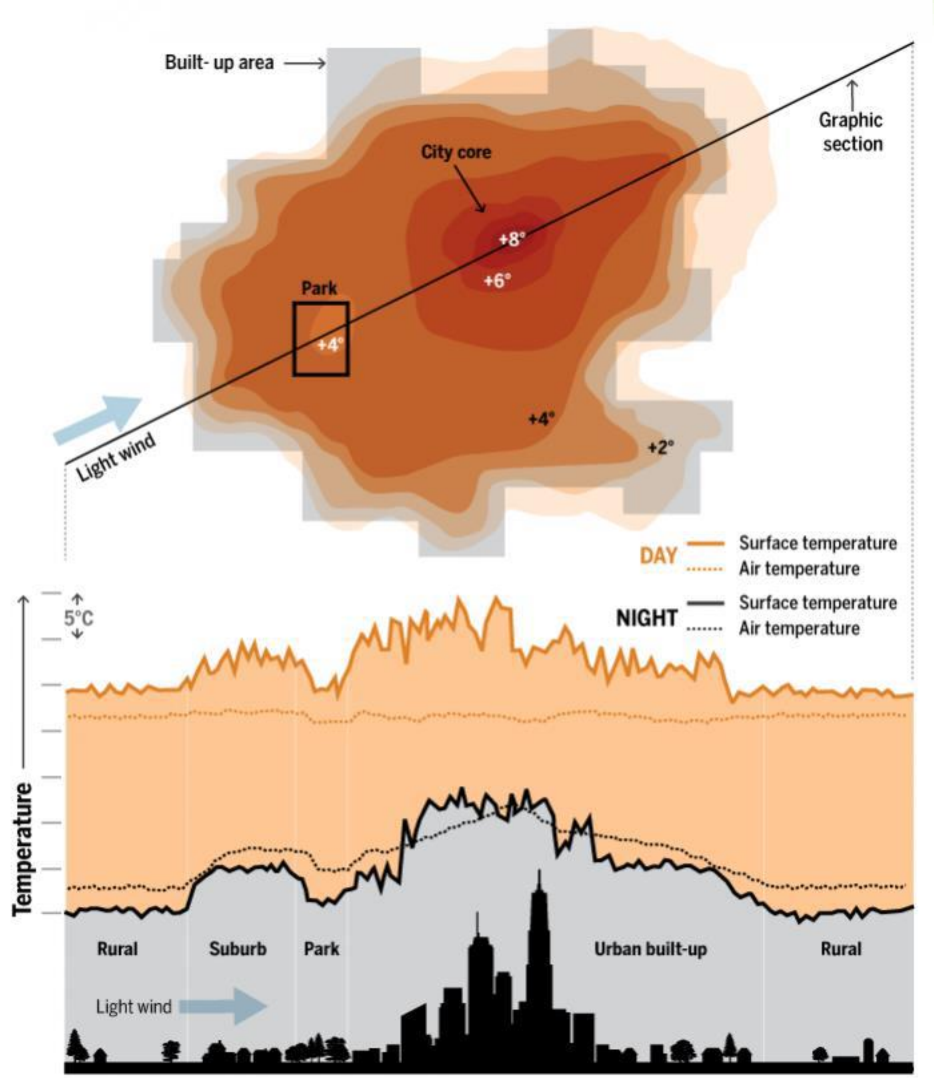
3.1 Phenomena to be taken into account

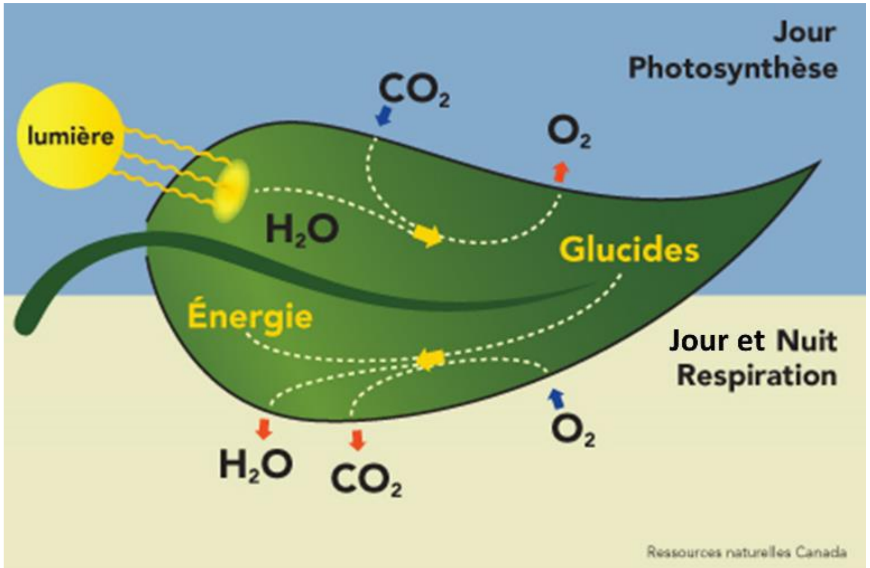


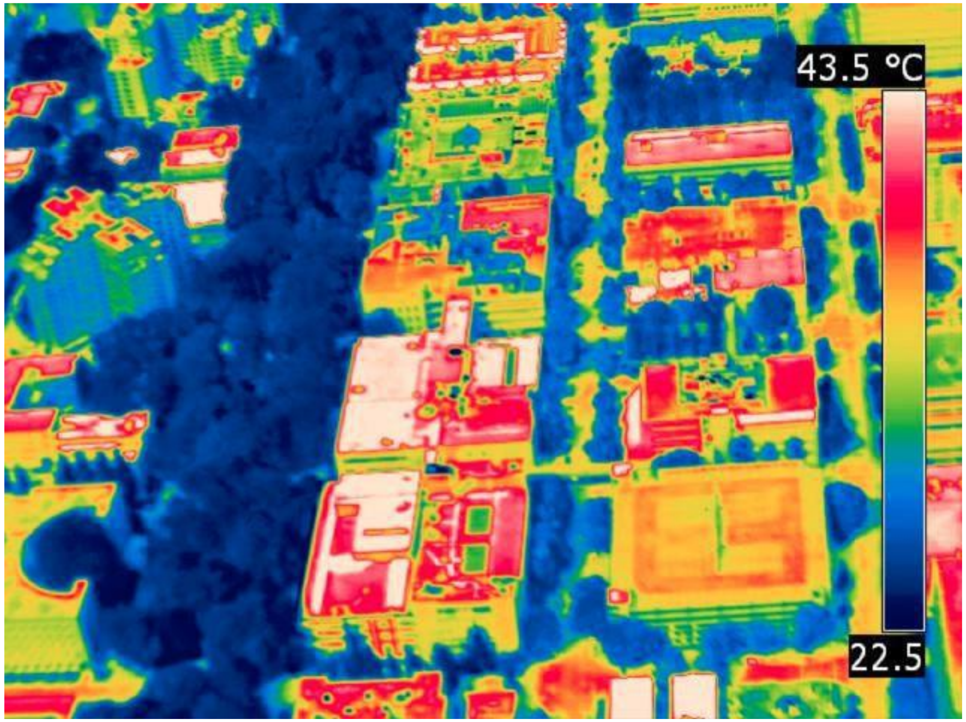
3.2. Urban Heat Island Effect



Vegetation :

- Larger albedo than concrete
- Absorbs and retain rainwater
- Evapotranspiration



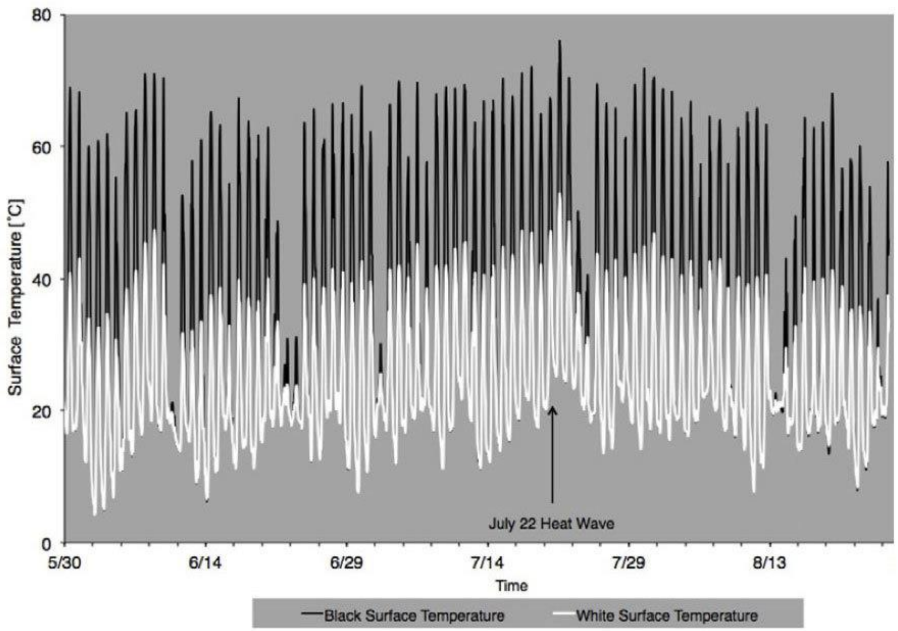


© Portland State University

$$C_6H_2O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + energy$$

© Ressources naturelles Canada

3.2. Urban Heat Island Effect



© Gaffin et al.

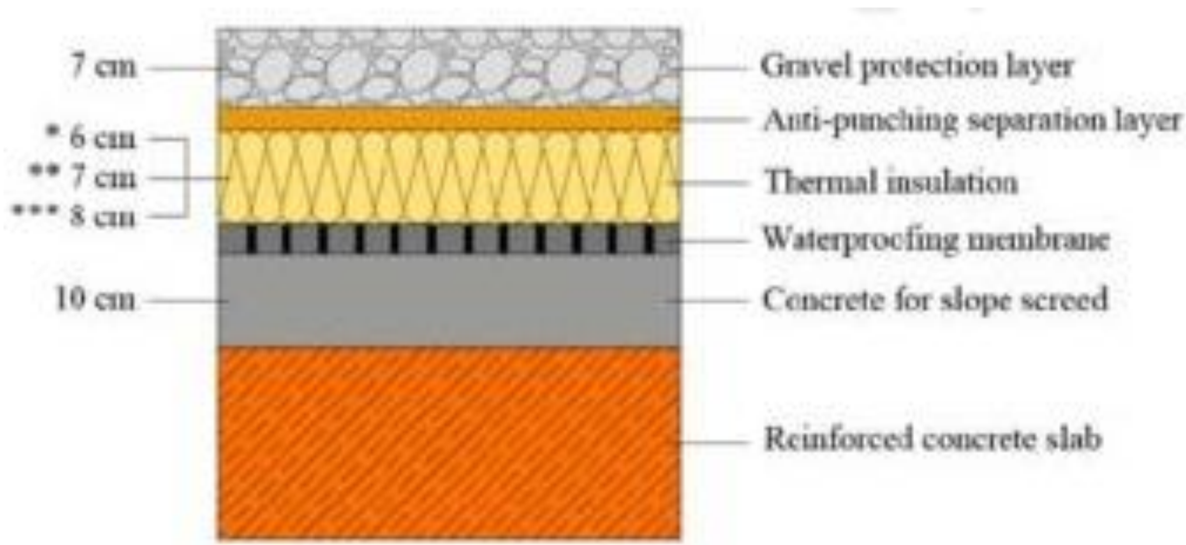
© NASA

New York « Cool Roofs » Initiative

© Huffington Post

	Material	Specific heat capacity	Thermal conductivity	Density	Effectiveness
	water	4200	0.60	1000	high
	stone	1000	1.8	2300	high

Specific heat in J/kg.K, density in kg/m^3, thermal conductivity in W/m.K
© Greenspec



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Determine the temperature in an igloo.

Introduce your assumptions and determine what is the most efficient way to heat the igloo.

<u>Parameters you may find useful:</u>

$$\lambda_{snow} = 0.15\, W.m^{-1}.K^{-1}$$

$$\lambda_{packed\,snow} = 0.3\, W.m^{-1}.K^{-1}$$

$$\lambda_{ice} = 1.7\, W.m^{-1}.K^{-1}$$

$$\sigma = 5.67 \times 10^{-8}\, W.K^{-4}.m^{-2}$$

Wikipedia:

- T_{ext} = -45°C, T_{in} = -7 – 16°C

Ice hotel:

- T_{ext} = -25°C, T_{in} > -5°C

© Ice Hotel

ASSIGNMENT for March 5th

On Dokeos/Documents/Physics_and_Architecture/Bibliography_Thermal_Considerations, choose one article and summarize it.

Alternatively, choose a subject in relation with thermal issues in the building or in the city, research it and summarize your findings.

Start by giving the article's main point (usually stated in the « abstract »).
Mention whether it is a theoretical study, a modeling or an experimental work.
Outline the main arguments and shortly discuss them (critically).
A schematics is also acceptable if properly labeled.

Between ½ a page to 1 page should be enough. Post it on Dokeos/Travaux/