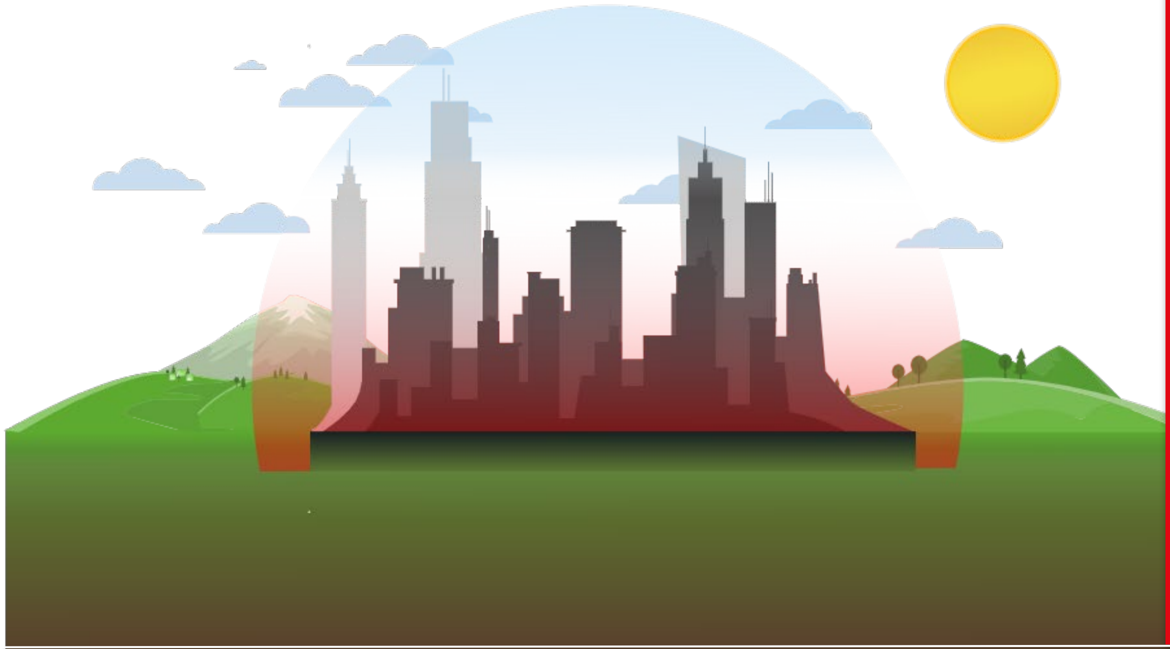

CIVIL-309: URBAN THERMODYNAMICS

Assist. Prof.
Dolaana Khovalyg

Lecture 11:
Urban Renewable Energy Sources

16 December 2024

Course Schedule

Week	Date	Time	ID	Topics	Responsible
12	25.11	2 x 45’	**L9**	**Human Outdoor Comfort:** Parameters affecting human comfort and comfort indices (UTCI, PET)	DK
		1 x 45’	**P9**	**Group work – simulation practice based on L9:** methods to calculate thermal comfort indices from ENVI-met simulation, dynamic thermal comfort simulation	KL
13	02.12	3 x 45’	--	**Intermediate presentations of group projects**	DK, KL
14	09.12	2 x 45’	**L10**	**Climate-Sensitive Urban Design:** complex interaction of all urban elements and their effect on UHI and outdoor environmental quality	KL
		1 x 45’	**P10**	**Group work – simulation practice based on L10:** developing an integrated solution in ENVI-met for the climate-sensitive urban design	KL
15	16.12	2 x 45’	**L11**	**Urban Energy** (renewable energy sources in cities). **Summary of the course.**	DK
		1 x 45’	**P11**	**Group work** - finalizing the analysis and the report	KL

Deadlines

Assist. Prof. Dolaana Khovalyg

- **Deadline for all submissions: January 10, 2025 (12:00)**

1. **Submit your group projects:** email your PDF files to dolaana.khovalyg@epfl.ch, indicate "**CIVIL-309_Group # report**" in the email subject (# - your group number)
2. **Complete the on-line course evaluation on Moodle:** already open!
3. **Submit your peer-evaluation:** everyone should complete the following *confidential* surveys according to their group number
   - Group 1: https://forms.gle/UZFqJLRWCxqLa57b9
   - Group 2: https://forms.gle/aAT9GiGgynEQNaJB9
   - Group 3: https://forms.gle/4wLNHZRwaSQZLwoA6
   - Group 4: https://forms.gle/rWP76fpuom7cCK989
   - Group 5: https://forms.gle/PRhTPy9WckzaqVyz6
   - Group 6: https://forms.gle/QdCs9QSNa6SHC9oZ8
   - Group 7: https://forms.gle/EhXv7pa8qgQ4ww9y9
   - Group 8: https://forms.gle/eBRjqY1BRbUsndfQ8
   - Group 9: https://forms.gle/CBFP6Nar9GKzGVSv6
   - Group 10: https://forms.gle/8VuSgLU6o5Y6TrZb9

CONTENT:

Urban Renewable Energy Sources:

- Introduction
- Solar energy (PV and solar thermal)
- Wind energy
- Geothermal energy
- Hydropower
- Open issues

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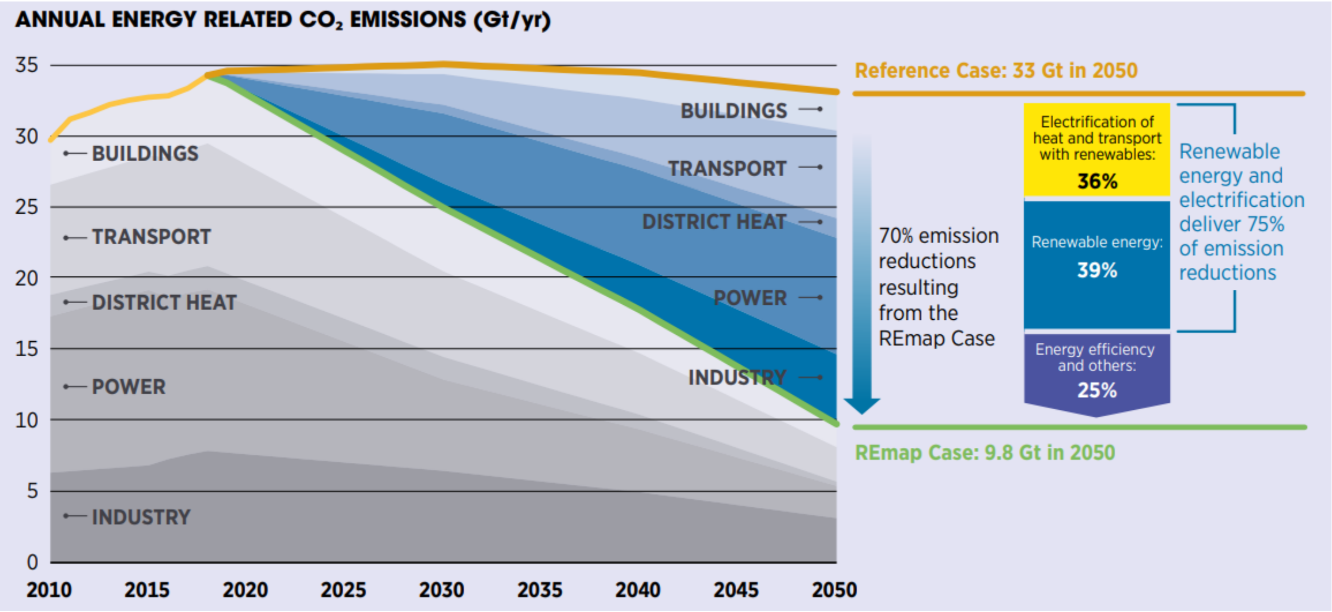
Renewable Energy Sources

- **Renewable energy**: energy obtained from **natural** and **persistent sustainable sources of energy available in the environment**. They are not depleted by the use (e.g. solar energy, hydroelectric, wind, and geothermal).
- Renewable energy currently accounts for only ~ **20%** of urban energy use, with around **2/3** in **the buildings sector** and **1/3** in **transportation** (IRENA, 2016).

- Approximately 40% of the global energy is used by the industry, 40% by commercial and domestic consumers, and 20% in transport.
- The use of **renewable energy** is **a necessity**, as with the current rate of energy use, **fossil fuels will be exhausted** by the end of **the 21st century**.



Source: IRENA, Rise of renewables in cities, 2020

What types of renewable energy can be harvested in the urban environment?

Pick top 3 energy sources

Please login:

responseware.eu

Session ID: **CIVIL309**

A. Biomass energy
B. Geothermal energy
C. Wind energy
D. Solar energy
E. Hydro power

Name the main challenges of harvesting renewable energy in cities

Please login:

responseware.eu

Session ID: **CIVIL309**

CONTENT:

Urban Renewable Energy Sources

- Introduction
- **Solar energy (PV** and solar thermal**)**
- Wind energy
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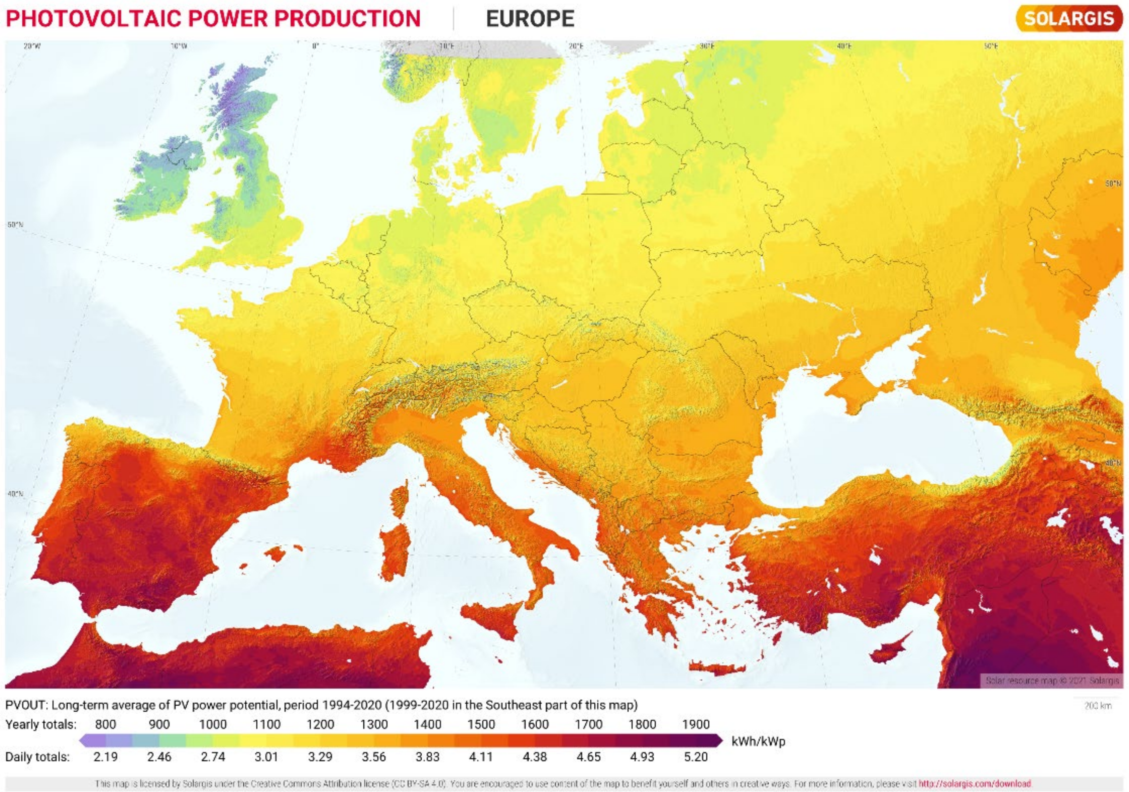
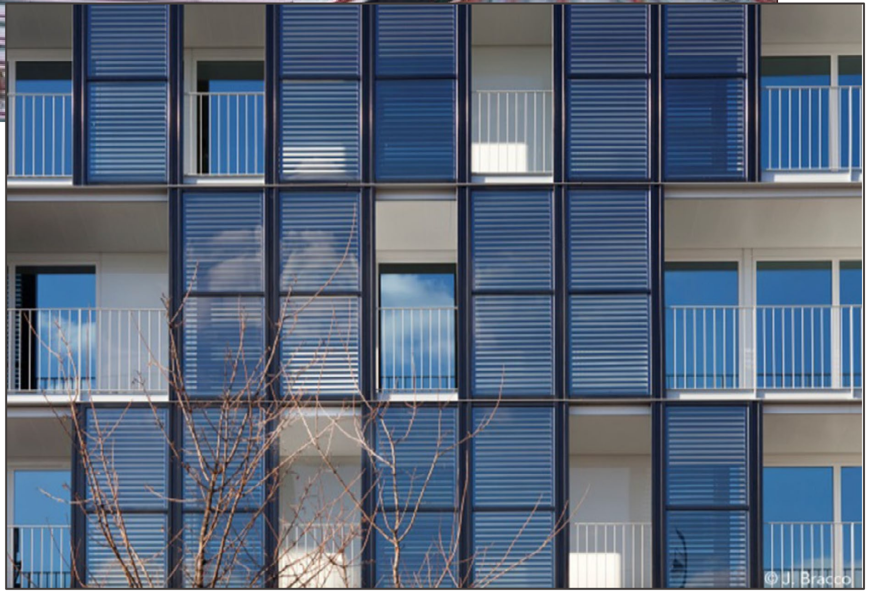
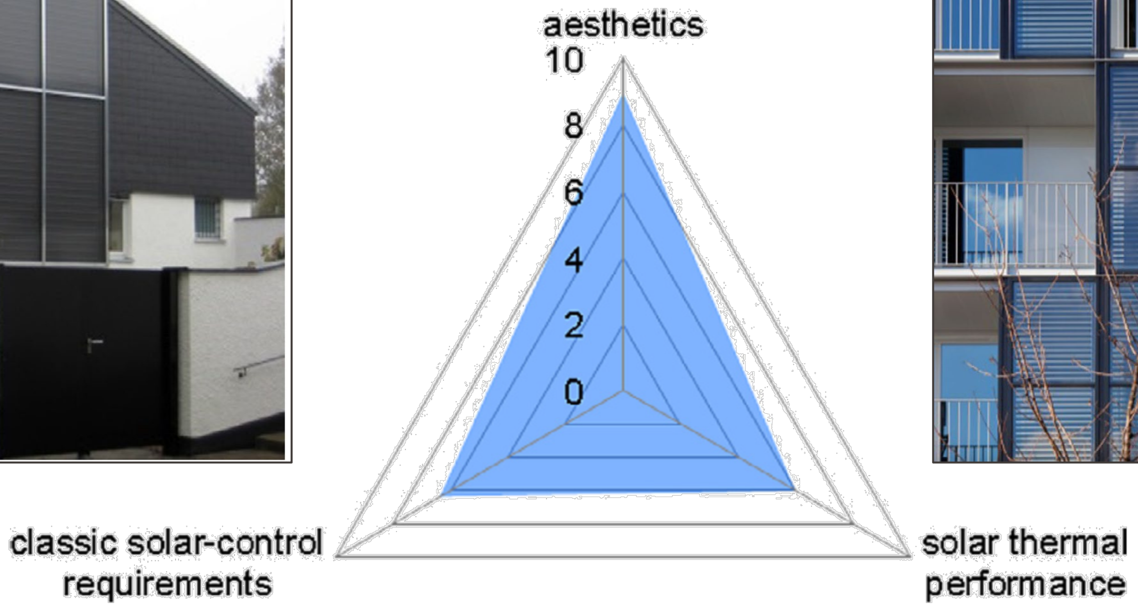
Urban renewable energy sources: Solar

- Solar energy has a relatively small energy flux density in Europe $< \mathbf{500}\ \frac{W}{m^2}$, large surfaces are required to harness it.
- The two existing solar collecting systems:
  - **Solar photovoltaic** (PV) to produce **electricity**
  - **Solar thermal** to produce **thermal energy**

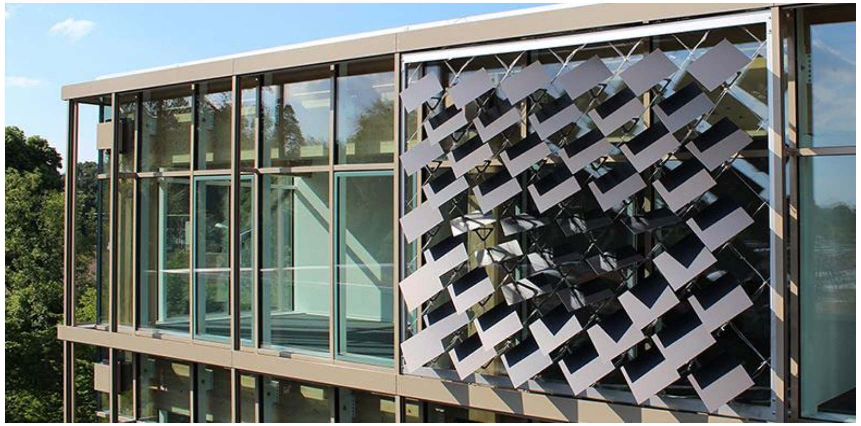


Building integrated solar systems



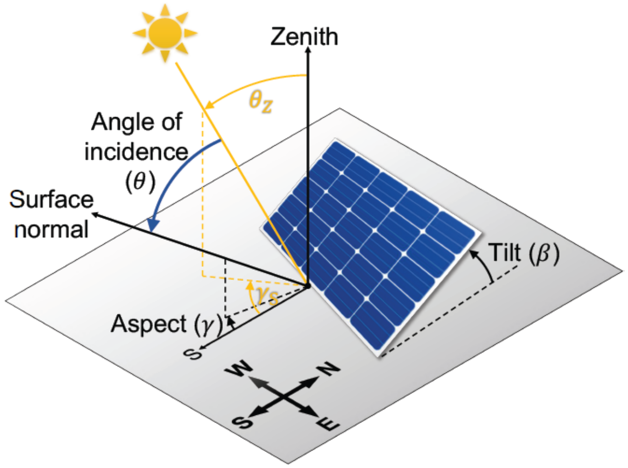


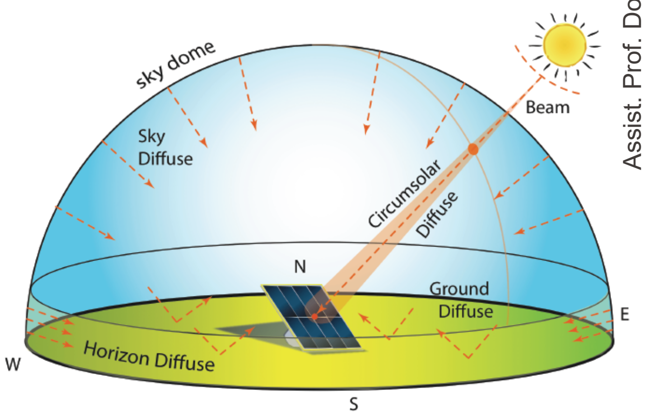
Photovoltaics: BIPV Façades and Roofs



Photovoltaics: Performance

- **PV electricity produced** is **driven** by **three factors**:
  - *Solar radiation* received on the (tilted) surface of the panel: $K_{\downarrow} = S + D$
  - *PV surface area* (A_{PV})
  - *PV system efficiency* including
    - PV panel efficiency (η_{PV})
    - Inverter efficiency (η_{inv})
    - Other losses (η_{losses})
- **PV panel efficiency** η_{PV} is a *function of temperature*. For typical mono- and poly- crystalline silicon panels, the performance reduces as temperature of the panel increases.





$$\boldsymbol{E_{PV}} = K_{\downarrow} \times A_{PV} \times \eta_{PV} \times \eta_{inv} \times \eta_{losses} \quad (10\text{-}1)$$

$$\boldsymbol{\eta_{PV,e}} = \eta_{PV,ref} + \gamma \times \left(T_{PV,actual} - T_{PV,ref}\right) \quad (10\text{-}2)$$

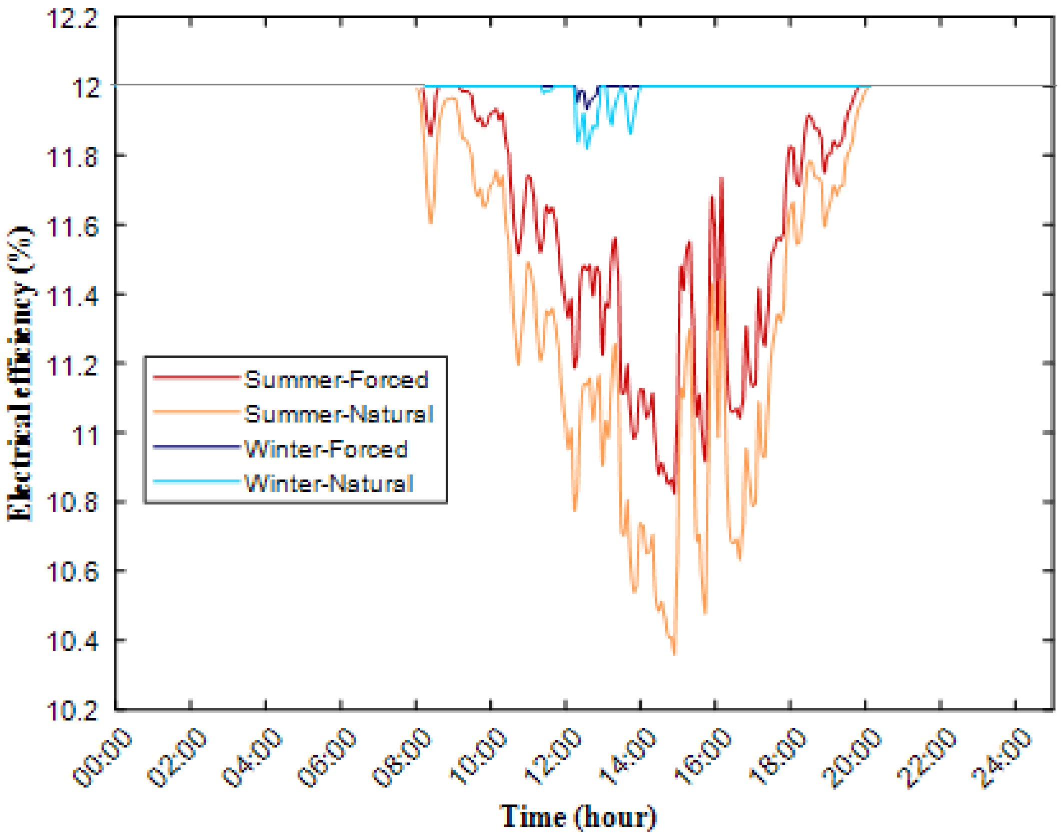
$\eta_{PV,ref}$ - rated efficiency of the PV panel at a reference temperature;
$T_{PV,ref}$ - reference temperature (25°C) for rating efficiency of PVs;
$T_{PV,actual}$ - actual temperature of the PV panel;
γ – temperature coefficient of electrical power (W/K),
($\gamma = -0.0004$ for typical polycrystalline panels)

Source: A. Walch, (2022) EPFL PhD thesis 9014

Performance of Ventilated BIPV Façades

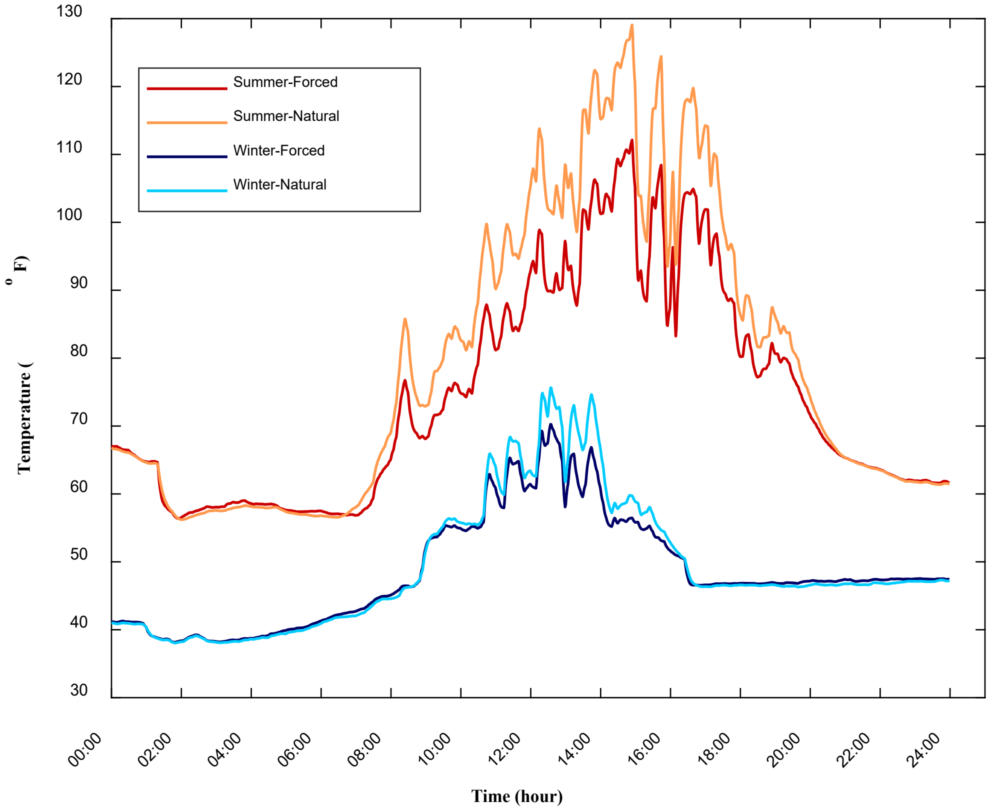
Variation of the electrical efficiency of the PV panel

(η_{PV}) in two representative days: **August 13th** (summer) and **December 14th** (winter) of 2019



Variation of the temperature of the PV panel

(T_{PV}) in two representative days: **August 13th** (summer) and **December 14th** (winter) of 2019



Source: Rahiminejad M. (2022) EPFL PhD thesis 10050

CONTENT:

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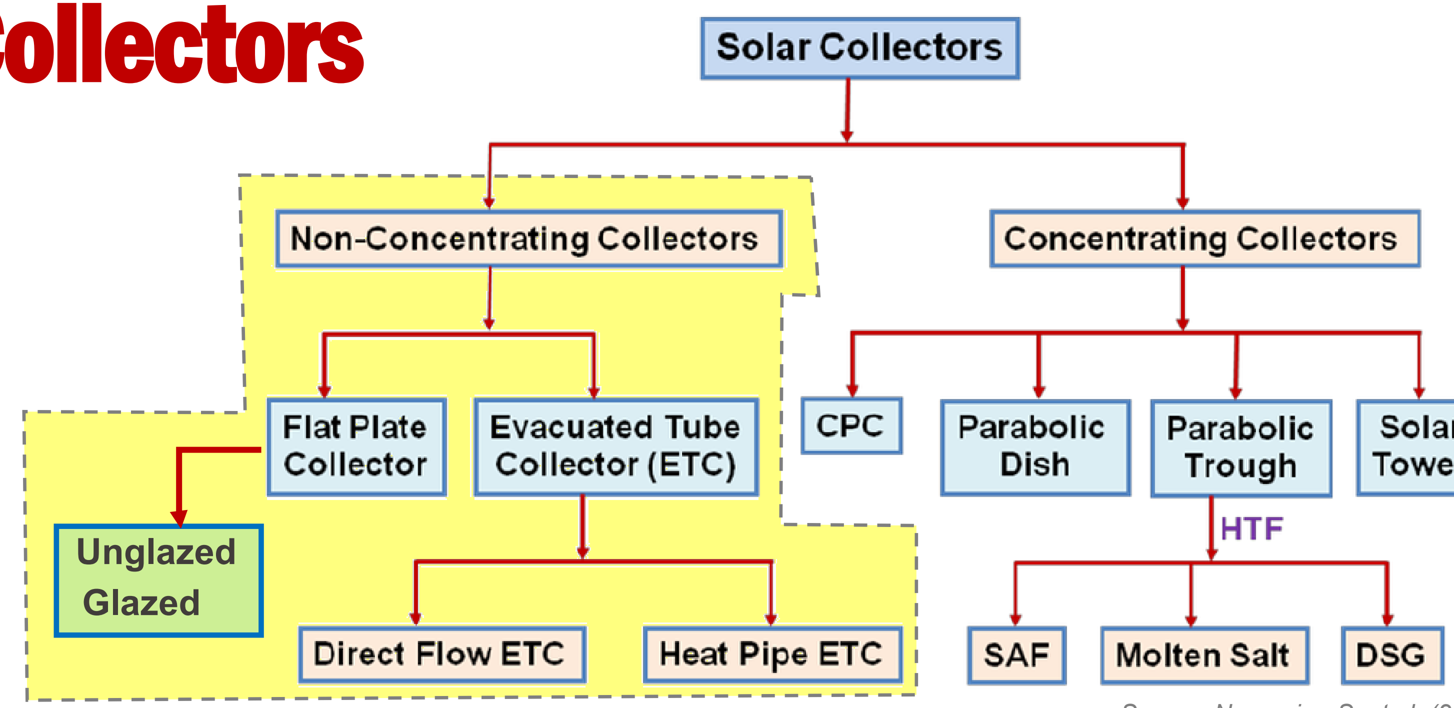
Urban renewable energy sources: Solar Thermal

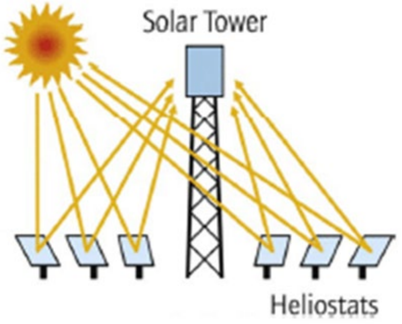
Source: https://www.nytimes.com/2016/11/02/opinion/in-greece-property-is-debt.html

Solar Thermal Collectors



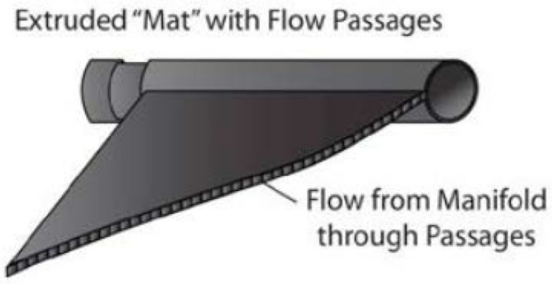
Source: Nagarajan S. et al. (2010)

Solar Tower



- Temperatures ~ 500-1000°C
- Concentration ratio
  R ~ 100 - 1000

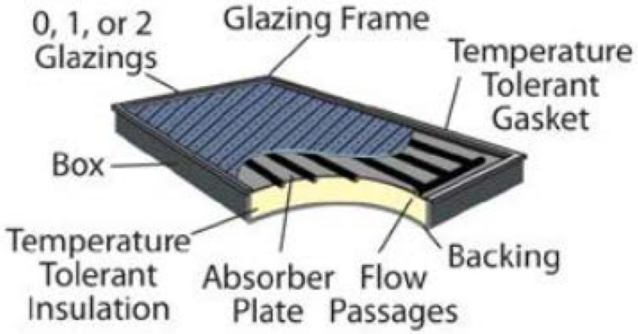
Unglazed Flat Plate



Top cover: EPDM, polypropylene, and polyolefin

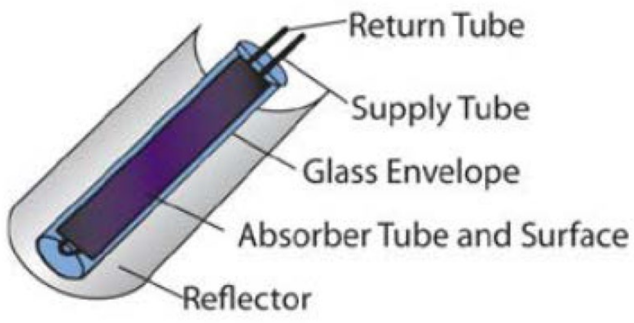
- Temperatures ~ up to **55°C**
- For swimming pools and pre-heating DHW

Glazed Flat Plate



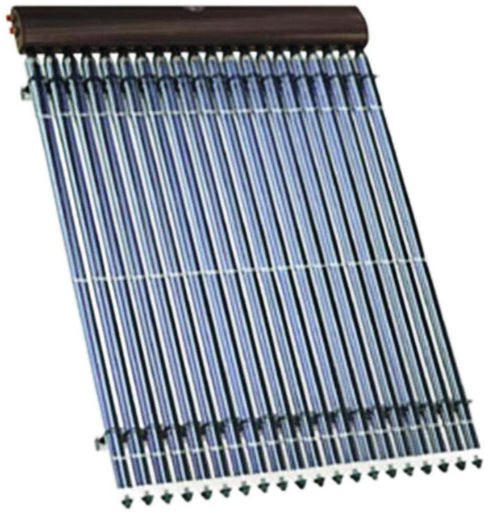
- Temperatures ~ **80°C** to **100°C**
- Possible production of DHW at high T

Evacuated Tube



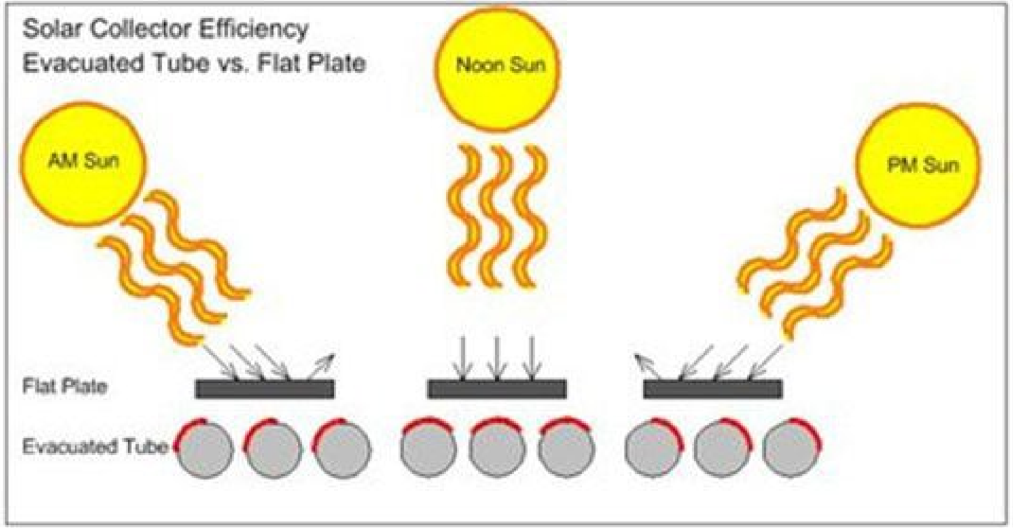
- Temperatures ~ up to **200°C**
- Contribution to the production of DHW and space heating

Solar Thermal Collectors: Flat Plate vs. Evacuated



Evacuated Tubes

Flat Panel



Characteristic	Flat Plate	Evacuated tube
Less expensive	✓	✗
Easy snow removal	✓	✗
Efficiency less affected by the collector orientation	✗	✓
Collector efficiency is high at higher temperatures	✗	✓
Suitable for heating water up to high temperatures	✗	✓
Better production in cold and cloudy climates	✗	✓
Heat losses are low	✗	✓

Solar Thermal Collectors: Performance

- **Concentration Ratio:** ratio of the area of aperture of the system (projected area of the collector facing the beam) to the area of the receiver
- **Temperature Range:** range of temperature to which the heat-transport fluid is heated up by the collector
- **Collector Efficiency:** ratio of the energy actually absorbed and transferred to the heat-transport fluid by the collector (useful energy) to the energy incident on the collector

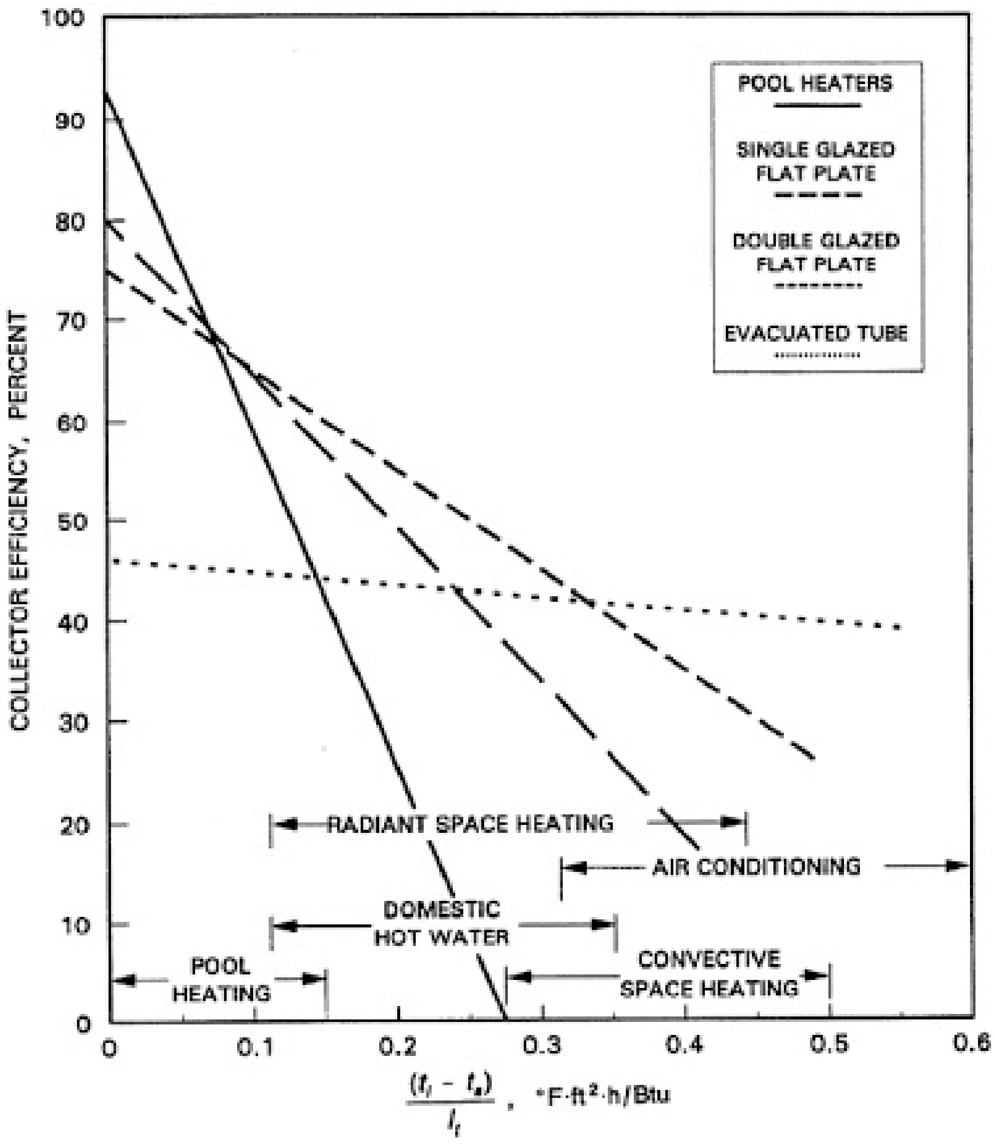
Useful heat delivered by a solar collector

=

Energy absorbed by the heat transfer fluid

-

Heat losses to the surroundings



Collector Efficiencies of Various Liquid Collectors

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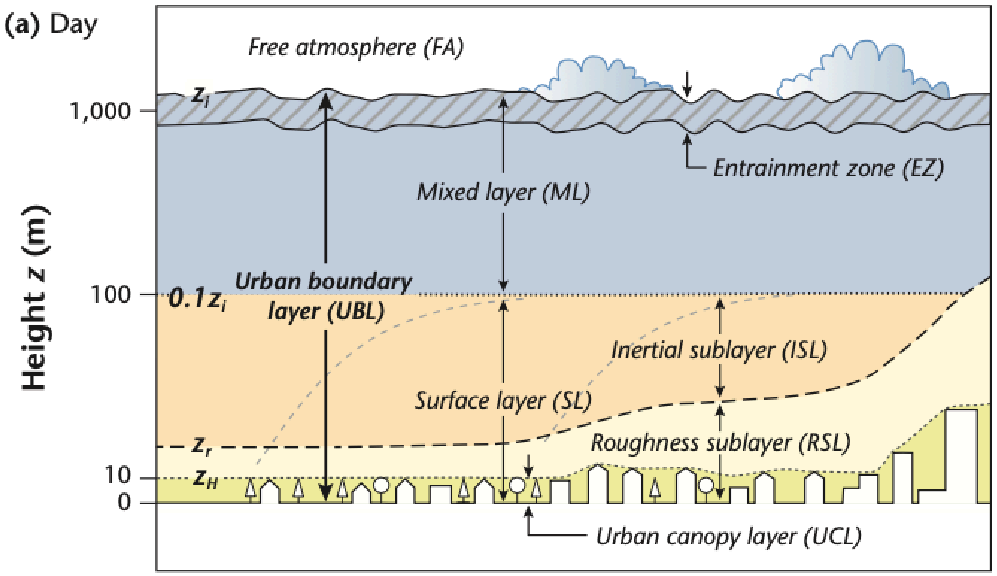
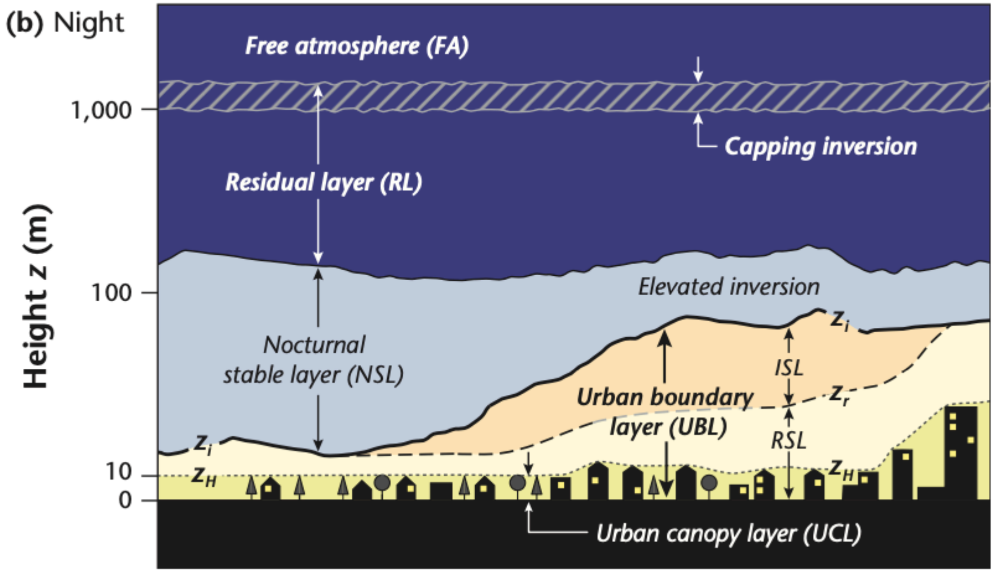
Atmospheric Boundary Layer

Reminder from L2

- The **urban boundary layer** is composed of *two* layers:
  - **Surface layer** (lower 10%)
  - **Mixed layer** (upper 90%)
- **Surface layer**: a layer with *heat* and *mass exchanges* between the Earth and its atmosphere. It is composed of 2 layers:
  - **Roughness sublayer (RSL) -** *lower part* affected by individuals elements, it is turbulent and 3D.
  - **Inertial sublayer (ISL) -** the *upper part* affected by assembles of individual elements, it varies mainly in the horizontal direction.
- **Mixed layer:** heat and mass exchange are *dampened* by turbulent motion; temperature, water vapor, wind speed are almost *uniform* with height

Source: Oke, Urban Climates, p. 31





Source: Oke, Urban Climates, p.31

Urban renewable energy sources: Wind

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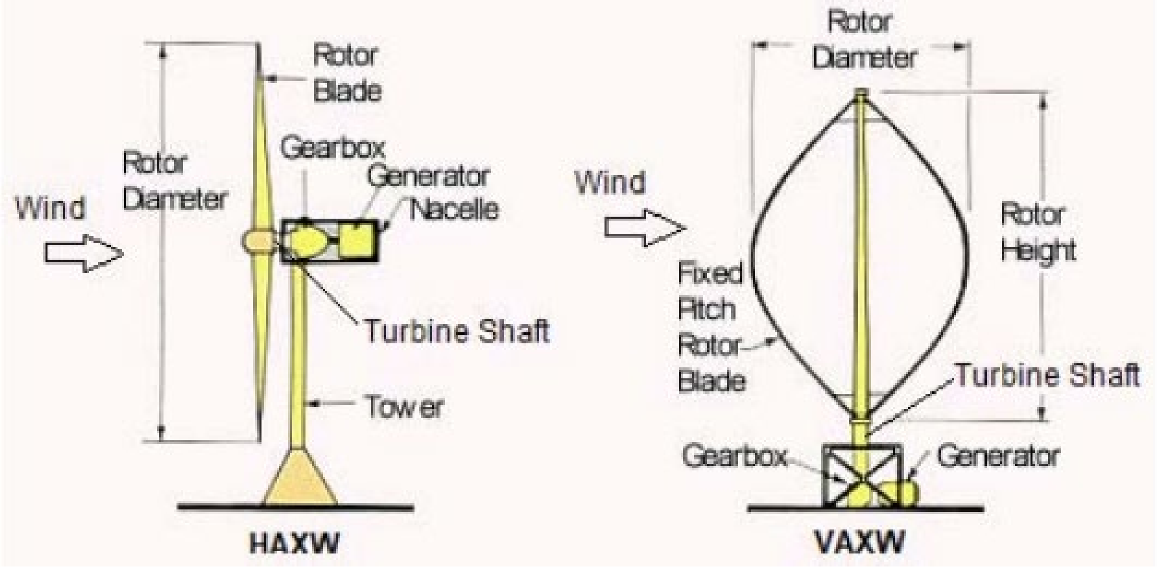
- Two types of wind turbines:
  - **HAWT**: *horizontal* axis wind turbine
  - **VAWT**: *vertical* axis wind turbine
- Collecting wind energy in urban areas is a challenge, given the *considerable variability* in wind and *its magnitude*.

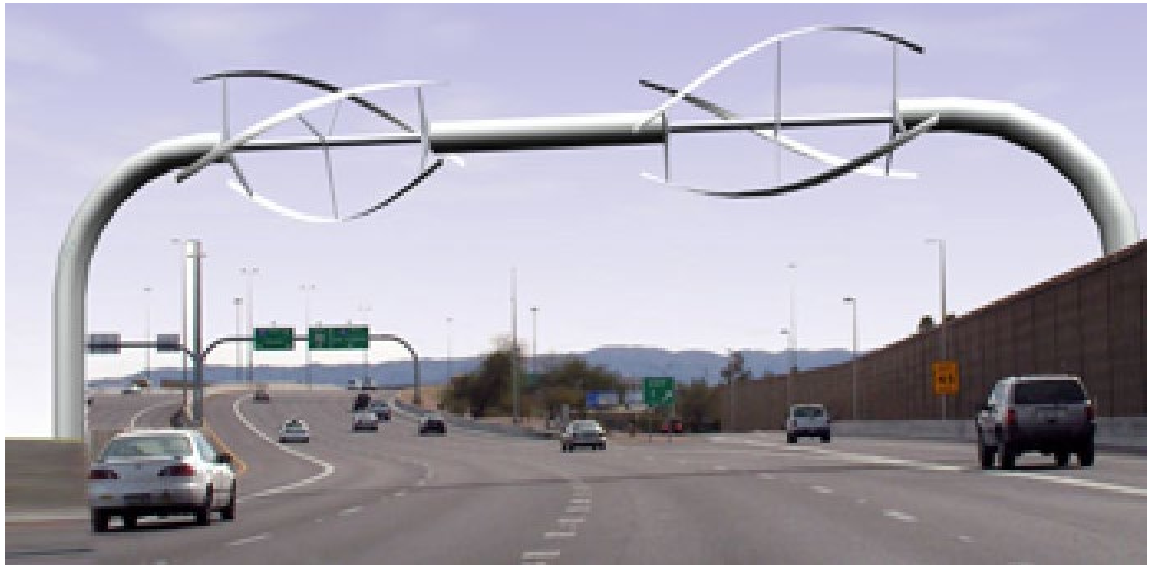


- **VAWTs** are better suited for urban areas. They are *adapted for low speed wind* and *turbulent flow*. They have *less noise* and *vibration*.

  Positioning: stand-alone, retrofitted on buildings, architecturally integrated (building integrated wind turbines).

- *Large scale* applications and *wind farms* are challenging in cities due to *the source viability* depending on wind speed and *building density*.

Urban renewable energy sources: Wind



Urban renewable energy sources: Wind

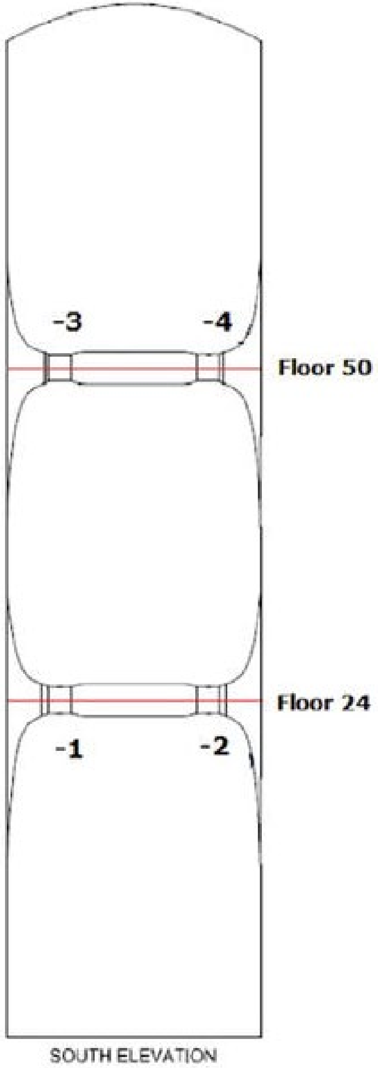
Strata SE1, London

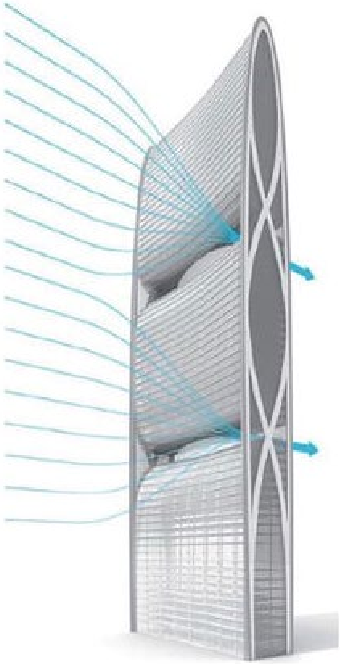
Bahrain World Trade Center

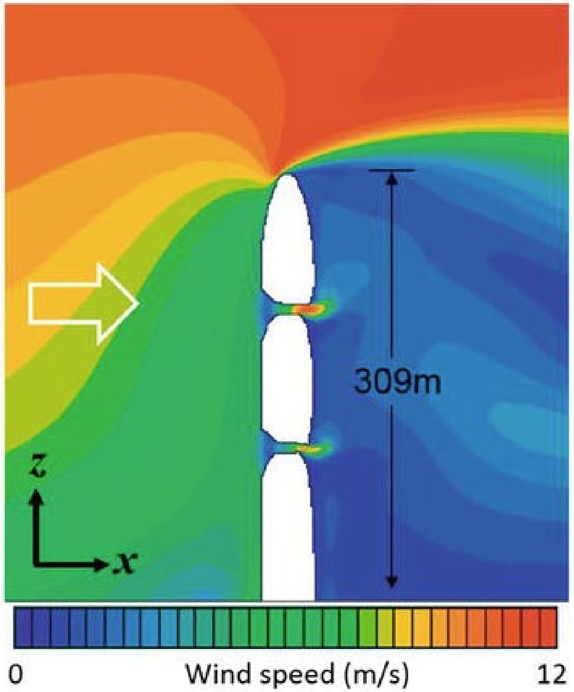
Perl River Tower, Guangzhou

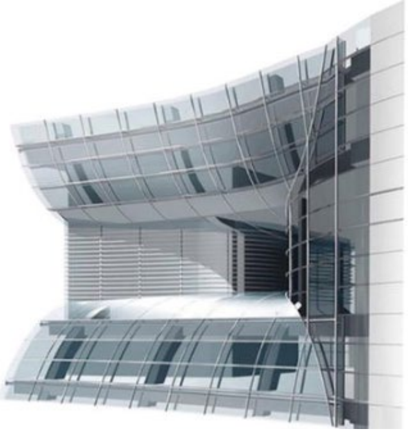
Urban renewable energy sources: Wind

Perl River Tower, Guangzhou









Source: https://www.intechopen.com/chapters/71418

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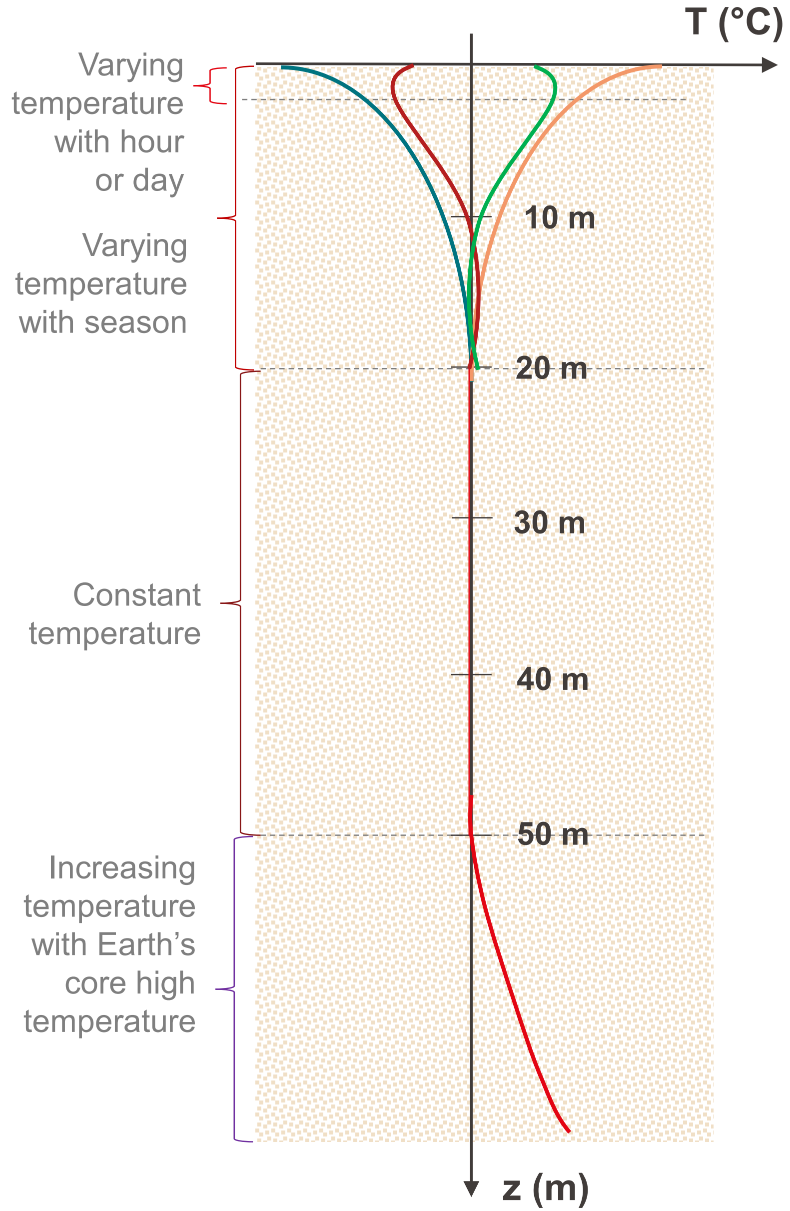
Sub-surface Temperature

Reminder from L6

- The **sub-surface temperature** varies **along its depth:**
  - Right below the surface, temperature *varies* with *atmospheric conditions.*
  - After a certain depth, the impact of the atmospheric conditions on temperature *is negligible,* ground temperature is *constant*. For Lausanne, it is ~14°C.
  - Under 50 m below the surface, the ground temperature *increases* due to the *geothermal heat flux* from the Earth's core.
- Two types of **ground sub-surface temperature variation**:
  - **Diurnal variation:** up to 1 m under ground surface
  - **Seasonal variation:** up to 20 m under ground surface
- The **ground sub-surface temperature depends** on:
  - *Surface energy balance* affecting temperature variation up to 20 m depth
  - *Thermo-physical properties* of the soil (depends on the soil structure and composition, moisture content)



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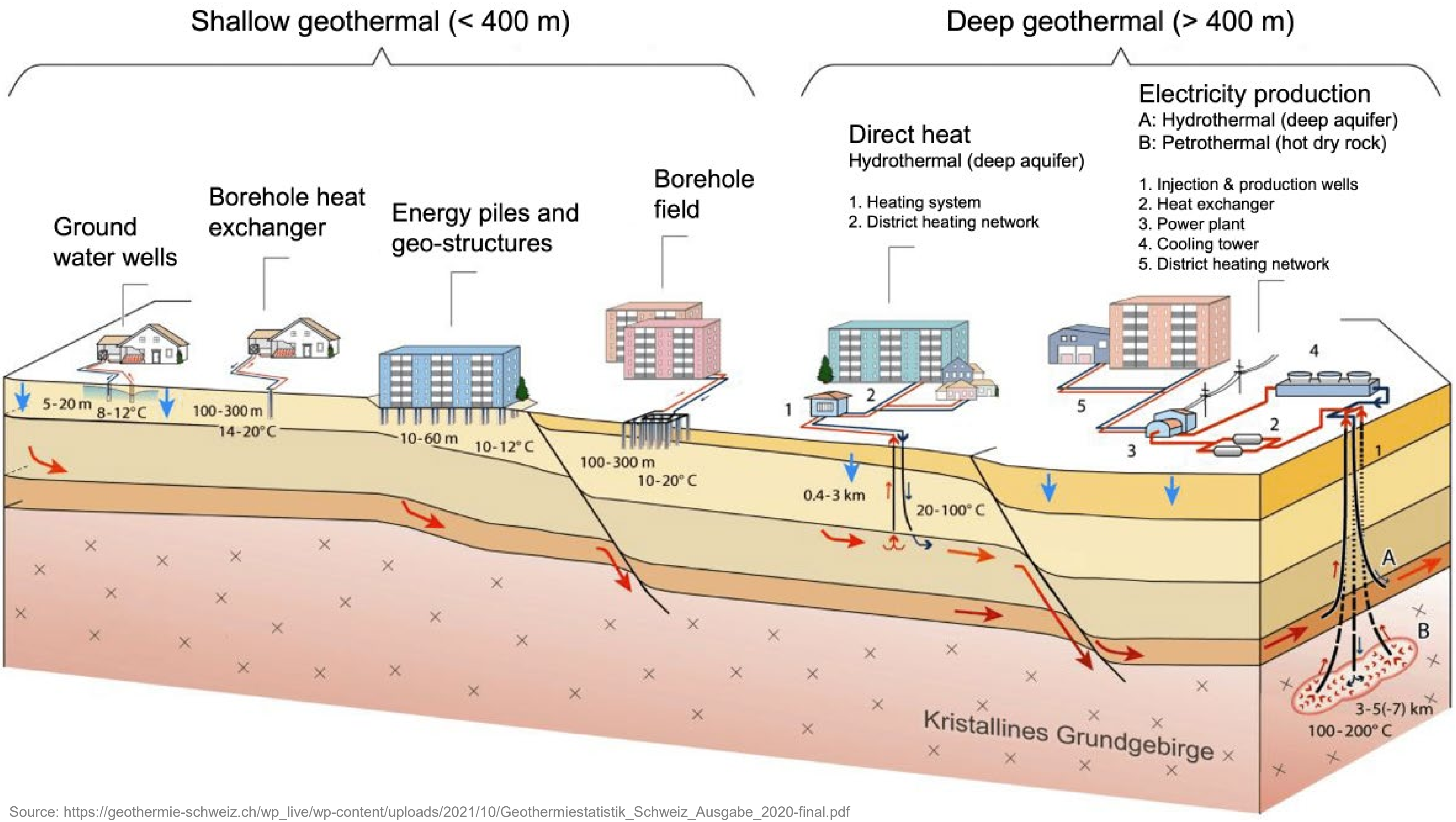
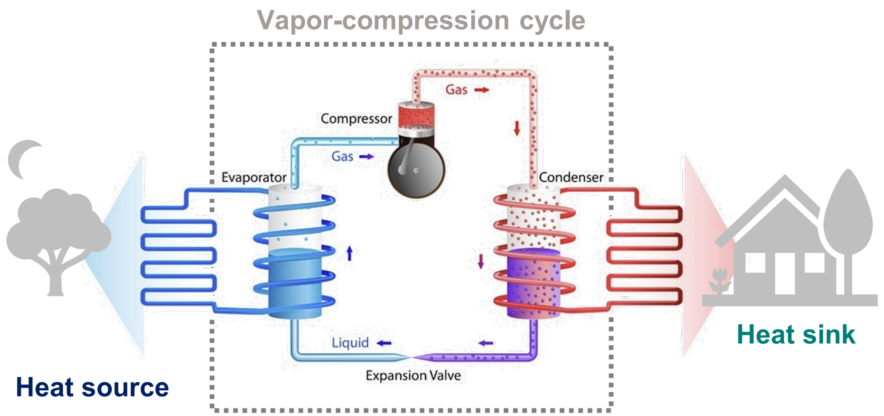
Urban renewable energy sources: Geothermal

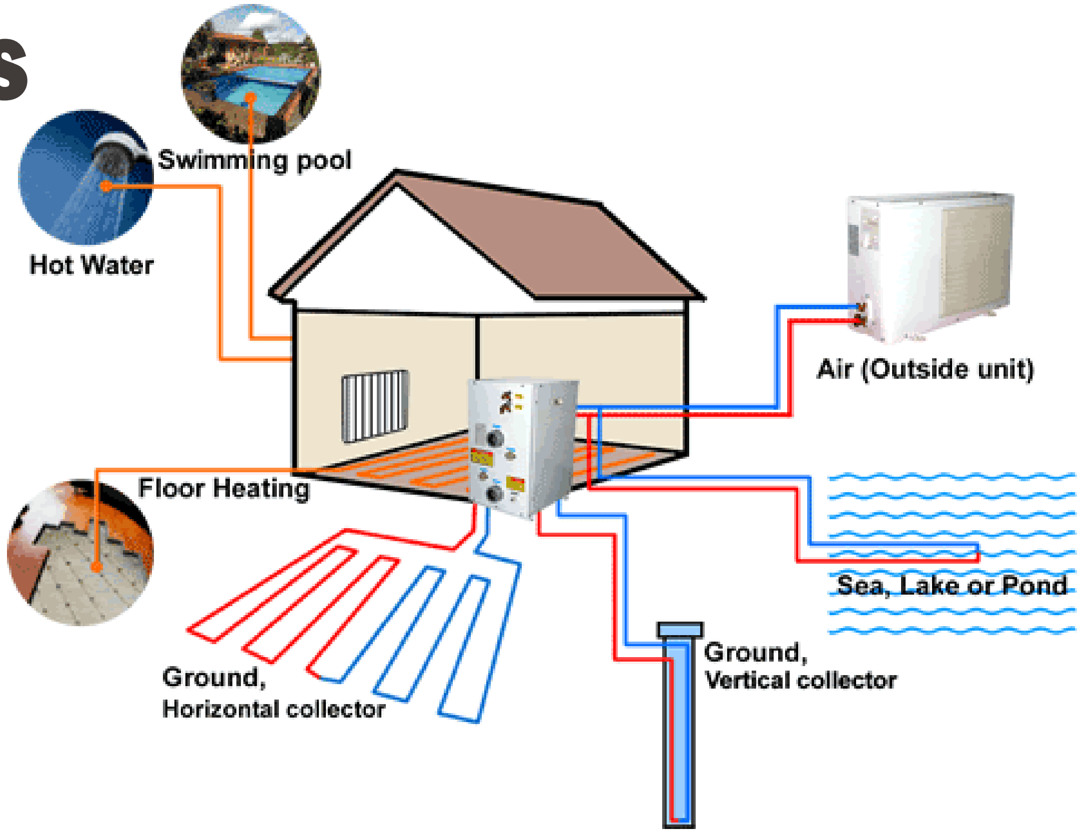


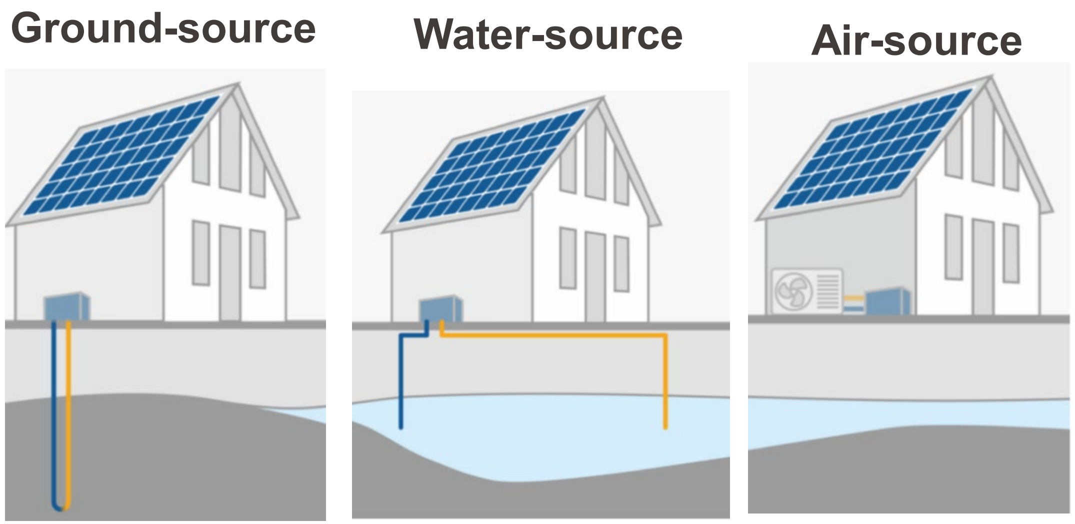
Source: https://geothermie-schweiz.ch/wp_live/wp-content/uploads/2021/10/Geothermiestatistik_Schweiz_Ausgabe_2020-final.pdf

Ground-source Heat Pumps

- **HP** is a system that **convert the energy stored in the environment** (air, ground or water) into **usable heat** using **a vapor-compression cycle**
- Usually, the **heat extracted is delivered to heat up the water** in order to be use either for **space heating** or **domestic hot water** (heat sinks)
- The ***vapor compression cycle*** is used for refrigeration, making use of the **latent heat** enabling **large quantity of heat to be extracted** for a given refrigerant mass flow rate.

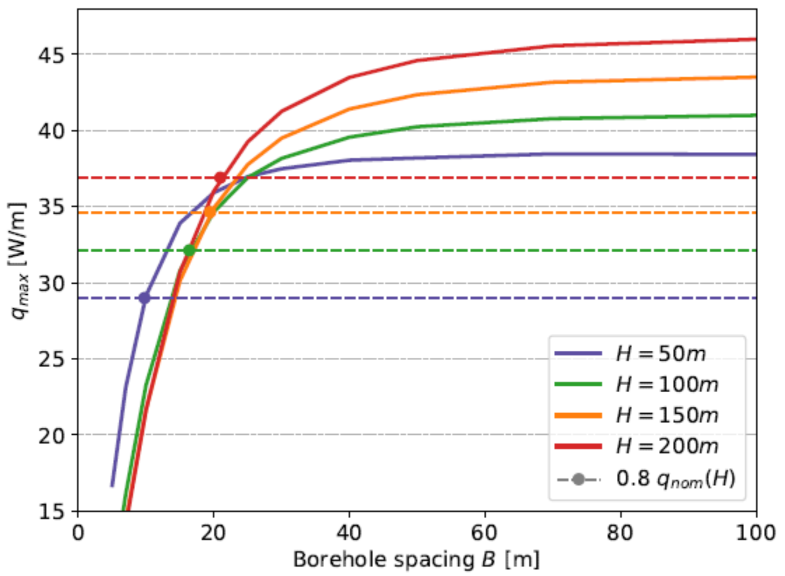


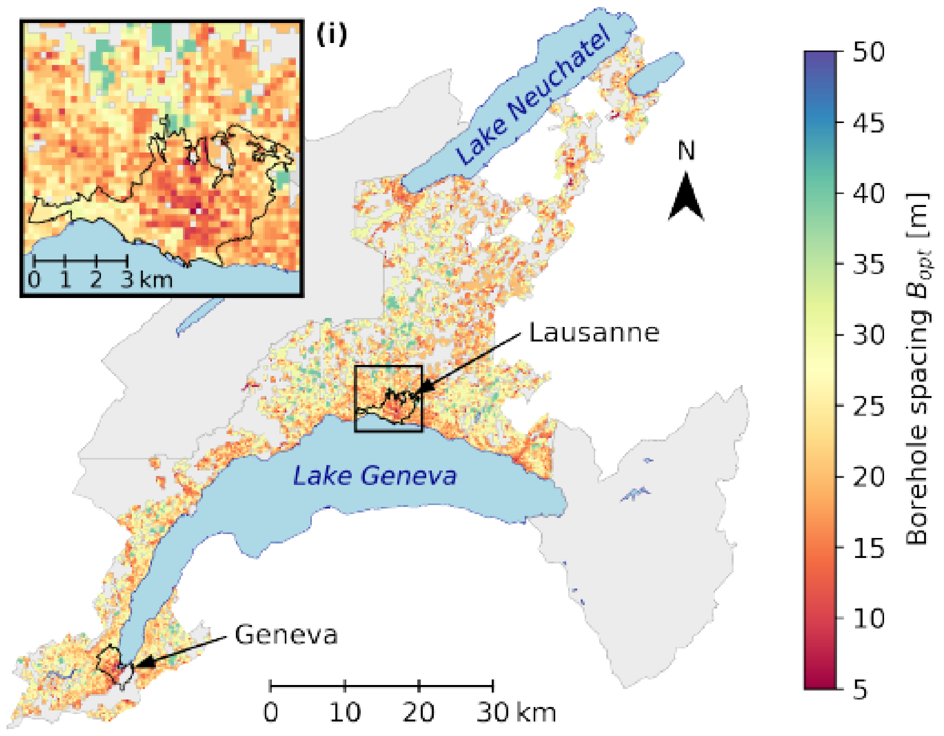


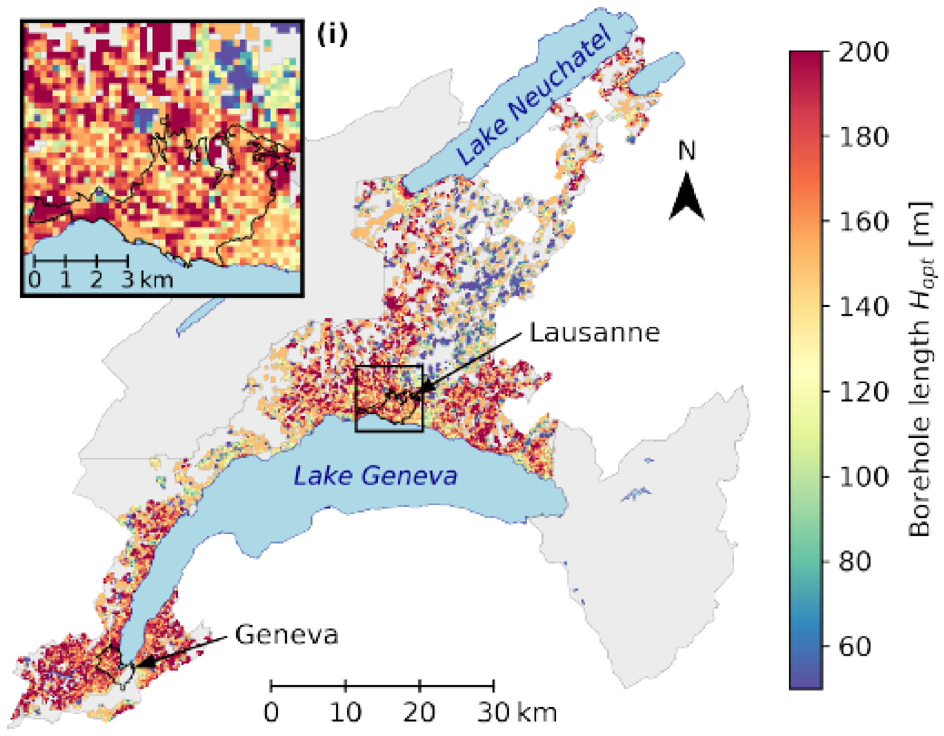


Shallow Geothermal Energy

- The **heat extraction rate** from boreholes depends on the *spacing* between the boreholes (thermal interaction between them) and their *depth*.
  - Thermal resistance between boreholes reduces as log of distance
  - Heat extraction increases with the depth (higher ground temperature)







Source: A. Walch, EPFL PhD thesis 9014

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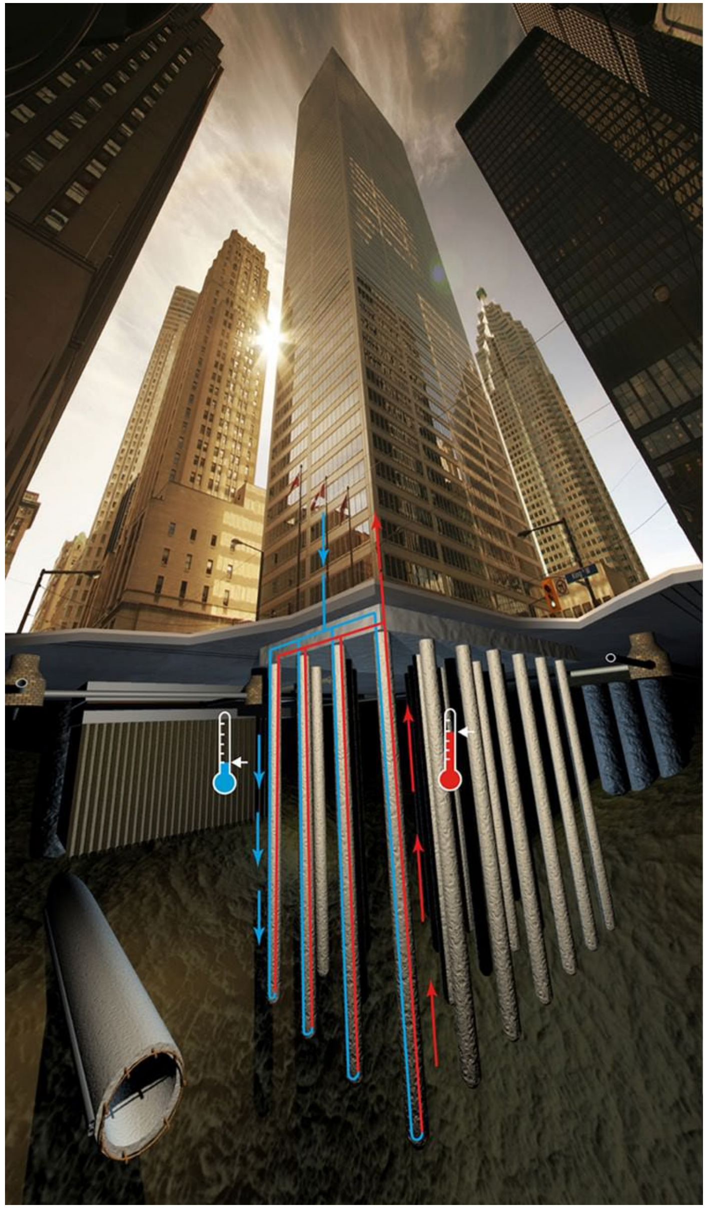
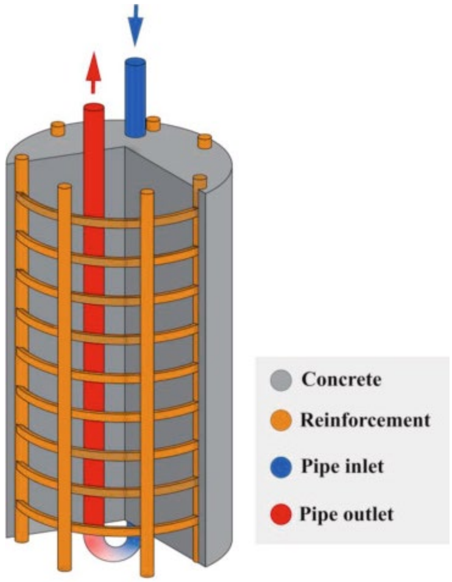
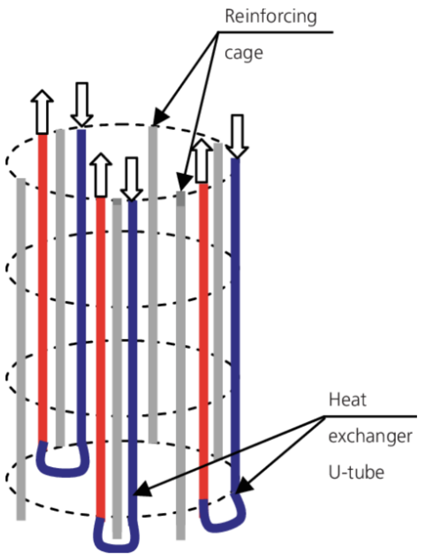
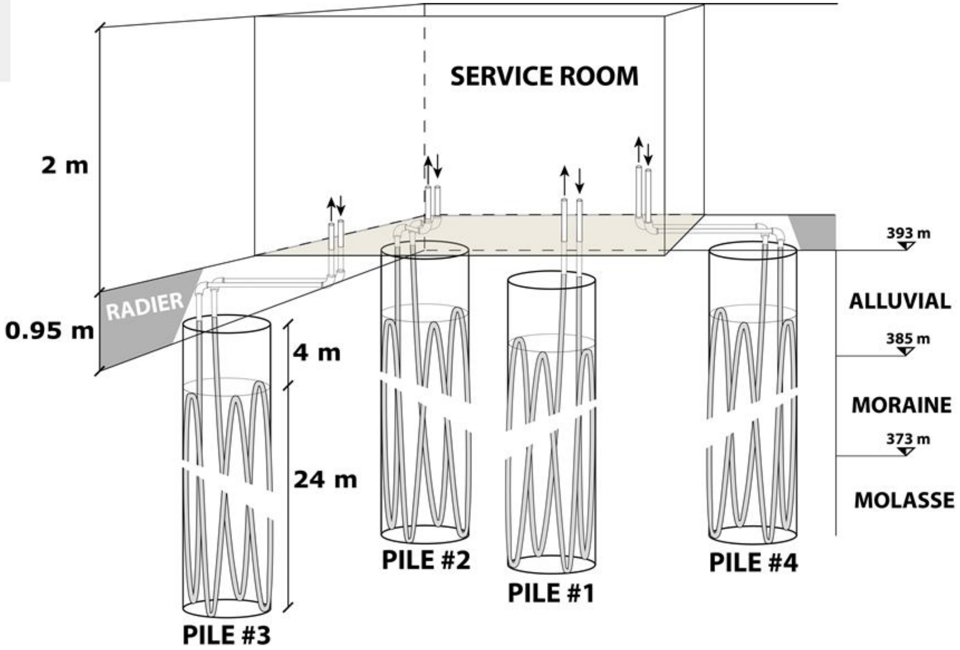
Shallow Geothermal Energy: Energy Piles



https://www.epfl.ch/labs/lms/thermopile-2/







https://www.epfl.ch/labs/lms/fr/notre-laboratoire-lab-logs-energy-pile-group-experiment/

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- **Hydropower**
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Urban renewable energy sources: Hydropower

- **Hydroelectric** power exist at small scale and is still competitive with other power generation systems.
- **Pumped storage** is especially interesting to provide additional electrical power during peak consumption.
- New emerging technologies:
  - **Inpipe hydropower:** Piping systems produce an abundance of *unused* energy. Could be installed in water treatment plants, undergound water systems where water is highly pressured.
  - **Mini-hydro power plants:** Disadvantage of space requirements. Could encourage the presence of significant water bodies in cities.

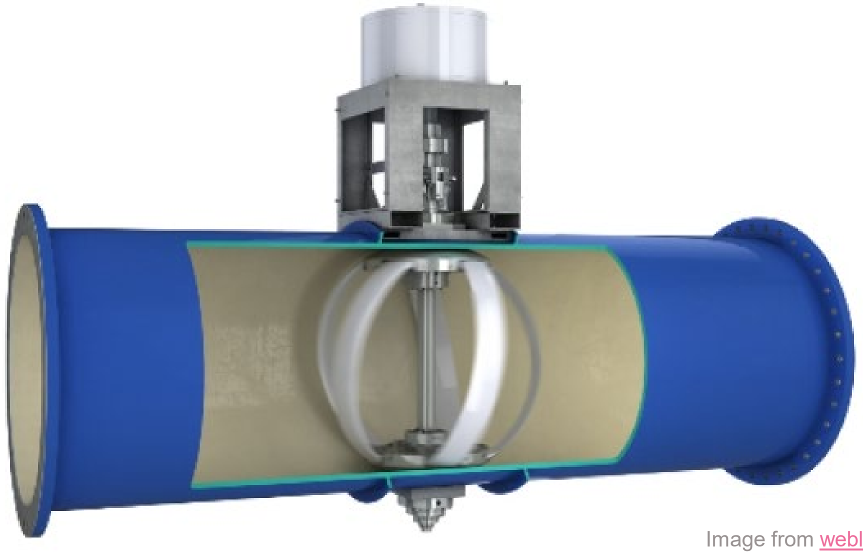
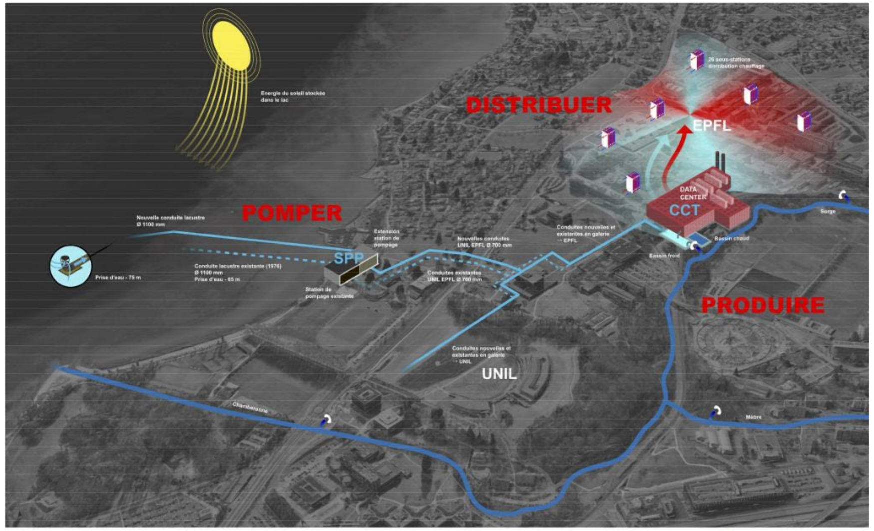


Image from weblink

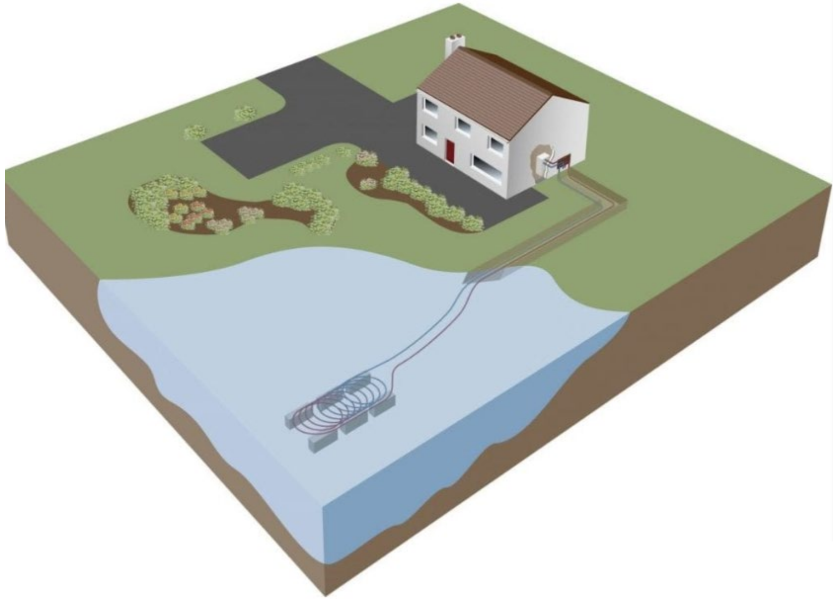
Source: Comino, Mini-hydro power plant for the improvement of urban water-energy nexus toward sustainability

Urban renewable energy sources: Water

- Water bodies (lake, pond, river, sea) can be used as **a heat source** for **heat pumps**
- **Water-source heat pumps** work by *extracting heat from a body of water* and *converting* in *into useful energy* to heat buildings.
  - They use a series of submerged pipes containing a working fluid to absorb the heat from water bodies, but can also be as an open loop
- **EPFL** uses water-source heat pumps for its heating.



https://www.epfl.ch/about/sustainability/energy/central-heating-unit/



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- Solar energy
- Wind energy
- Geothermal energy
- Hydropower
- Open issues

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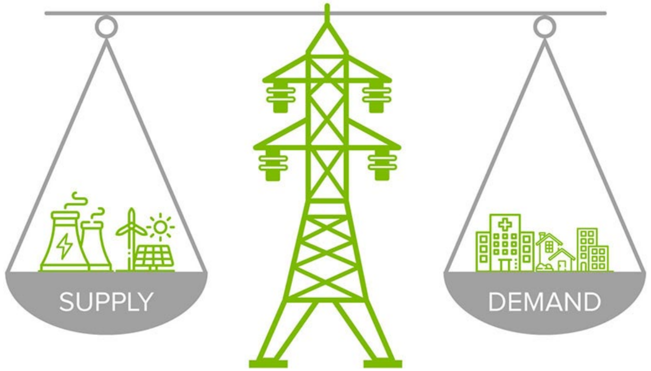
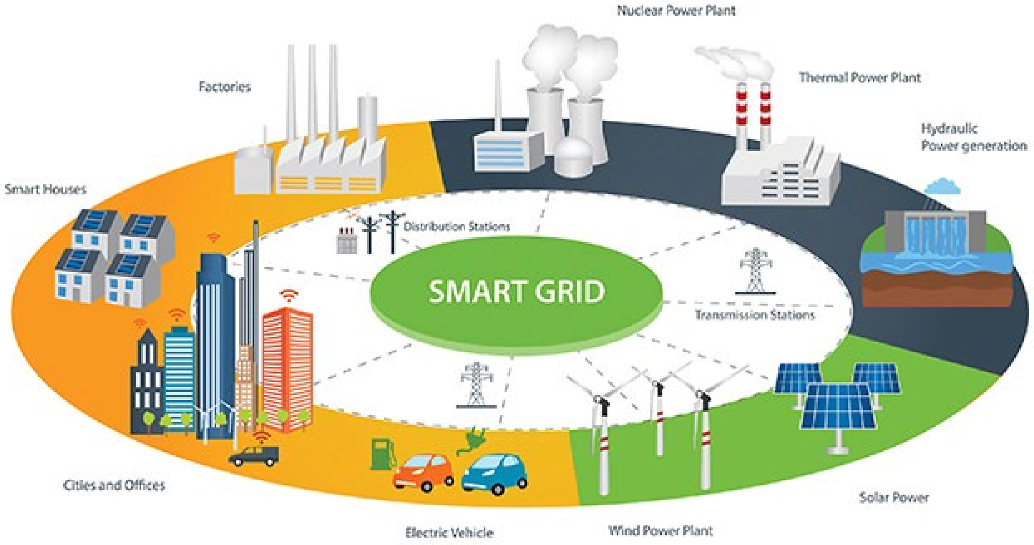
Urban renewable energy sources: Open Issues

- Without land for industrial sites, **small scale systems** only produce **small amount of energy**.
- Renewable energy sources are not *constant*, hence a need for the *combination of different sources*.
- **Power distribution grid must be adapted and flexible**.
- Flexibility is **the grid's ability to manage variability** and **volatility to balance supply** and **demand**.
- *Before thinking about production*, **necessary to reflect on consumption** (demand profiles and shifting)





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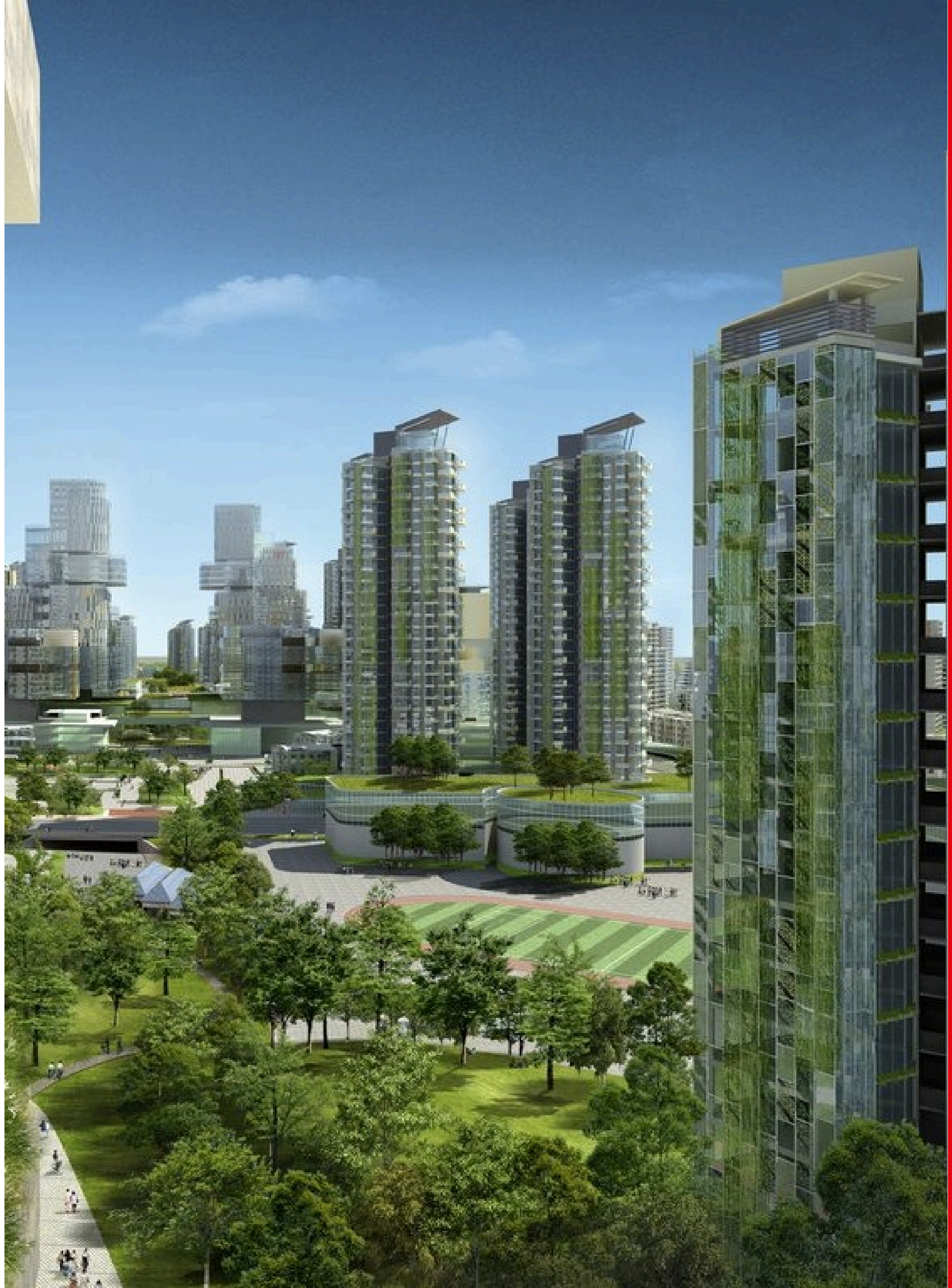

Thank you for your attention

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