The Sixth International Conference on
Efficient Building Design

Materials and HVAC Equipment Technologies

Pathways and Solutions towards Net-Zero Whole-Life Carbon Buildings by 2050

Beirut, Lebanon
| October 4, 2024

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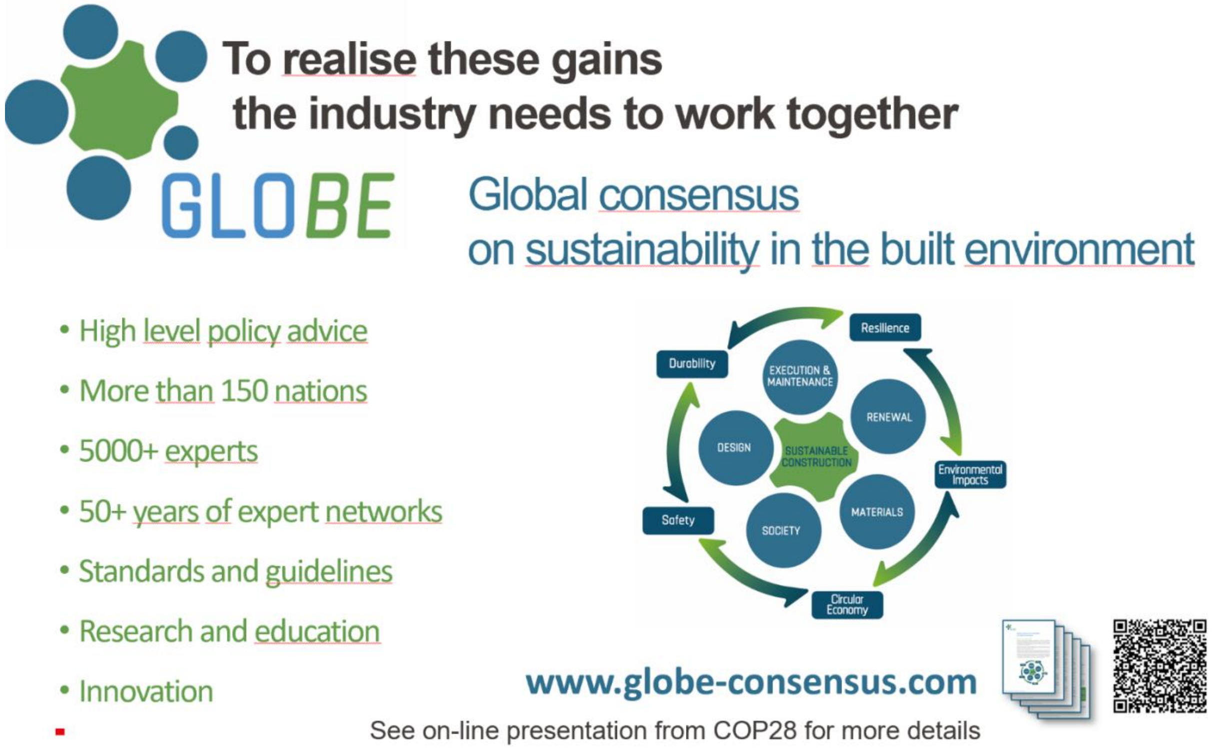
Acknowledgment

Beirut 04/10/2024

Prof. Dr. Nesreen Ghaddar

iiSBE · cib · FIDIC · UN environment United Nations Environment Programme



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AMERICAN UNIVERSITY OF BEIRUT | ASHRAE Shaping Tomorrow's Built Environment Today | ASHRAE Lebanese Chapter

Cause of Climate Change

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Climate Disruptions in MENA

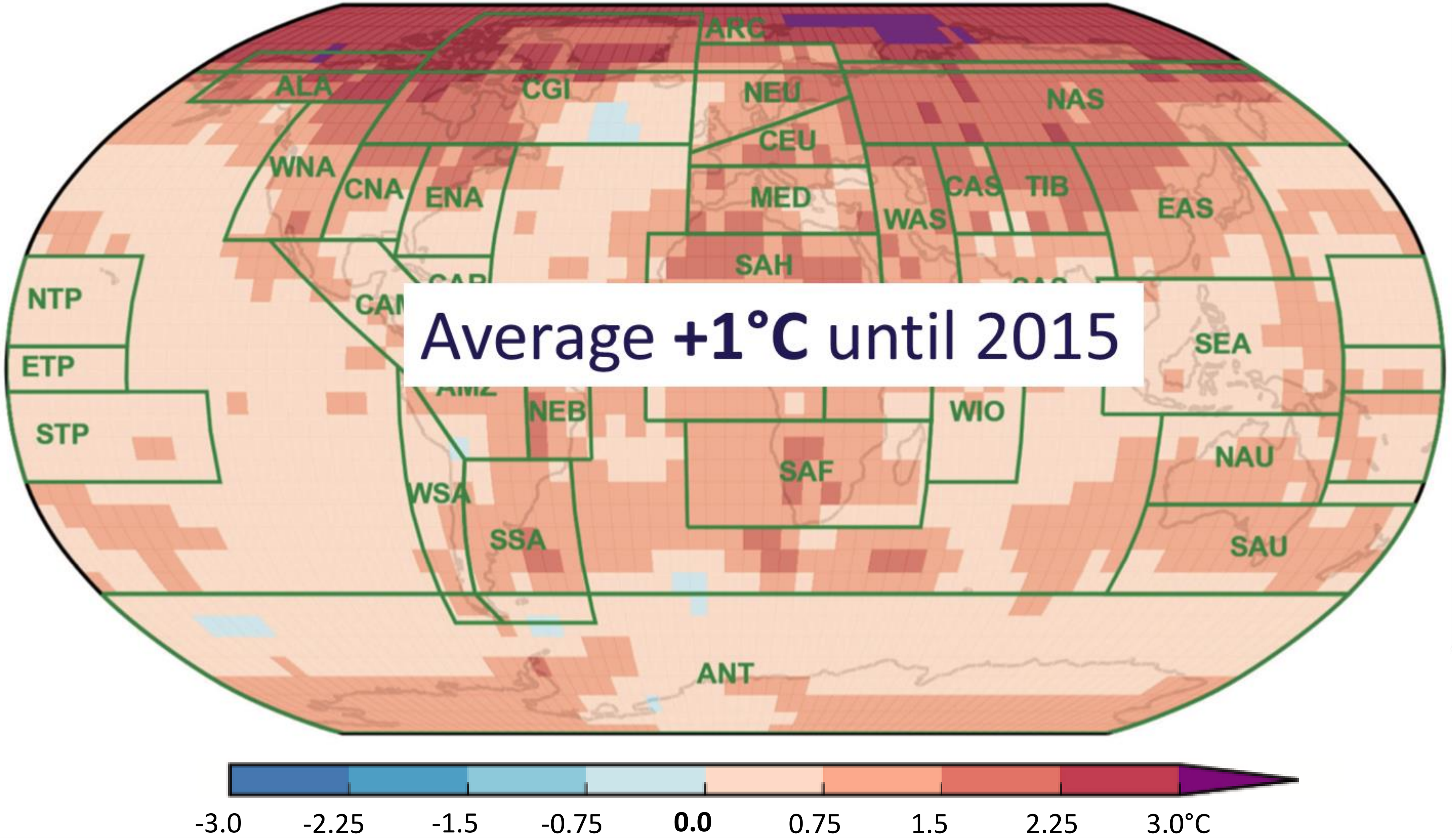
- Floods
- Sea Level Rise
- Wind Storms
- Heat Waves
- Fires
- Power outages
- Earthquakes
- Water Shortages
- Air Pollution
- Pandemics

- 2024 Dubai
- 2023 Darna
- 2021 Beirut
- 2019 Chouf
- 2018 Jeddah
- 2016 Kuwait

Source: Aerial view of Derna, Libya, on September 10-11, 2023. AYMAN AL-SAHILI / REUTERS

Global Climate Change

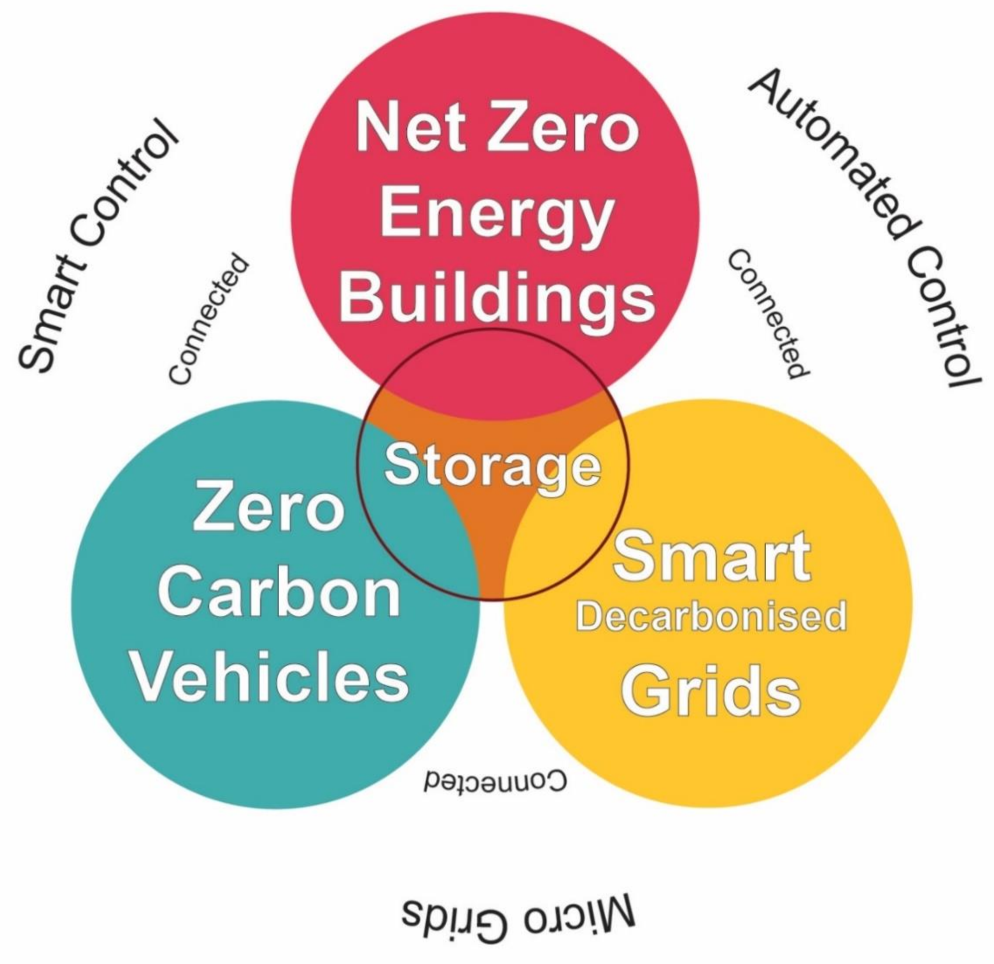
Paris Agreement 2015 Targets Compatibility



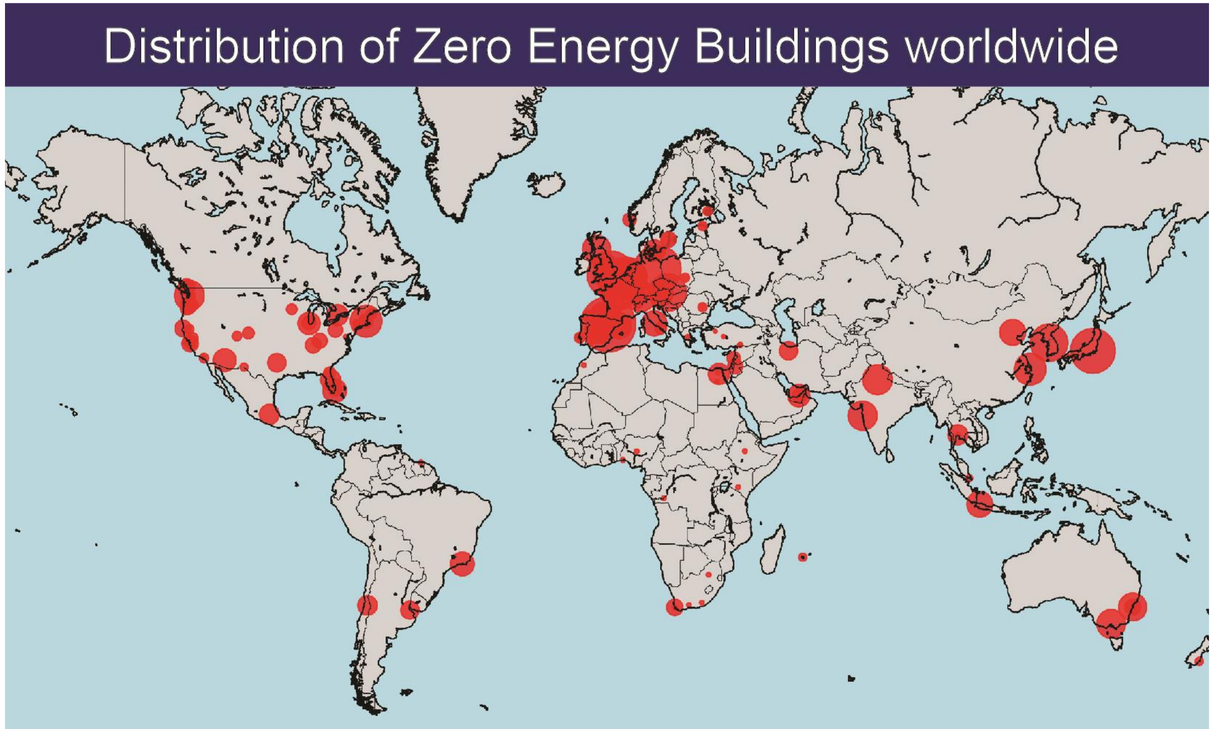
International Panel on Climate Change, 2019

Carbon Neutral Communities

Storage & Scale the Core of Carbon Neutrality

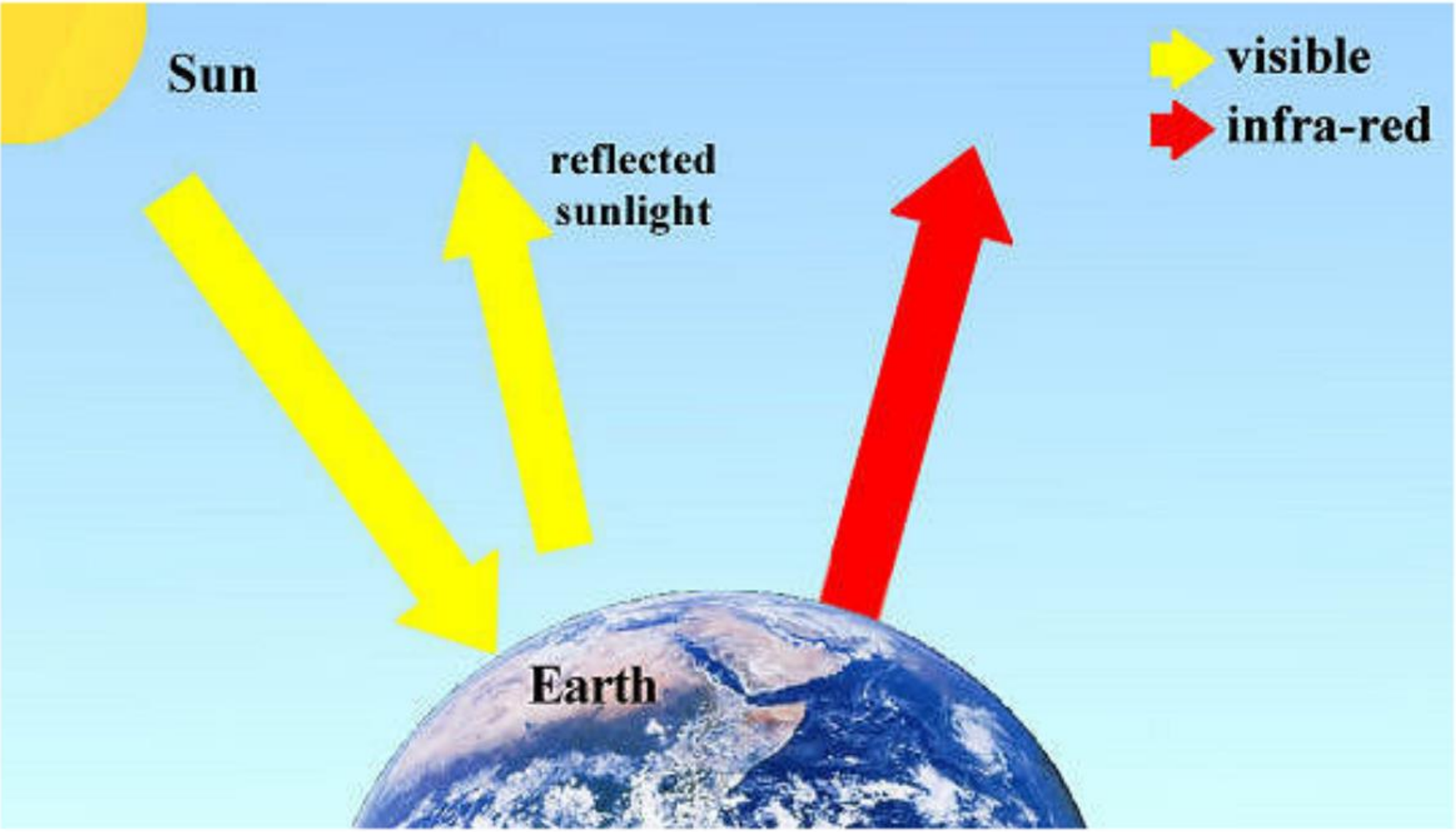


Source: Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd



What cause climate change?

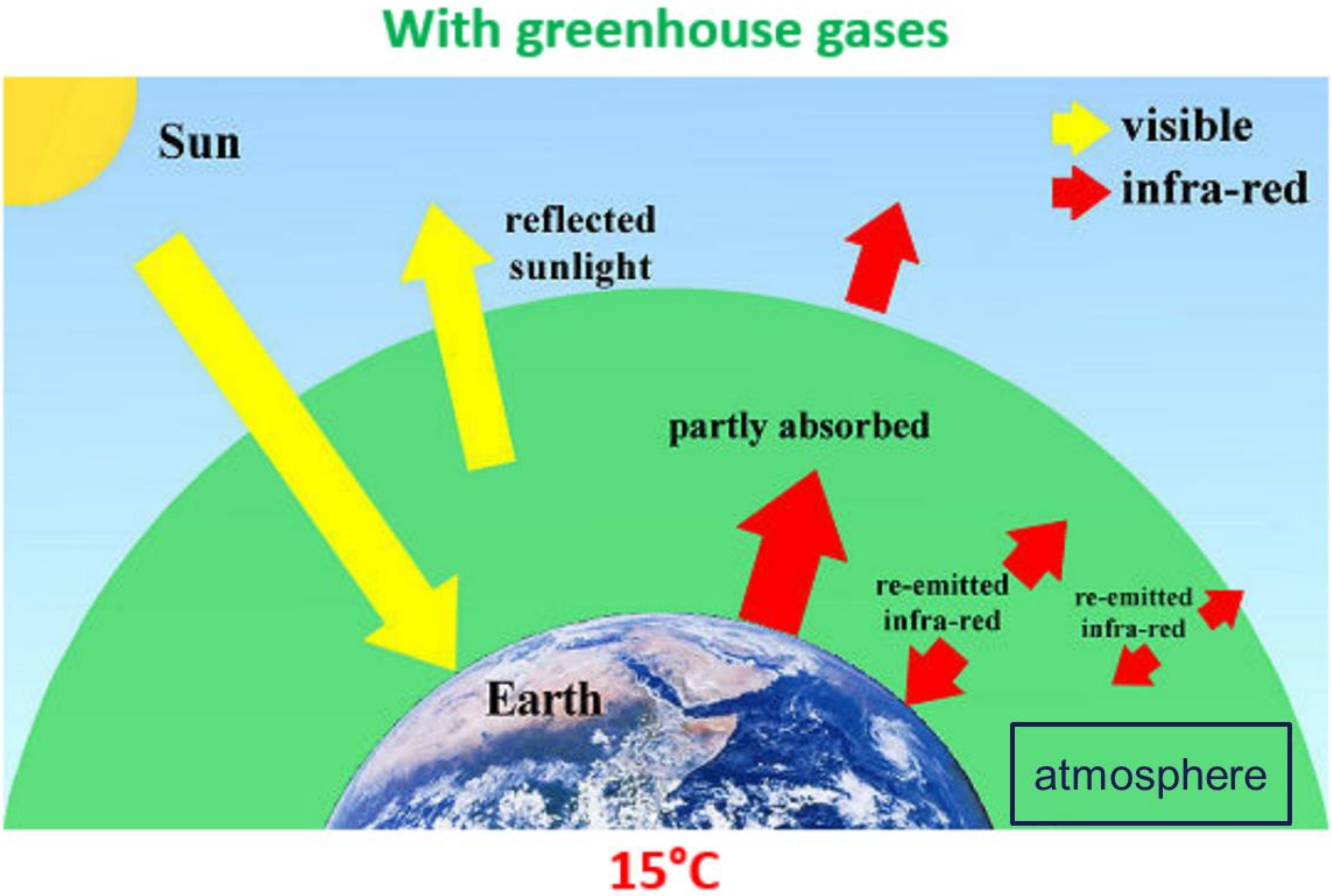
No greenhouse gases



-18°C

https://hklaureateforum.org/en/climate-change-and-its-impacts-to-hong-kong

What cause climate change?



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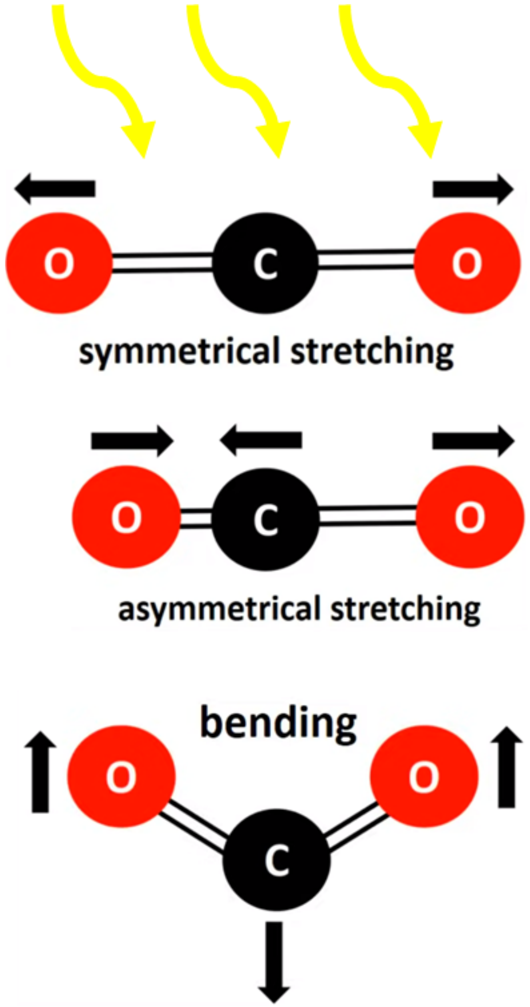
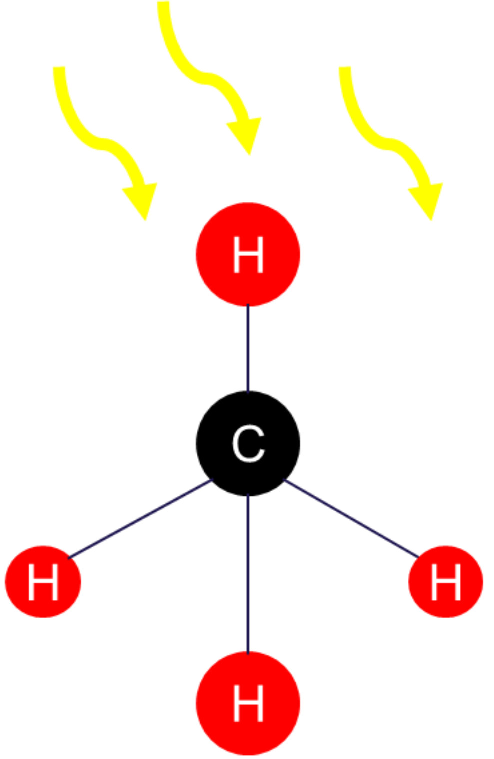
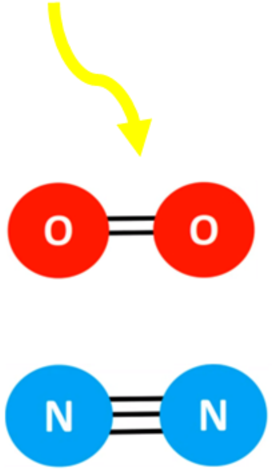
What cause climate change?



burning of fossil fuels such as coal, oil, natural gas, and deforestation



Methane is emitted by livestock, agricultural practices, decay of organic waste in municipal solid waste landfills and during processing of coal, oil, and natural gas. It traps the heat.



No GHG

https://www.youtube.com/watch?v=AF1JPg20amY

What cause climate change?

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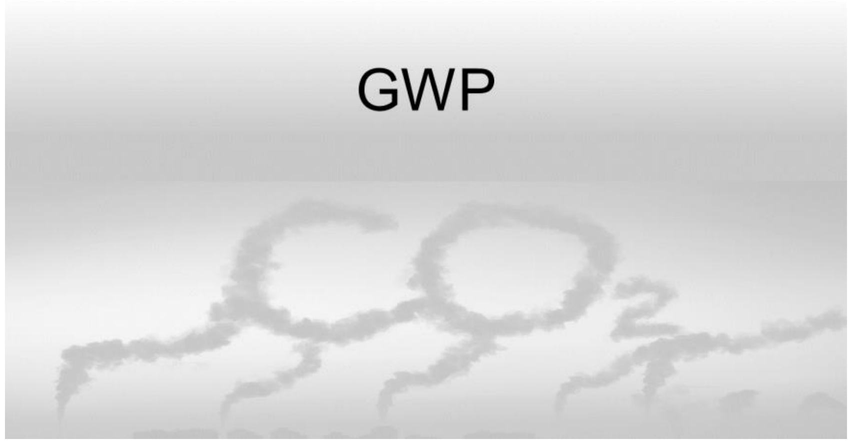
Molecule	x or %	µmol mol^{-1} (ppmv)[a] (2014)	µmol mol^{-1} (ppmv) (1750)
N_2	0.78 or 78%	780 900	780 900
O_2	0.21 or 21%	209 400	209 400
H_2O	0.03 (100% humidity, 298 K)	30 000	31 000
H_2O	0.01 (50% humidity, 298 K)	10 000	16 000
Ar	0.01 or 1%	9300	9300
CO_2	3.8×10^{-4} or 0.038%	393	280
Ne	1.8×10^{-5} or 0.002%	18	18
CH_4	1.77×10^{-6} or 0.0002%	1.80	0.72
N_2O	3.2×10^{-7} or 0.00003%	0.32	0.27
O_3[b]	3.4×10^{-8} or 0.000003%	0.034	0.025
All CFCs[c]	8.7×10^{-10} or 8.7×10^{-8}%	0.0009	0
All HCFCs[d]	1.9×10^{-10} or 1.9×10^{-8}%	0.0002	0
All PFCs[e]	8.3×10^{-11} or 8.3×10^{-9}%	0.00008	0
All HFCs[f]	6.1×10^{-11} or 6.1×10^{-9}%	0.00006	0

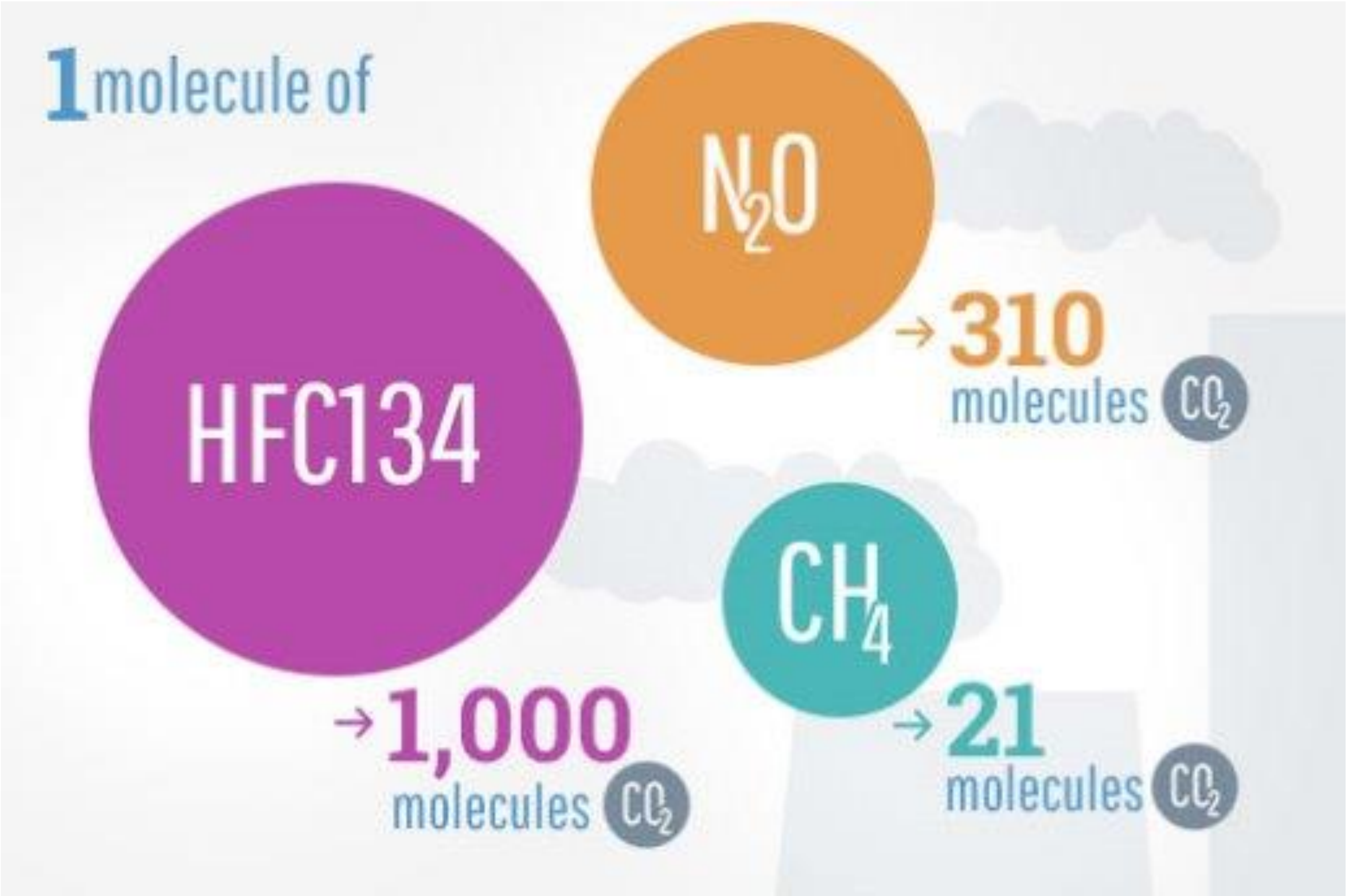
ISBN: 9780444635242

Climate change indicator?

~~EUI~~
~~Energy Use Intensity~~
~~$kWh/m^2/year$~~

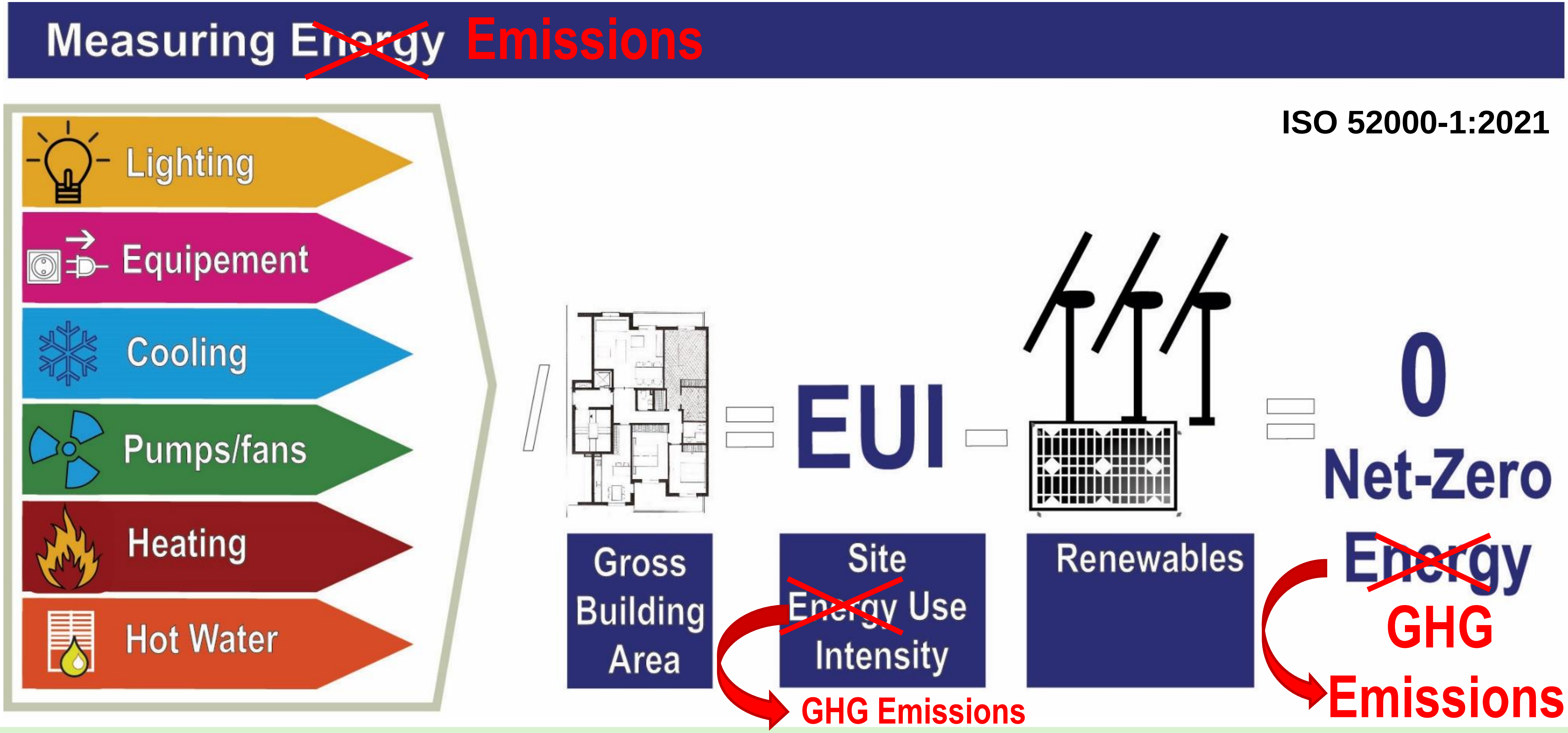
GWP
$kgCO_{2.e}/m^2/year$





Zero Net Carbon Buildings

From Energy Use Intensity to GHG Emissions Intensity



Why Whole-Life Carbon Buildings

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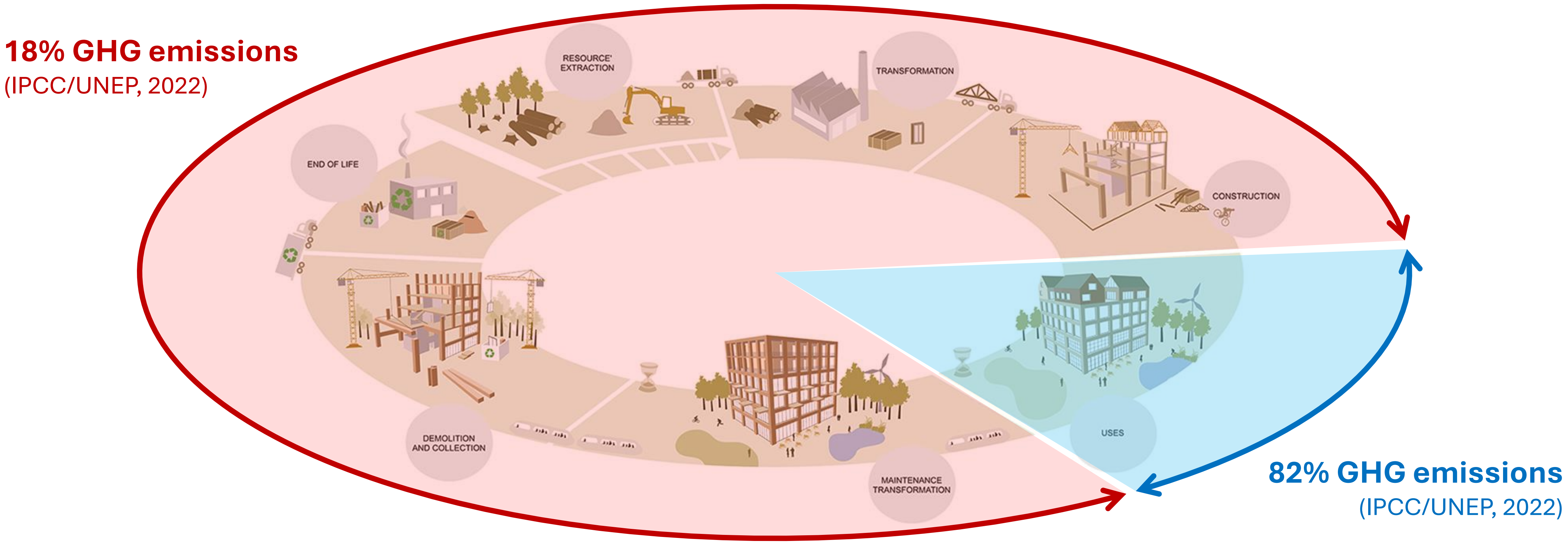
‘Embodied’ and ‘operational’ impacts



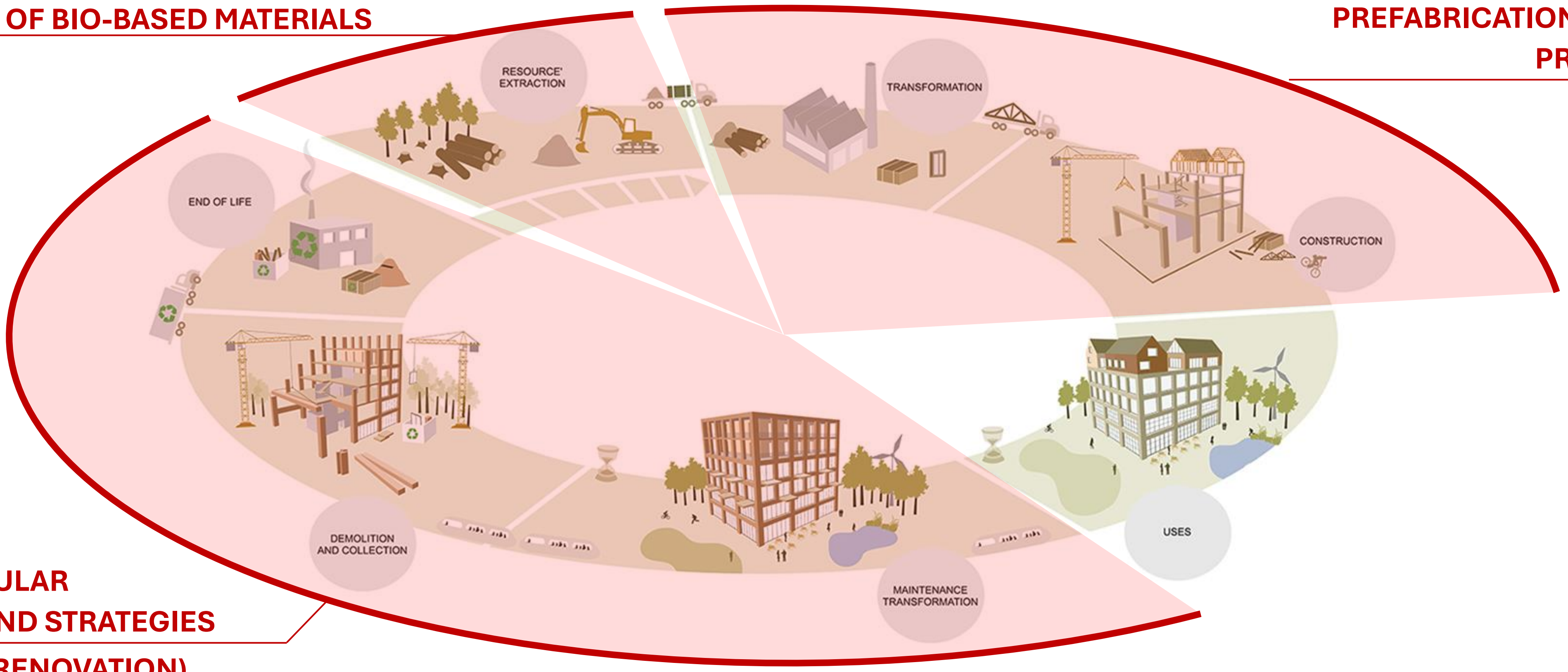
Life cycle phases of buildings

Source: https://www.smartlivinglab.ch/en/infrastructures/smart-living-building/

Reducing ‘embodied’ impacts

USE OF BIO-BASED MATERIALS

PREFABRICATION AND LEAN PRODUCTION

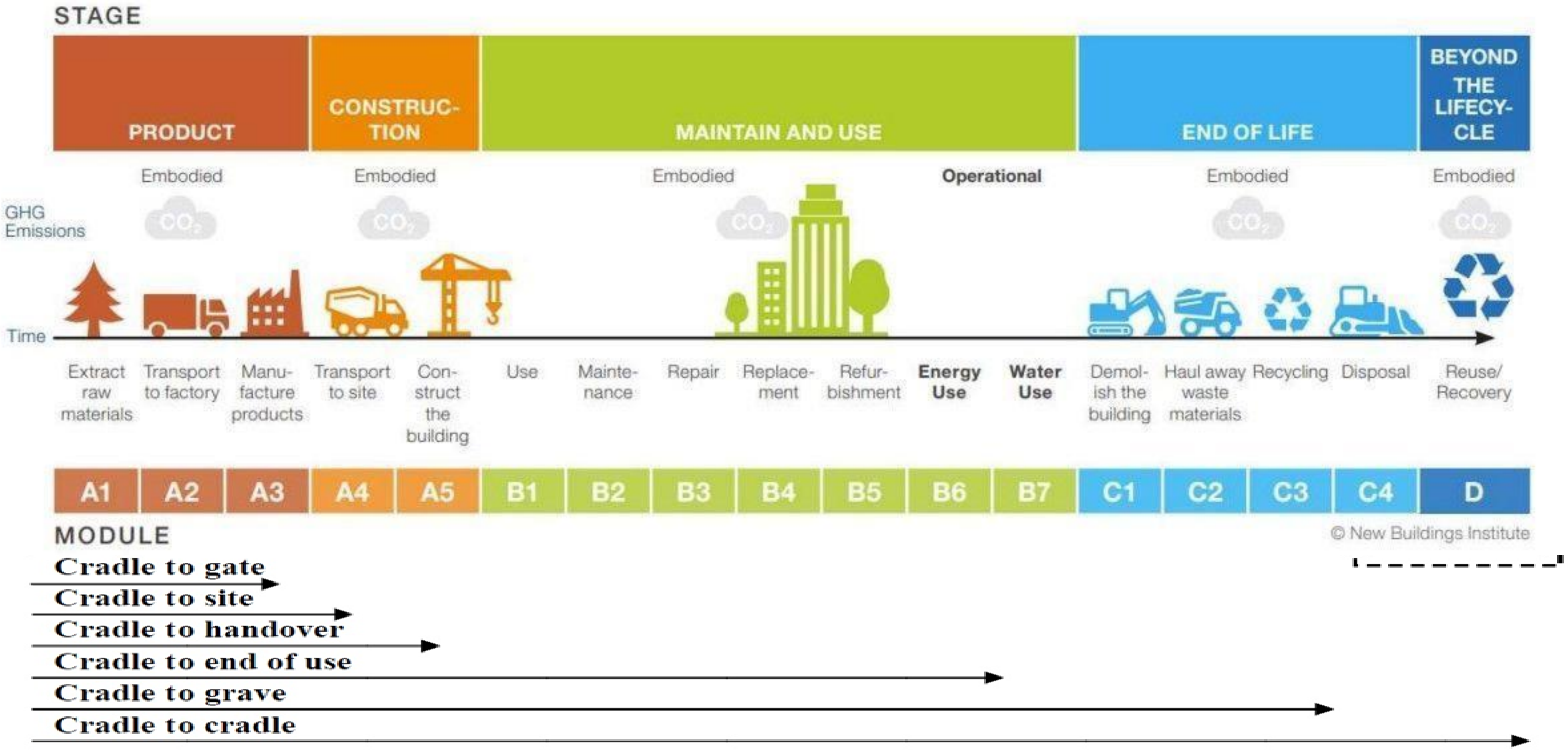


USE OF CIRCULAR MATERIALS AND STRATEGIES (INCLUDING RENOVATION)

Life cycle phases of buildings

Source: https://www.smartlivinglab.ch/en/infrastructures/smart-living-building/

Lifecycle Stages of Buildings: ISO 14040



Why whole life cycle carbon?

ISO 14040

1. **Comprehensive Carbon Footprint Assessment**
2. **Long-term Sustainability Goals**
   Climate-neutral by 2050.
3. **Regulatory Efficiency**
   Resources efficiency
4. **Market Transformation**
   accelerate the adoption of green technologies
5. **Holistic Environmental Impact**:
   circular economy

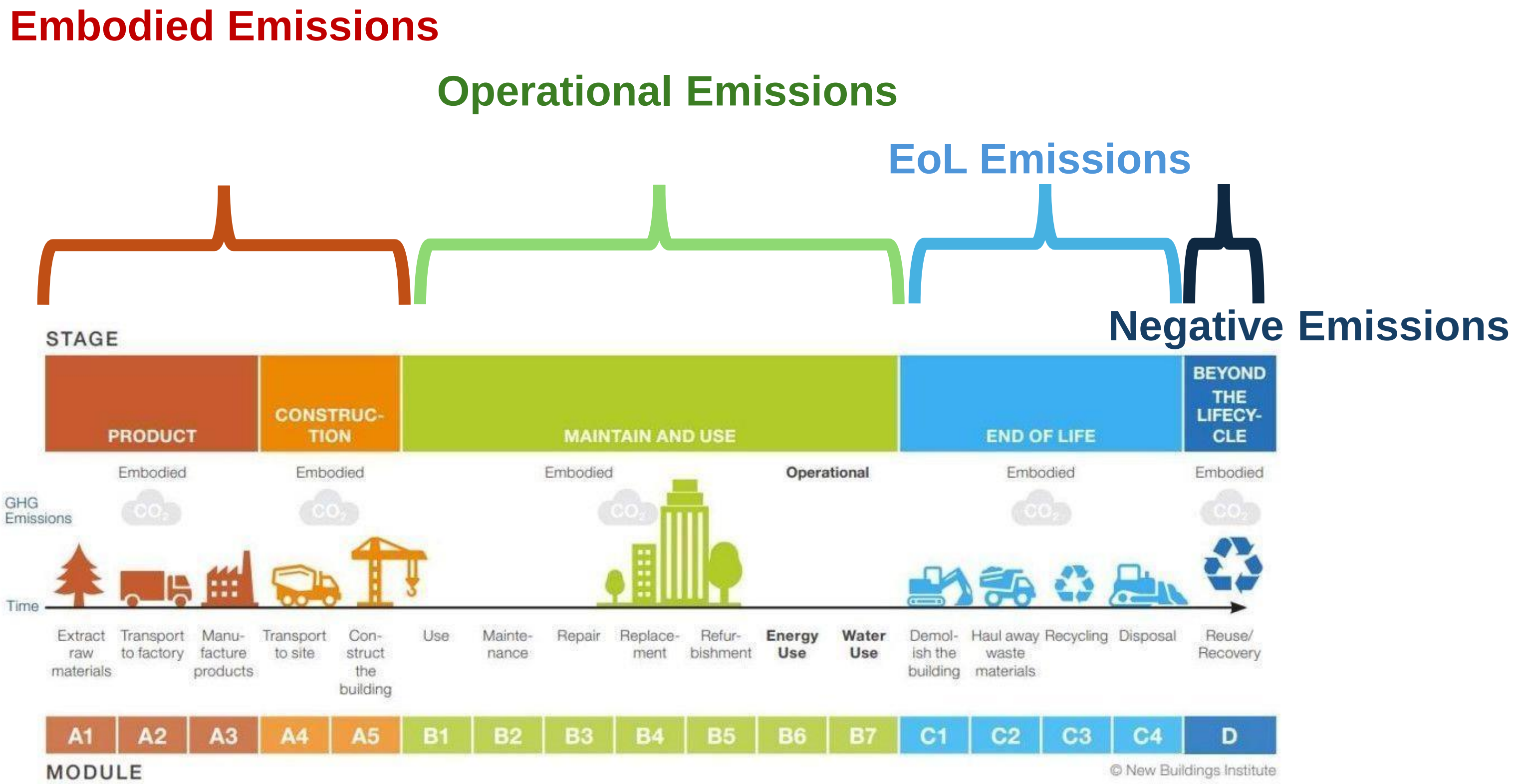


Figure 1: Lifecycle stages of building carbon. Data source: BS EN 15978:2011
Source: Bowles, Cheslak, and Edelson 2022

Net-Zero Whole-Life Carbon Buildings

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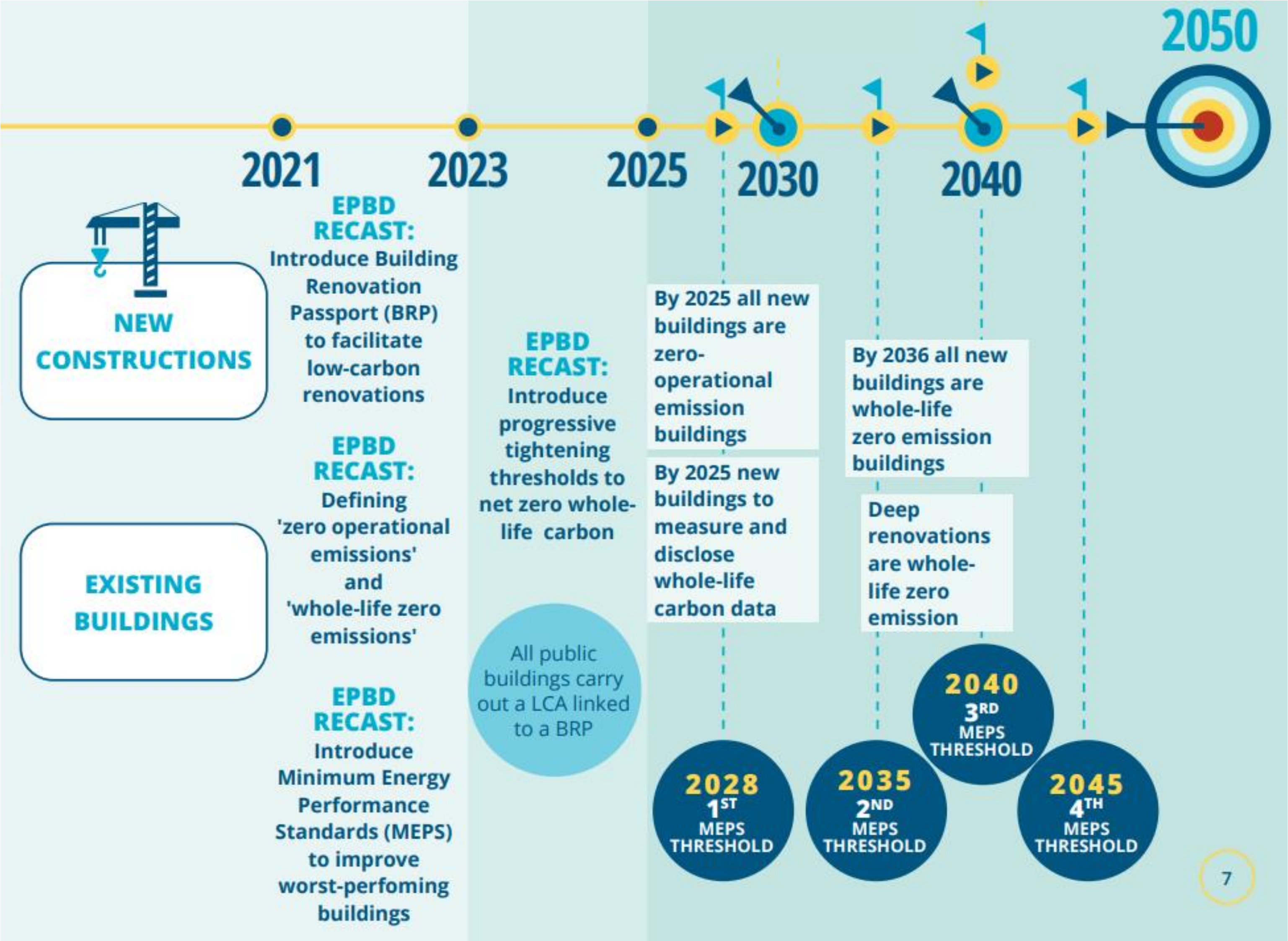
EU Carbon Neurality 2050

1. All-electric buildings
2. Low carbon buildings
3. Decarbonization of heating & cooling
4. Decarbonization of Energy Mix
5. Low carbon building services



Why whole life cycle carbon?

Denmark

- regulation year: 2023
- all new buildings > 1000 m_2
- system boundary: A1-A3, B4, B6, C3-C4
- lifespan: 50 years
- from 2025: max. 7,1 kg $CO_{2\text{-eq}}$ /m_2 / year
- 1,5 kg $CO_{2\text{-eq}}$ /m_2 / year: A4-A5

France

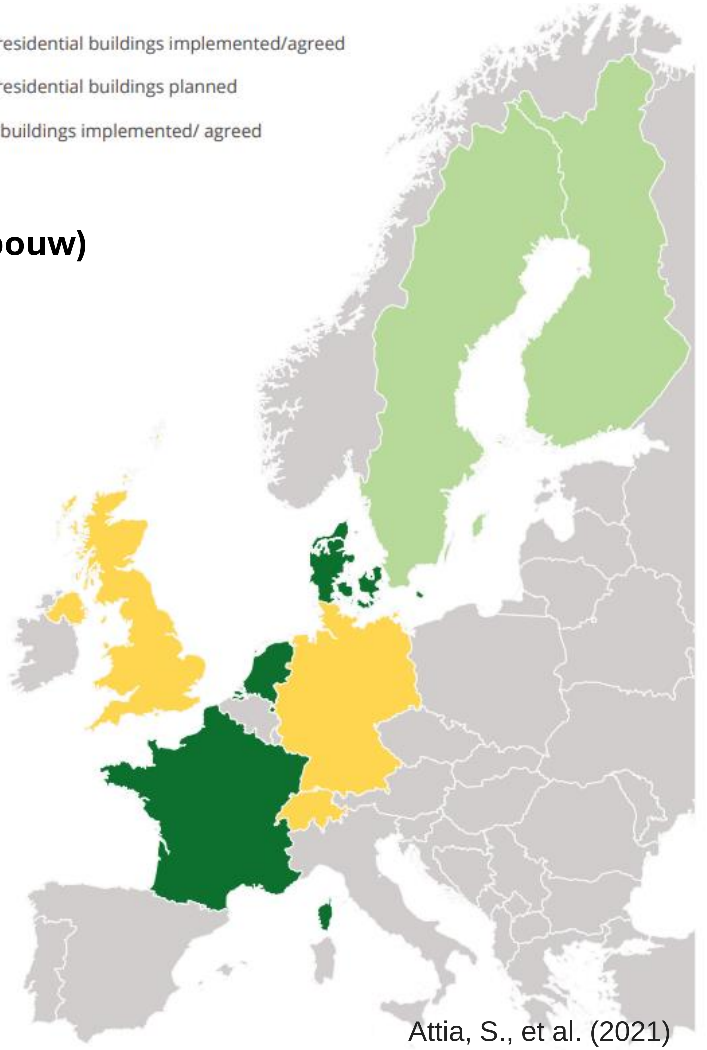
- regulation year: 2022
- all new buildings > 50 m_2
- system boundary: A1-A5
- lifespan: 50 years
- from 2022: max. 640-980 kg $CO_{2\text{-eq}}$ /m_2,
- depending on building typology

The Nederlands (MilieuPrestatie Gebouw)

- regulation year: 2017
- all new buildings > 100 m_2
- system boundary: A1-A5
- lifespan: 75 years (residential)
- from 2021: ≤ 0.8
- (DGBC max. 200-260 $CO_{2\text{-eq}}$/m_2 GFA)

Sweden

- regulation year: 2022
- all new buildings > 1000 m_2
- (single-family houses excl.)
- system boundary: A1-A5
- lifespan: 50 years
- from 2025: max. 180-460 $CO_{2\text{-eq}}$/m_2 GFA, depending on building typology



Attia, S., et al. (2021)

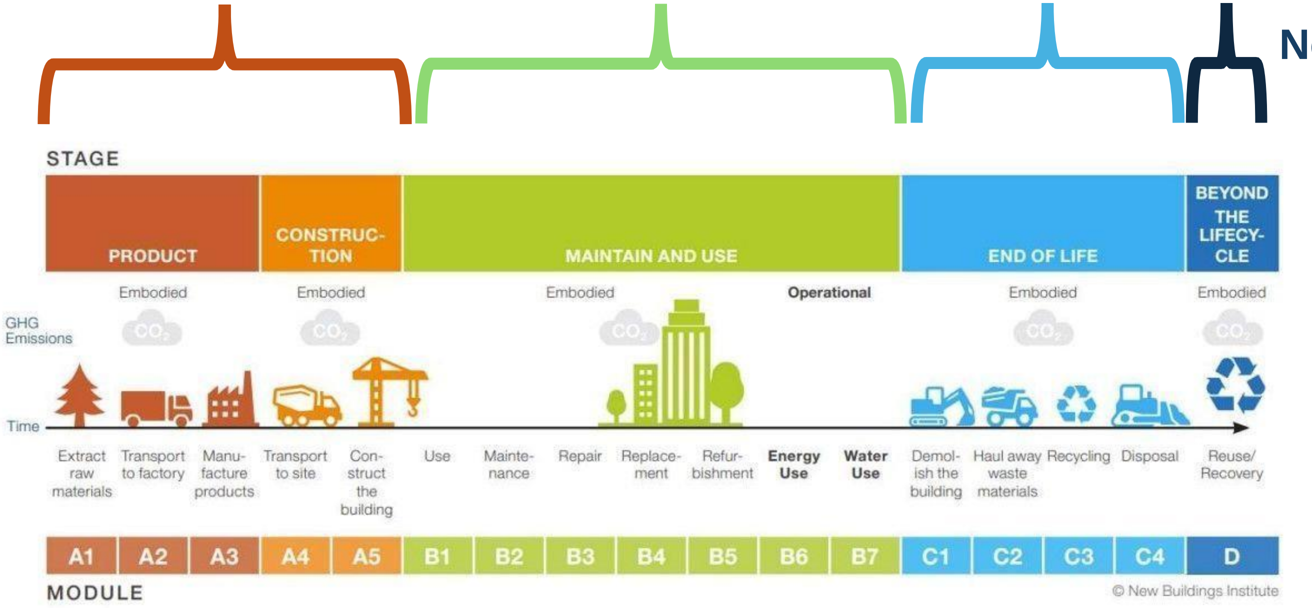
Operational vs Embodied emissions

Embodied Emissions

Operational Emissions

EoL Emissions

Negative Emissions



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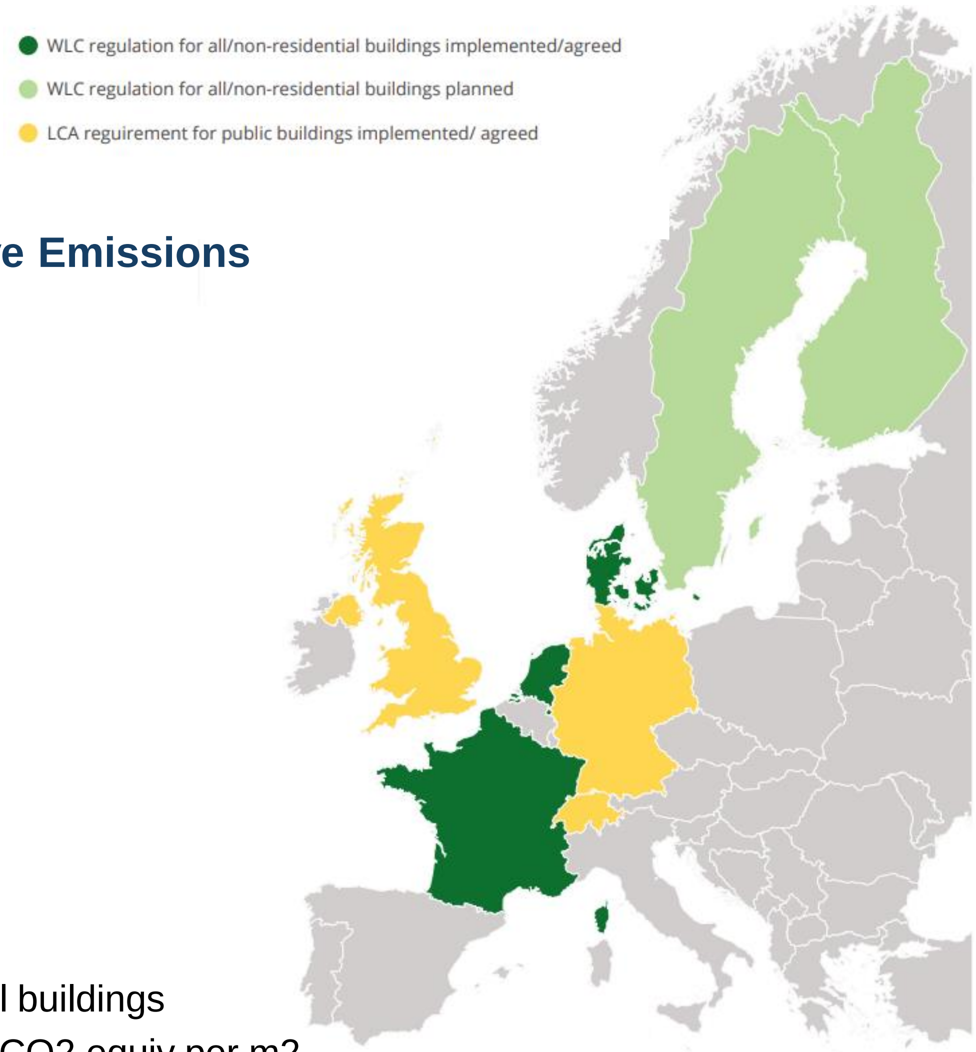
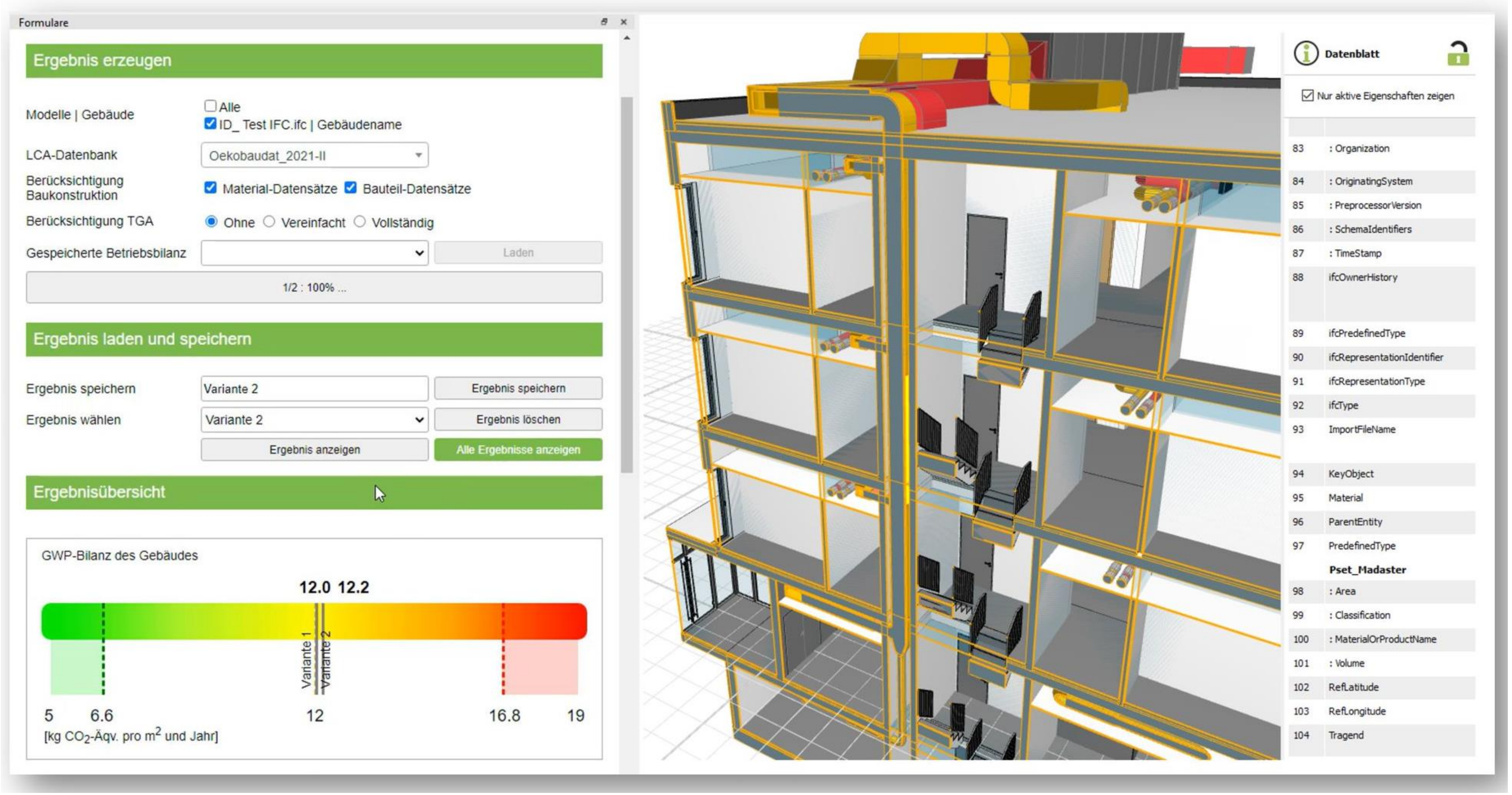


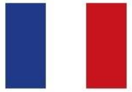
- RE2020 threshold of 4 kgCO2.equiv. operational emissions per m2 for new residential buildings
- Dynamic LCA calculation method + threshold for embodied carbon emission of 100 kgCO2.equiv per m2

Attia, S., et al. (2021)

GHG Emissions

Embodied and Operational Emissions





- 2023, Operational emissions:

4 kgCO2.equiv. per m2 for new residential buildings

- 2023, Embodied emissions (Office)

24 kgCO2.equiv per m2

- 2025 Operational + Embodied emissions:

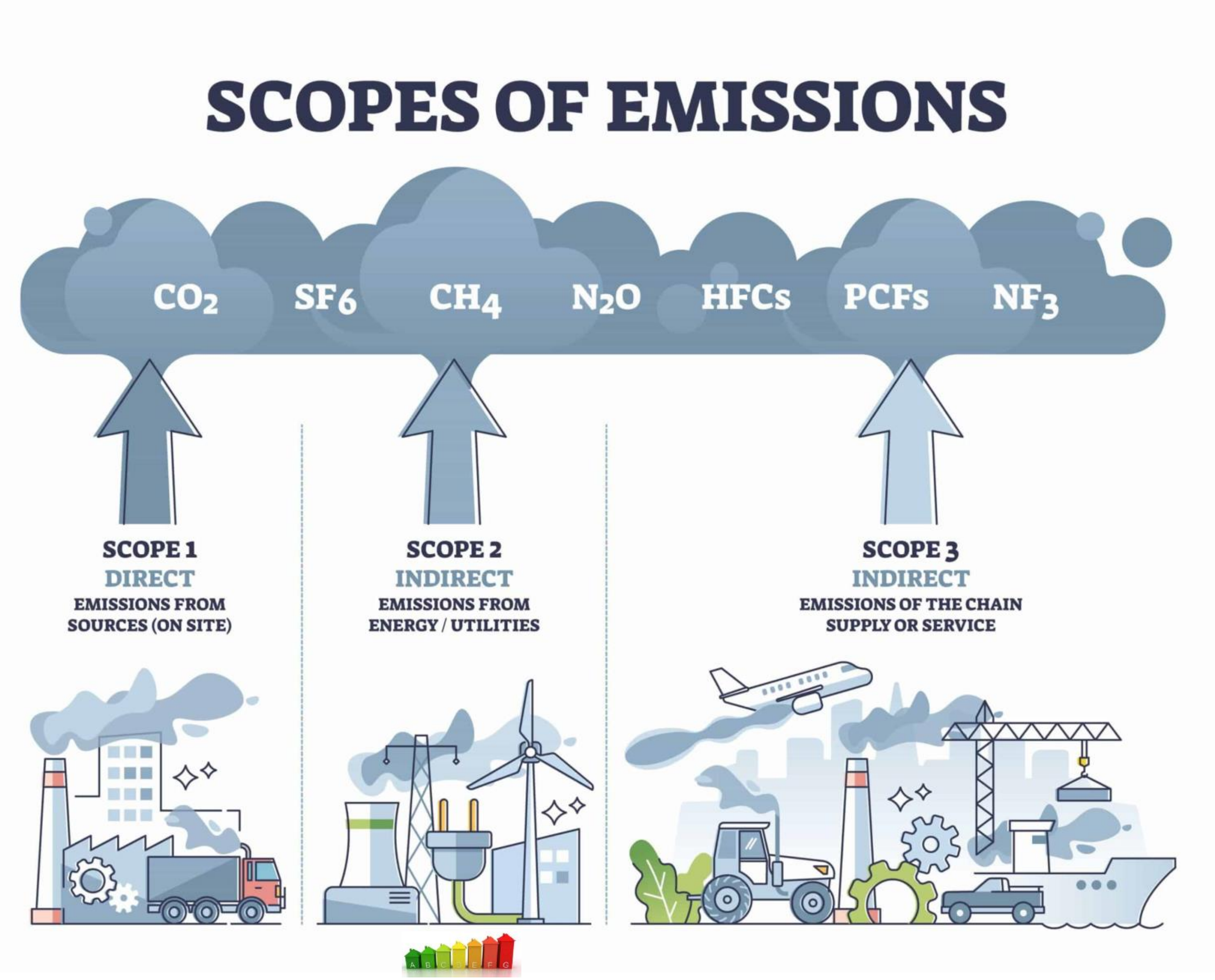
7,1 kgCO2.equiv. per m2 for new residential buildings: A1-A3, B4, B6, C3-C4

1,5 kg CO2-eq /m2 / year: A4-A5

Source: DGNB, Sebastian Theißen, BIM-based emissions modeling

Corporate ESG strategies

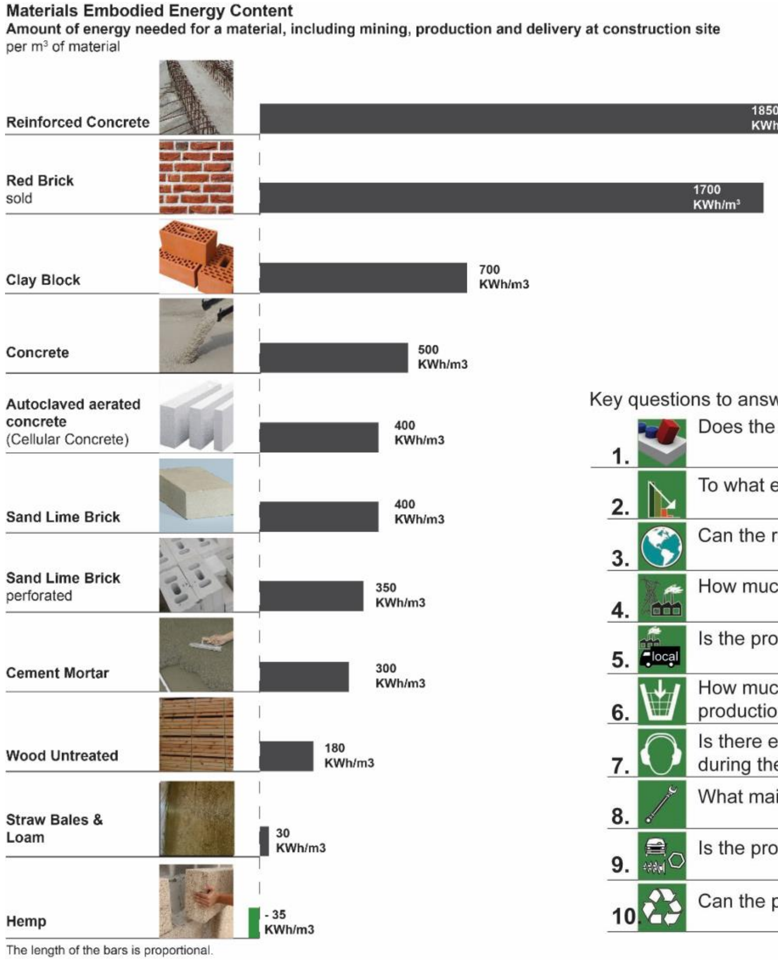
1. Tenants demanding low-carbon spaces
2. Office buildings reflect corporate carbon commitments
3. Market is seeing rents for these spaces rise due to demand



Embodied GHG Emissions

Many of the mostly widely used construction materials are from carbon-intensive heavy industries

Source: https://materialepyramiden.dk/



Embodied GHG Emissions

Categories of carbon negative materials


Timber


Straw


Cork


Hemp

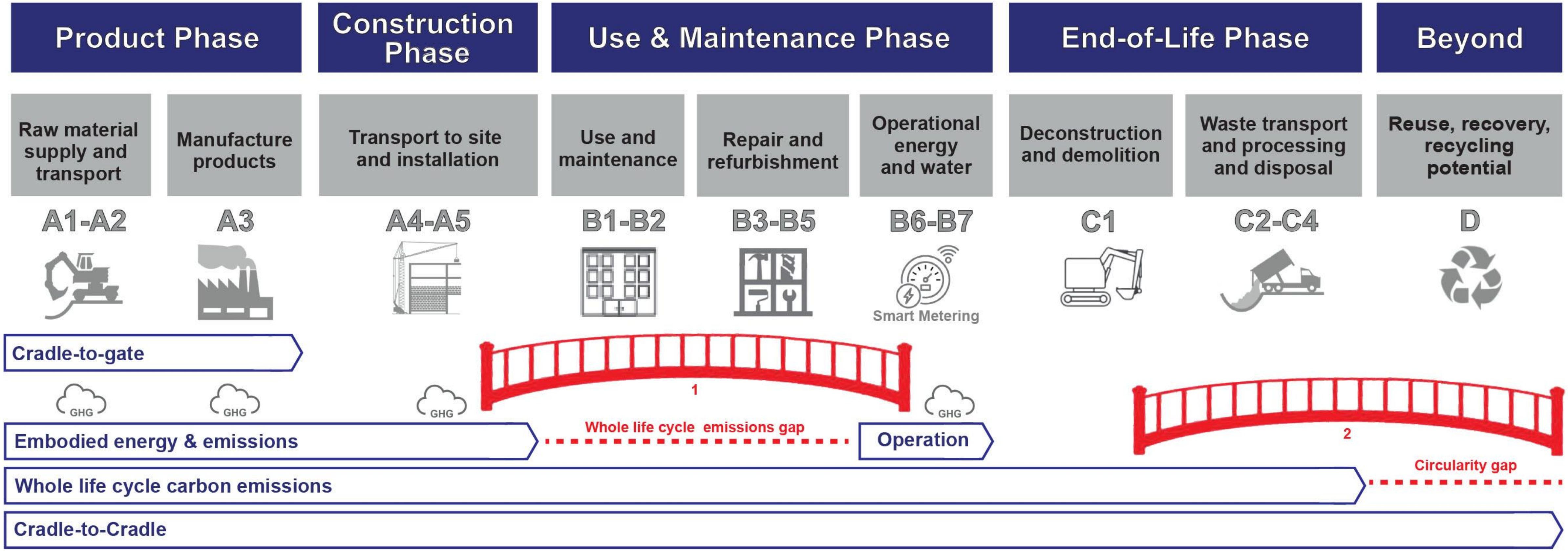

Biochar


Captured carbon


Biomineralization (Low carbon aggregates)

Embodied GHG Emissions

Coupling of Embodied and Operational GHG Emissions Modeling



Source: Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd

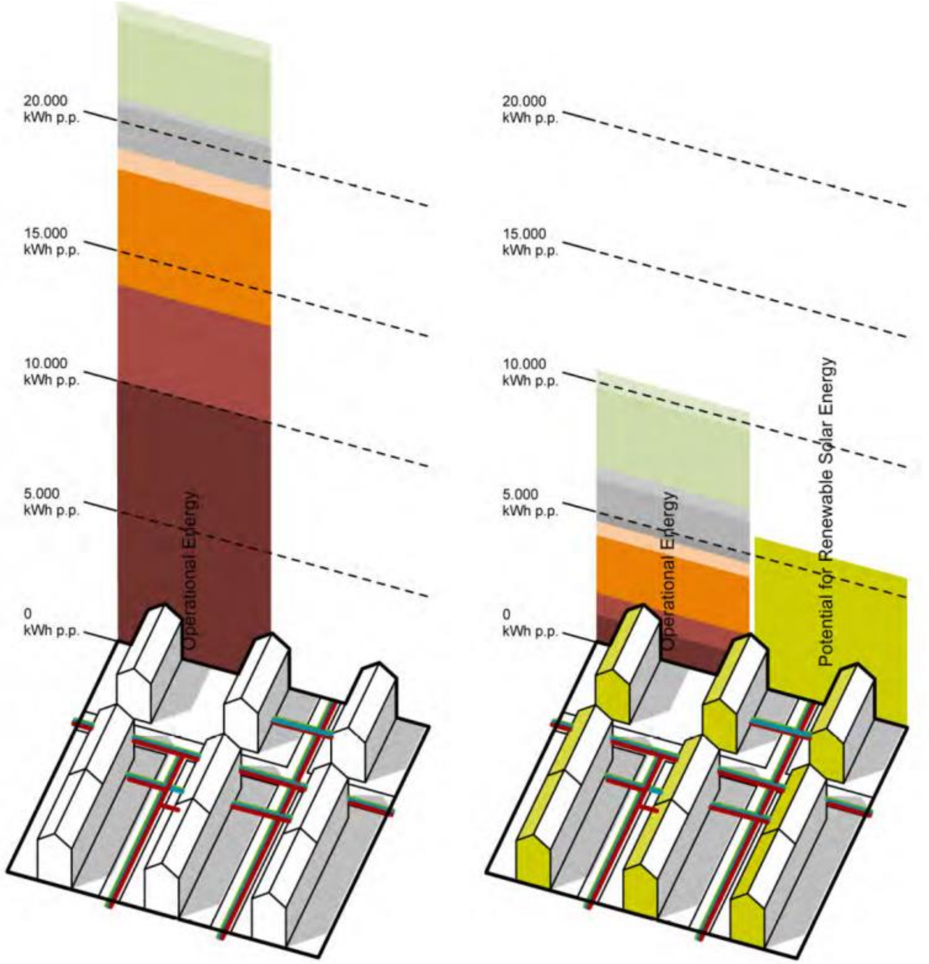
Embodied GHG Emissions

Some low carbon solutions

Nr.	Low carbon solutions	Category
1	Renovate instead of building new	Circularity principles and downsizing in the conceptual design stage
2	Design for flexibility, resilience and extended lifespan	
3	Design for disassembly	
4	Re-use existing materials in construction	
5	Optimize the use of space in offices, residential buildings	
6	Design based on light construction method instead of massive construction	
7a	Use industry by-products instead of cement	Carbon reduction in material selection and sourcing
7b	Use recycled concrete and other by-products as aggregate for new concrete	
8	Reduce concrete demand through material use optimization in (structural) design	
9	Offsite construction and design for less waste on-site	
10	Use of locally sourced materials and clean transportation	
11	Use timber structures in new construction	Carbon reduction in material selection and sourcing – bio-based materials
12	Use hybrid (concrete + timber) structures in new construction	
13	Use timber roof elements in standard structure	
14	Use other bio-based materials	

Building Stock Renovation

Evaluate systematic strategies to increase the deep renovation rate before implementation to gain time, money and energy.



Zero Net Carbon Buildings

De Tippe Zwolle (F6), The Netherlands

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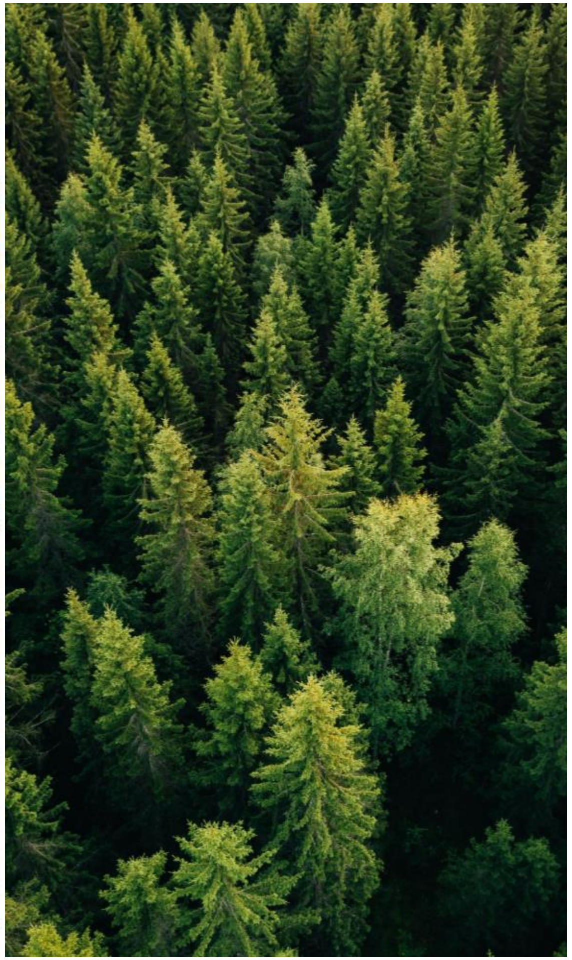
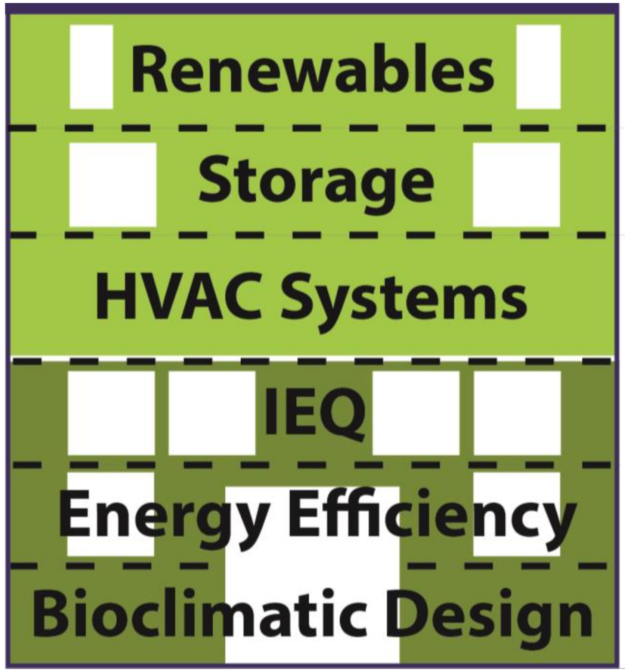


Pathways and Solutions

Zero Net Carbon Buildings

Definition

An ZNC is a grid-connected, carbon-efficient building **that balances its total annual carbon emissions by on-site generation.**
A ZNC building is a **highly energy efficient** building that produces on-site, or **procures, enough carbon-free renewable energy** to meet building operations energy consumption annually.



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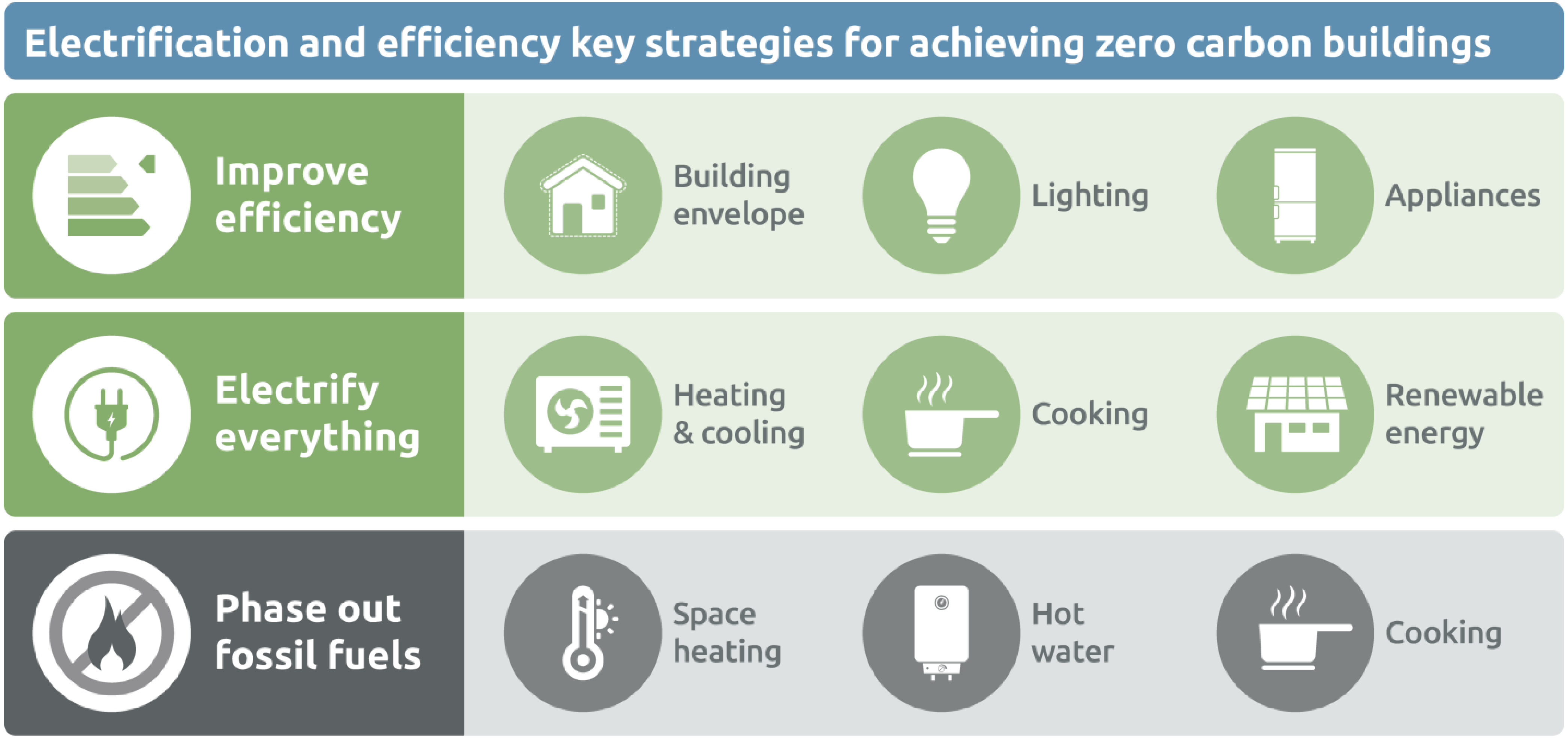
Zero Net Carbon Buildings

Electrification + Decarbonization

ASHRAE Standard 189.1, 2020



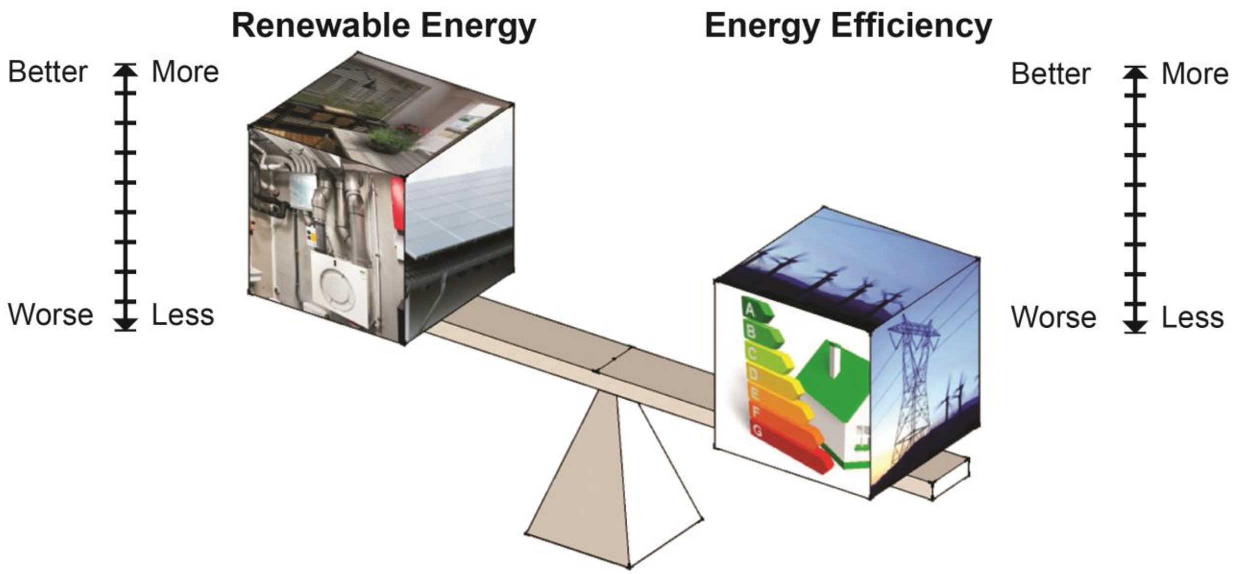
climateactiontracker.org

New report: Decarbonising Buildings - Feb 2022

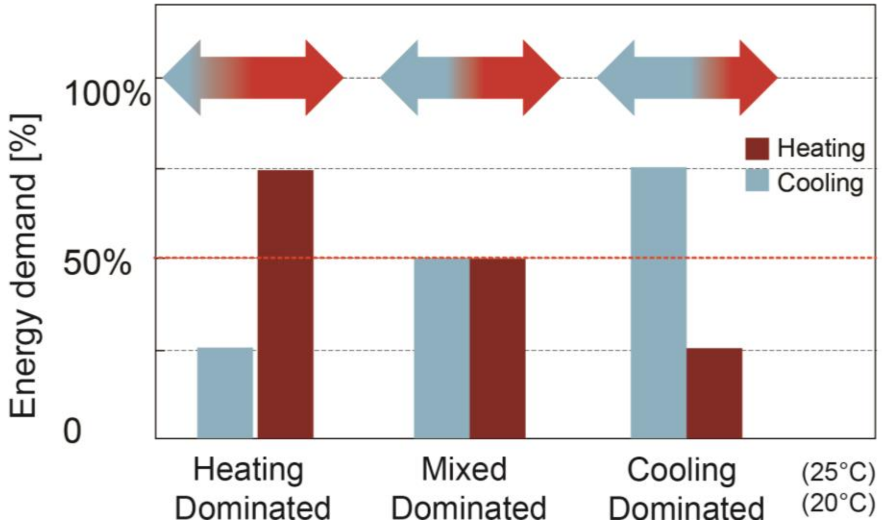
Zero Net Carbon Buildings

IEQ, Energy Efficiency and RES Balance

Challenge of Finding the Optimal Balance



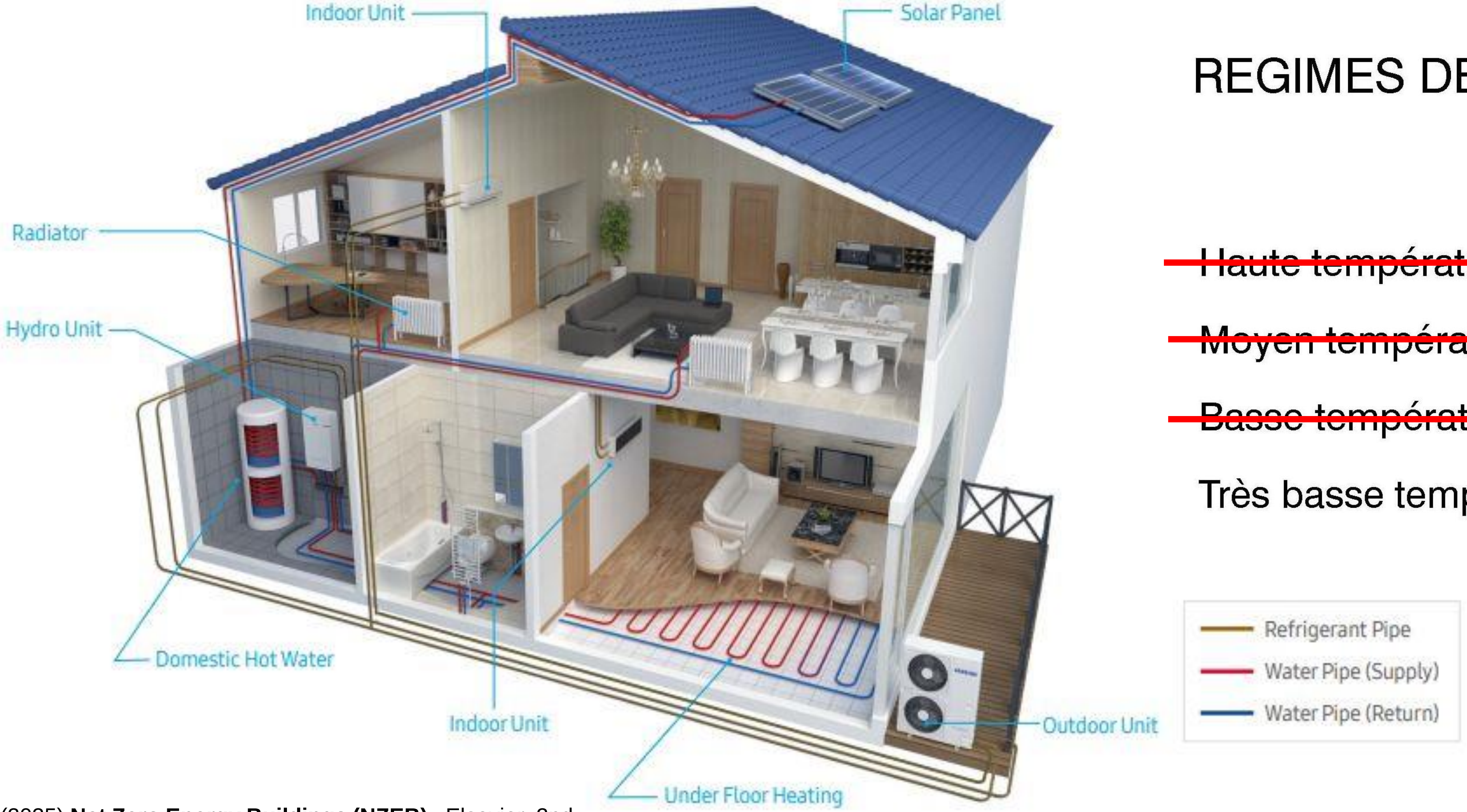
Cooling, Heating and Mixed Energy Demand Balance



Attia, S. (2035) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd

Zero Net Carbon Buildings

Decarbonization of Heating



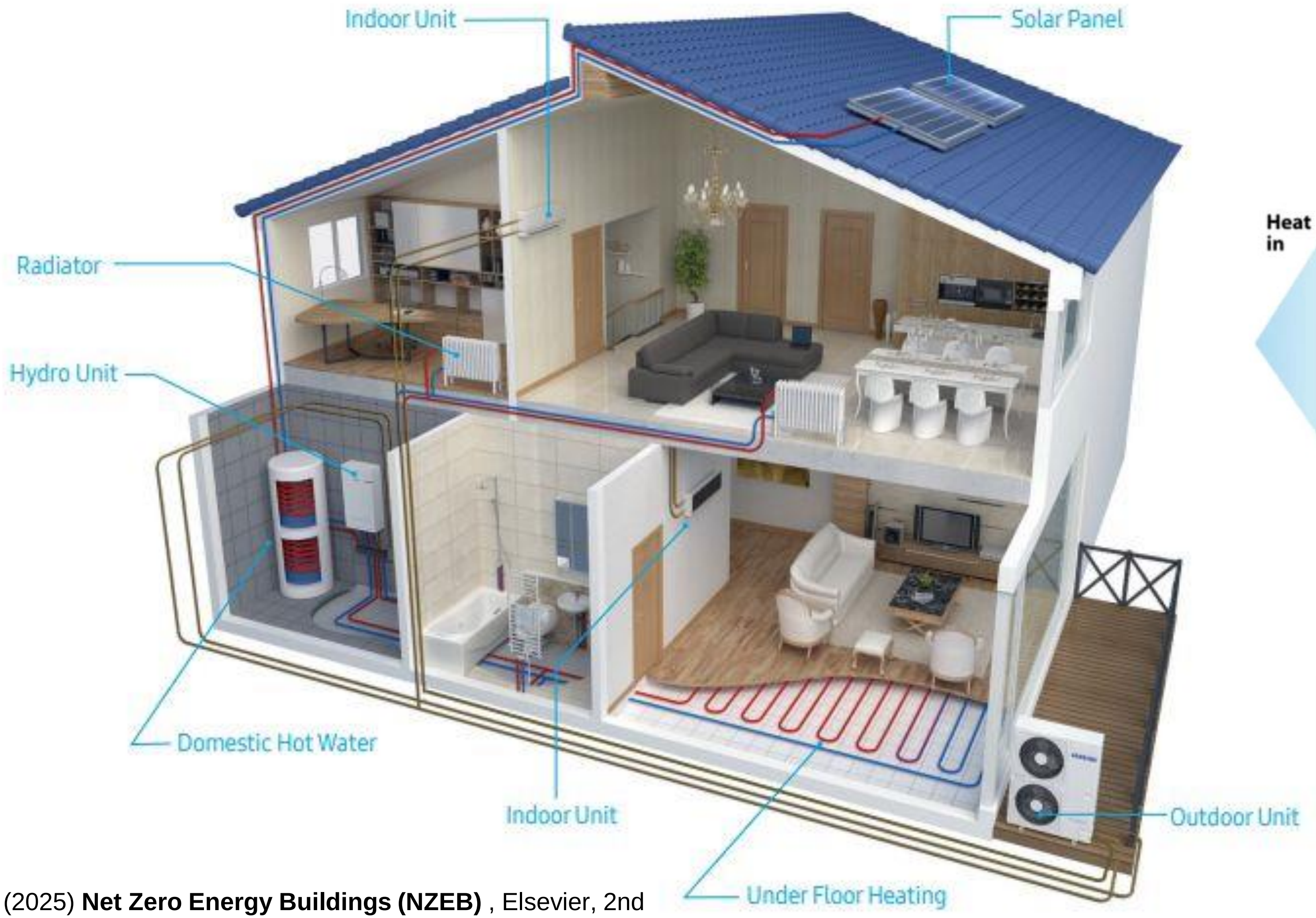
REGIMES DE TEMPERATURE

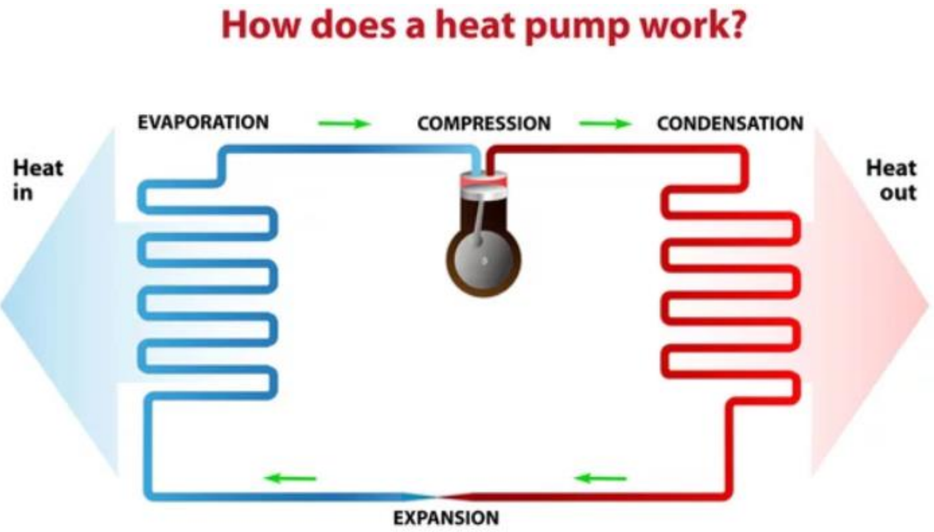
	T aller
~~Haute température~~	~~90°C~~
~~Moyen température~~	~~70°C~~
~~Basse température~~	~~55°C~~
Très basse température	30°C

Attia, S. (2035) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd

Zero Net Carbon Buildings

All Electric with Heat Pumps





Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd

Zero Net Carbon Buildings

Worlds largest heat pump to be installed in Helsinki, Finland.

1. **Full heating production capacity ranges from 20-33 MW, depending on the air temperature,**
2. **Can help deliver heat up to 90 degrees Celsius (194 Fahrenheit) while operating at temperatures as low as -20 degrees Celsius (-4 Fahrenheit).**
3. **The heat pump will provide heat for 30,000 homes in Helsinki annually, roughly saving 26,000 tonnes of CO2 emissions.**

Source: MAN Energy Solutions

Zero Net Carbon Buildings

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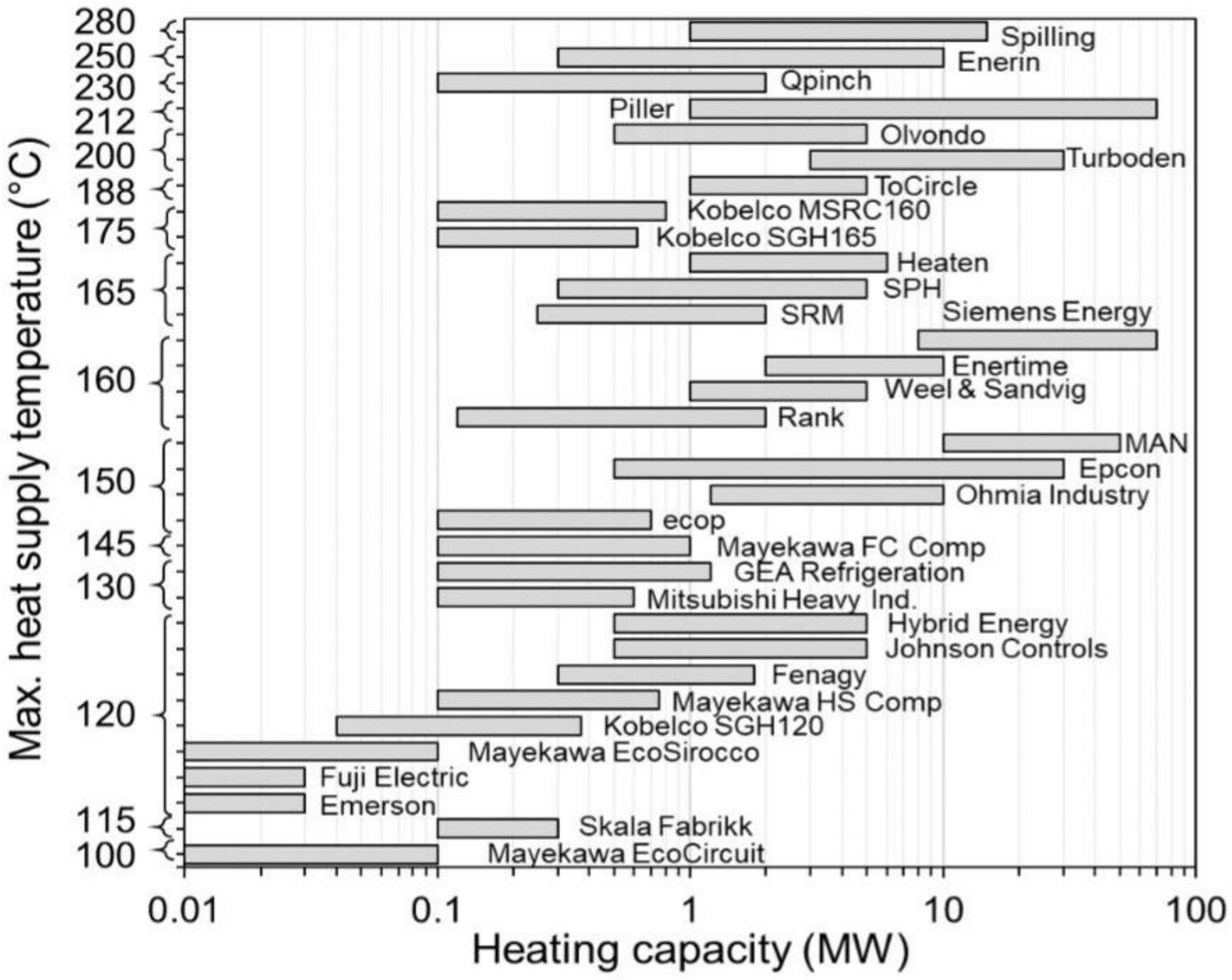
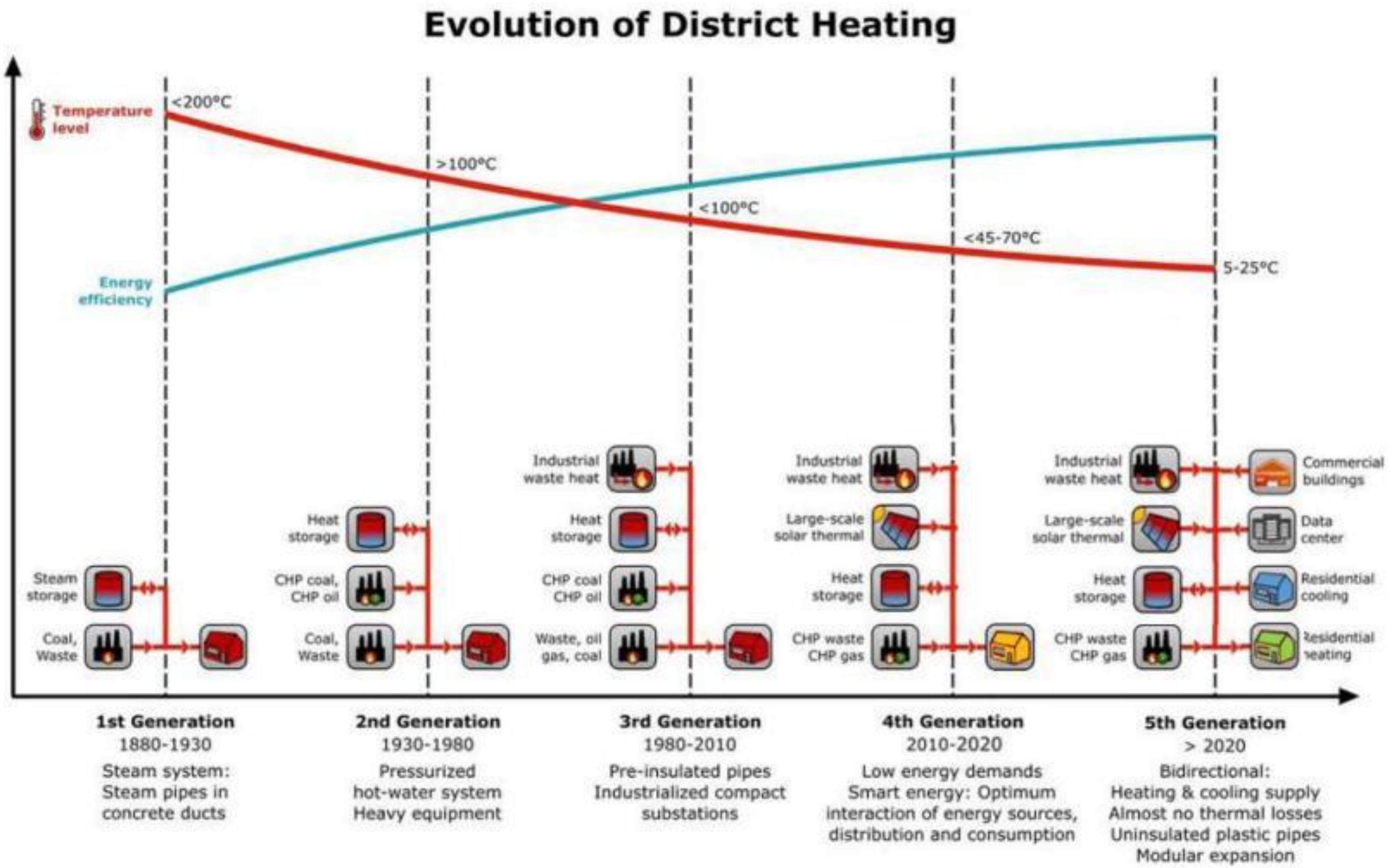
Industrial heat pumps are reaching ever-higher temperatures



1. **Industrial heat pumps can supply heat with more than 200C now.**
2. **Most of the heat pumps in the upper range are steam compressors, compressing steam generated by a bottom-cycle closed-loop heat pump.**

Source: Industrial electrification report Rosenow

District Heating & Cooling

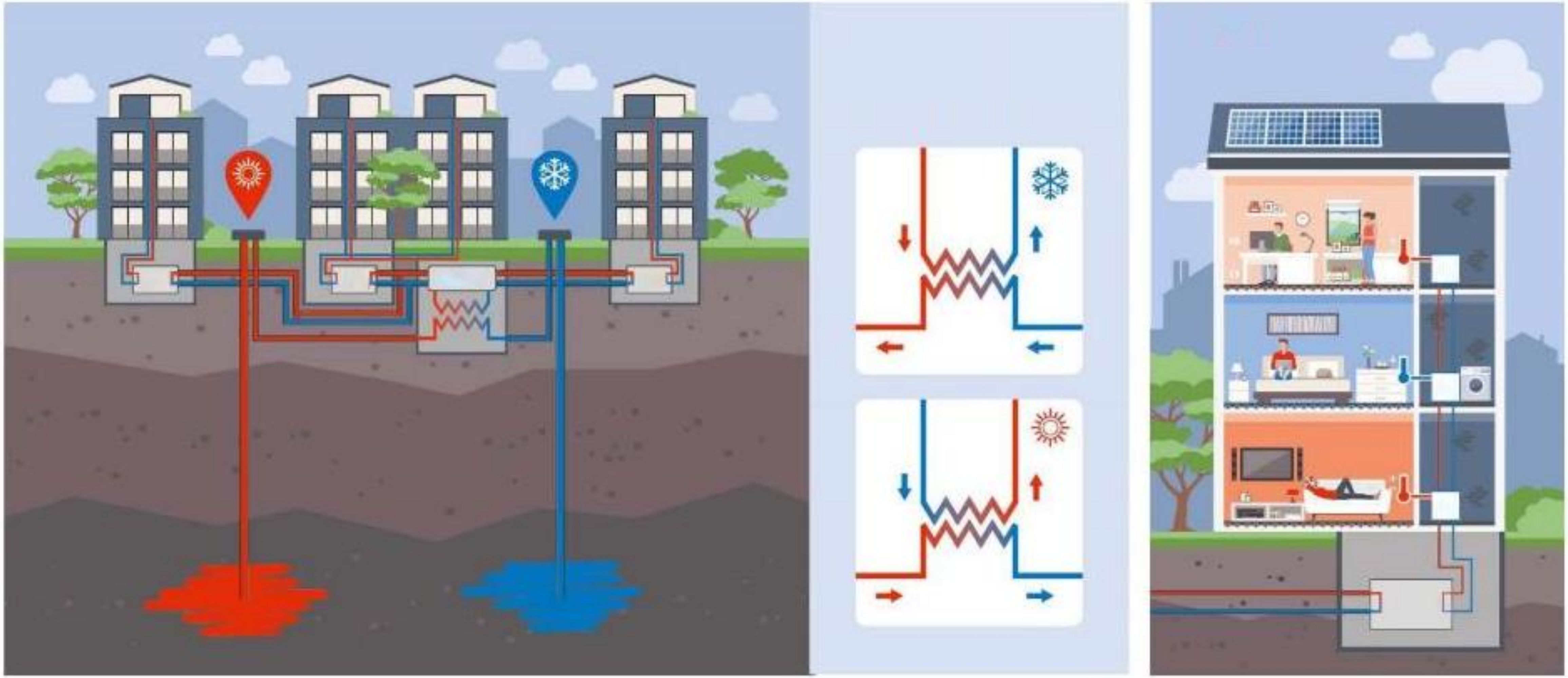


4th Generation:
District heating grid with a collective source

5th Generation:
Thermal energy directly from the subsurface (T 5 – 25 °C)

District Heating Grid: 5th Generation

The Neutral Grid: Centralized Heat Pumps



4th Generation vs. 5th Generation

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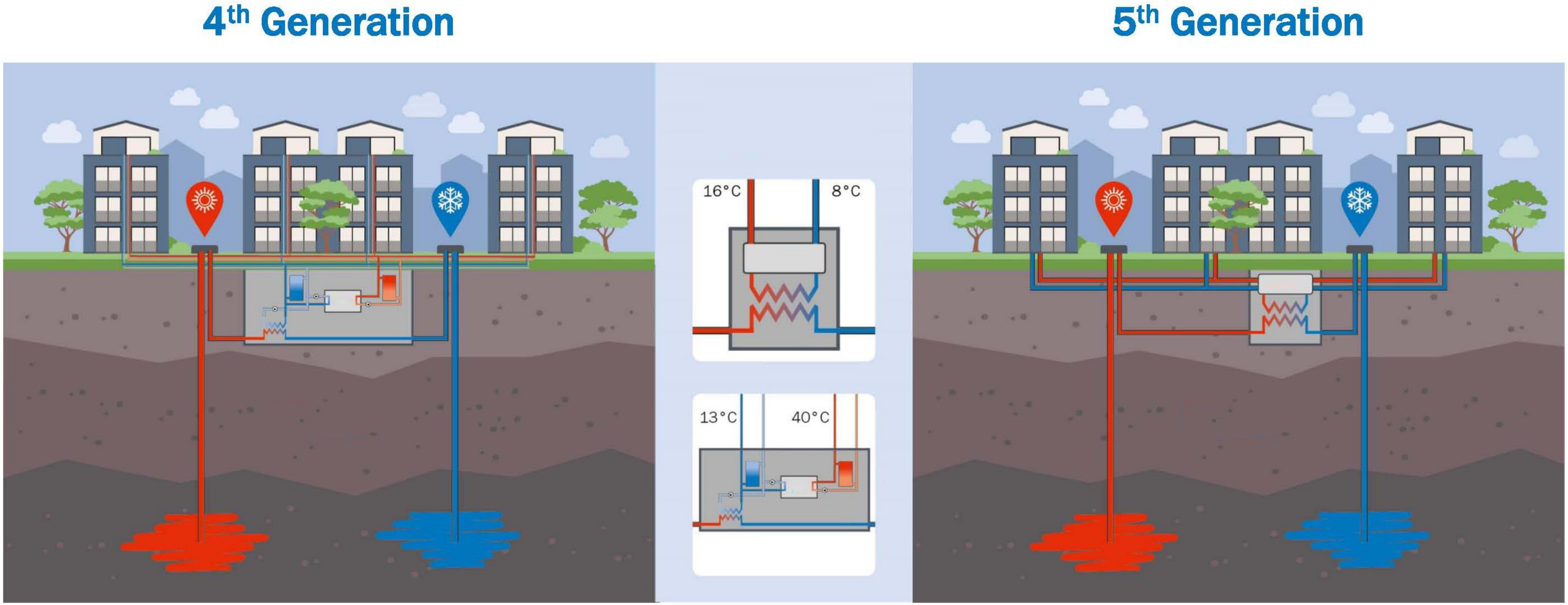
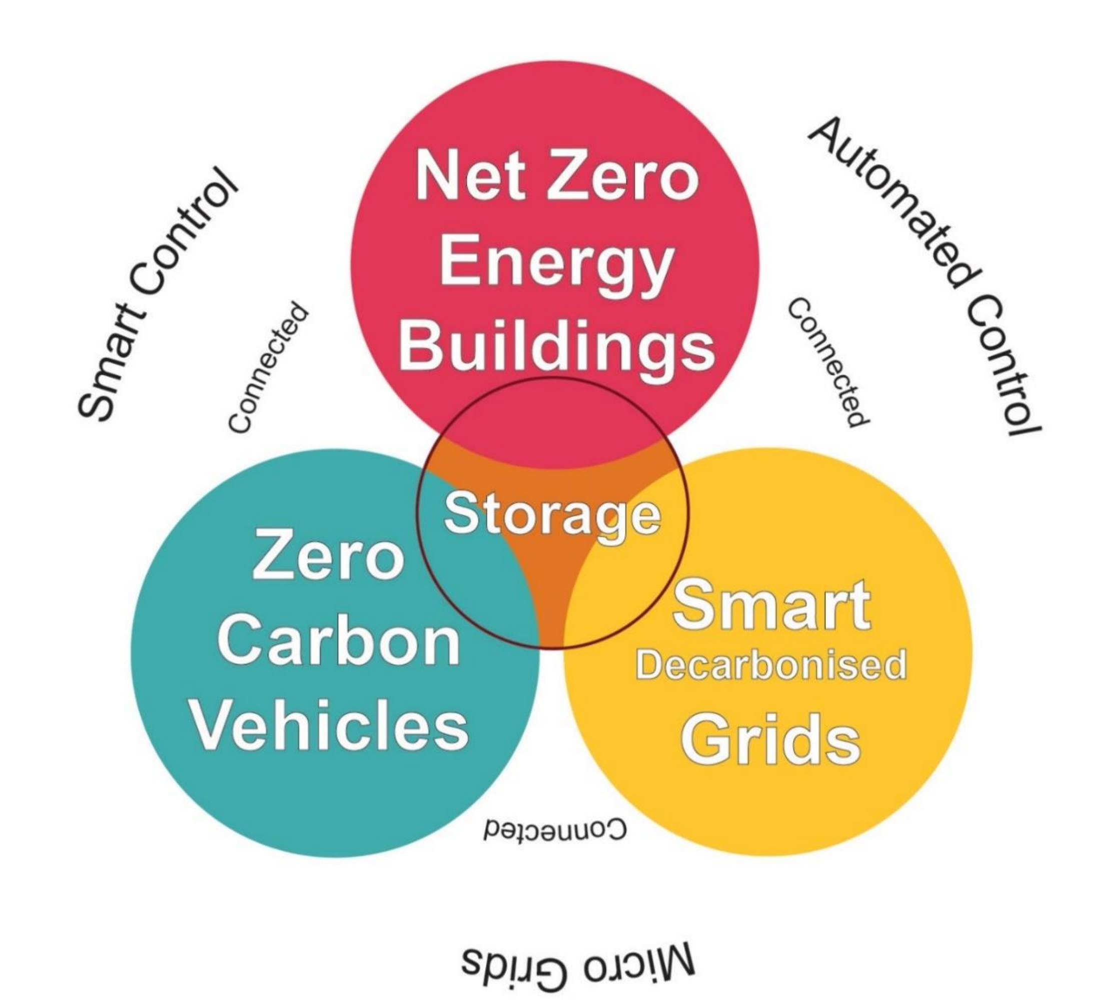
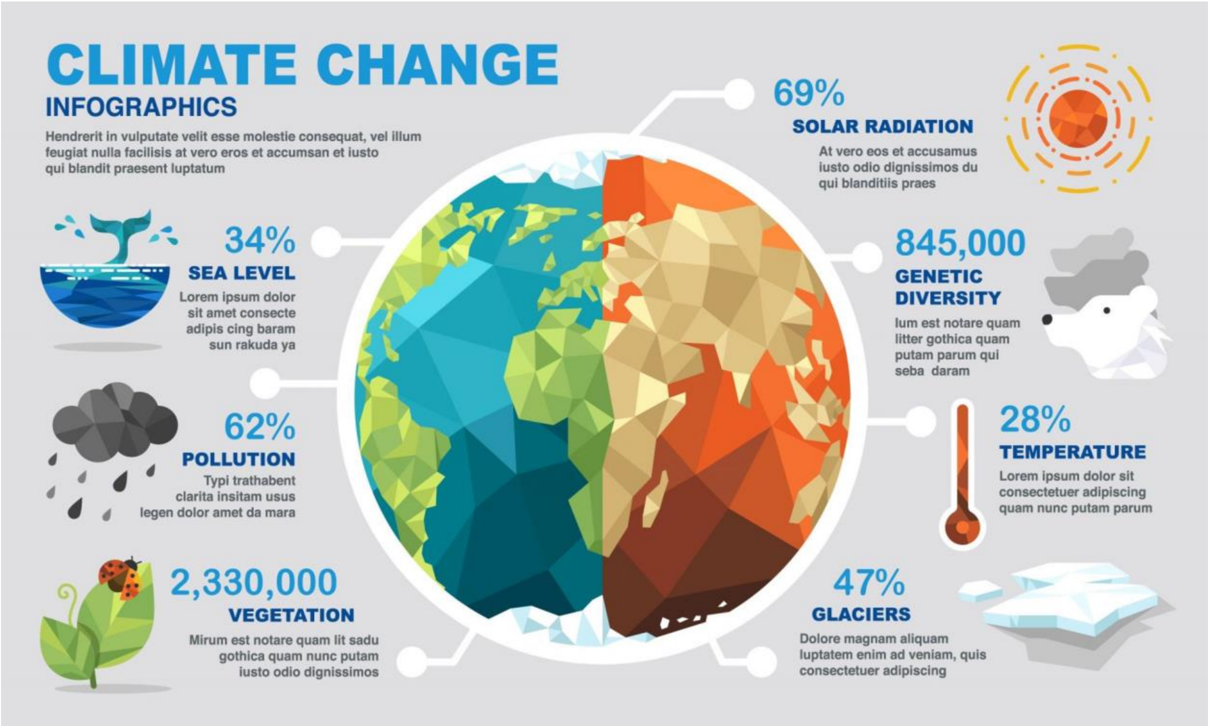


Carbon Neutral Communities

Storage & Scale the Core of Carbon Neutrality





Resilience

Source: Attia, S. (2018) **Net Zero Energy Buildings (NZEB)** , Elsevier, 2nd

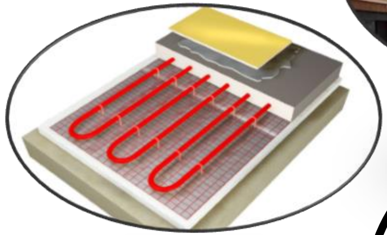
Energy Storage Systems

The Core of Carbon Neutrality

Buildings Storage Systems

Thermal Mass

Floor Heating Systems



Fuel Cells

Buffer Tanks

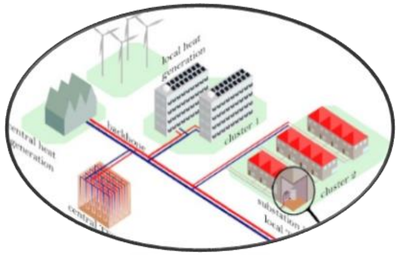
Batteries

PCM

TABs Thermally Activated Beams

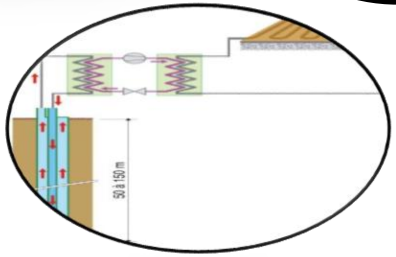
District Storage Systems

Mixed Use Districts



Neutral Networks

Energy Storage Systems



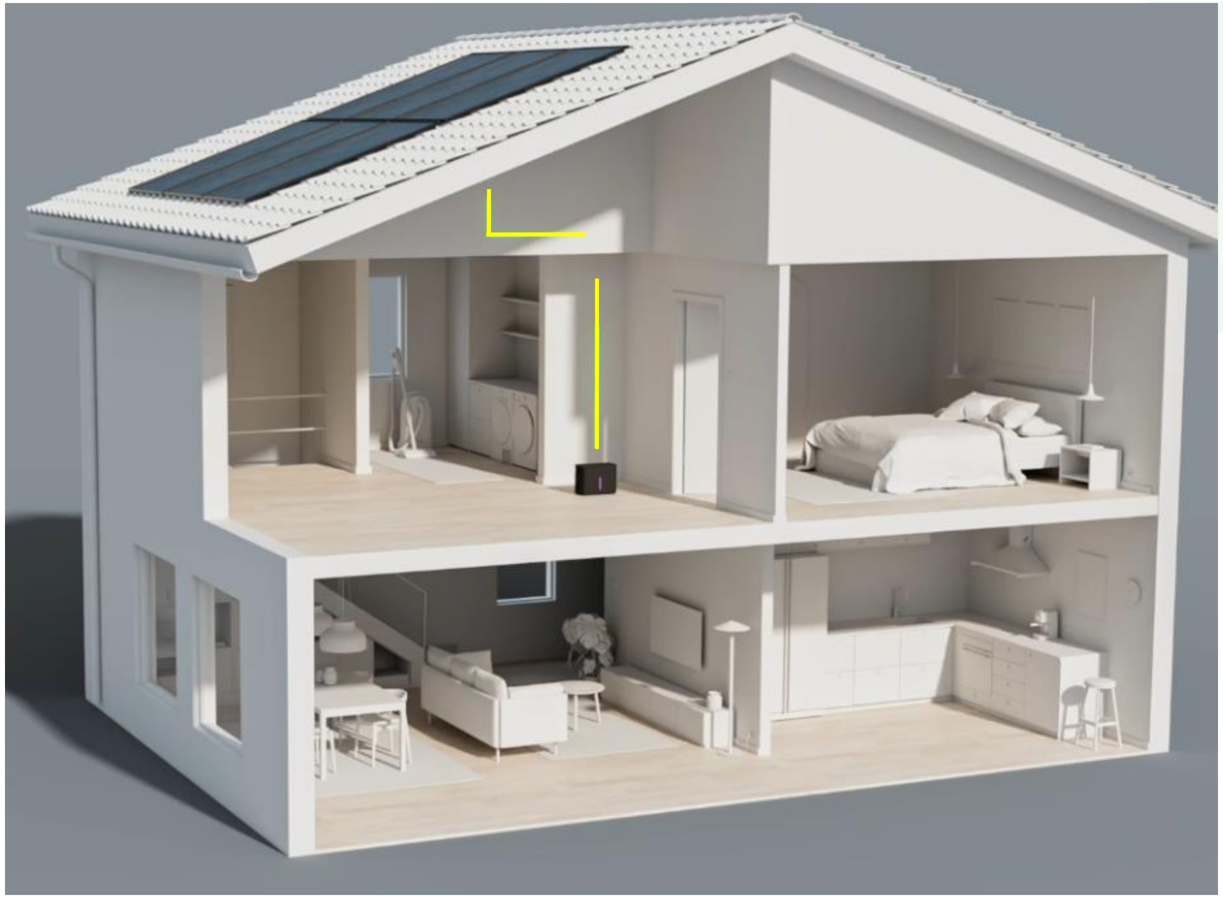
Geothermal Energy Storage

Micro Hydro Power for Storage

Zero Net Carbon Buildings

Plug-In Battery

2 kWh and 5 kWh cover all households equipments and appliances



Source: https://www.homewizard.com/

Zero Net Carbon Buildings

Regulations on Refrigerants

ISO 817

1. EU Directive introduced in 2006 on the direct impact of air conditioning systems
2. February 2024: EU set a steeper schedule for phasing down fluorinated gases
3. Prohibition of product categories: Chillers, Heat Pumps and Split Air Conditioning systems

Split Air-to-Water		
X <= 12 kW at 150 GWP	➡	1st January 2027
X <= 12 kW full F Gas prohibition	➡	1st January 2035
X > 12 kW at 750 GWP	➡	1st January 2029
X > 12 kW at 150 GWP	➡	1st January 2033

Time period	Updated EU phase down adopted in February 2024
2021 - 2023	
2024 - 2026	23.6%
2027 - 2029	10.1%
2030	5%
2048	2.38%

Zero Net Carbon Buildings

Modern refrigerants – new characteristics

ISO 817

R32 (GWP 675)

- Efficiency remains the same
- Capacity increases
- Technology only available for small inverter-driven compressors
- Specified due to availability of small DX compressors using inverters to manage higher discharge temperature

R290 – Propane (GWP 3)

- Used in industrial refrigeration for many years, known domestically in use for outdoor heaters and cookers
- Low GWP
- Non-toxic
- Good thermodynamic properties, making it highly energy efficient in systems
- Flammable

R410A (GW 2088)

- Good energy efficiency
- Higher cooling capacity
- Superior heat transfer coefficient which allows for better heat exchange
- Higher operating pressures which should be reflected in system design – correctly sized components are essential to optimize energy efficiency.

Zero Net Carbon Buildings

GHG emissions generated by refrigerant leakage

$$\text{GHG } Operation = \Sigma n\ \Sigma k\ W\text{n, k} \cdot (\text{GHG}k + \text{GHG}up,k) + \Sigma n\ \Sigma r\ Gn\ r \cdot \tau n \cdot \omega r \cdot \alpha + \Sigma n\ \Sigma j\ Mn,j \cdot \text{GHG } up\text{, j}$$

where **GHG*Operation***: the GHG equ. Emissions during the operation stage in kgCO2;
Wn， k : The amount of energy k consumed by the operation of the HVAC type of equipment (pipeline);
Gn， r: The amount of type r refrigerant charged by type n equipment， kg;
τn: Operating year of the HVAC device， year;
ωr: GWP value of the r refrigerant;
α: Annual leakage rate of refrigerant;
Mn， j : The amount of type j material consumed to maintain type n equipment (piping)， kg;

Source: Attia, S., Petersen, S., Hoxha, E., Gobbo, É., Bertini, A., Dasse, M., Abu-Ghaida, H., Heiranipou, M., Al-Obaidy, M., Norouziasa, A., & Stephan, A. (2024). Framework to Model Building Carbon Emissions. (Version 5). Liege, Belgium: Sustainable Building Design Lab, Liege, Belgium, doi:10.13140/RG.2.2.15338.73925/4

Zero Net Carbon Buildings

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New refrigerants – new rules

ISO 817

Refrigerant	GWP	Safety class ISO 817; PED (EU)
R718 (Water)	0	A1 (non-flammable)
R744 (CO2)	1	A1 (non-flammable)
R290 (Propane)	3	A3 (higher flammability)
R1234yf	4	A2L (mildly flammable)
R1234ze	7	A2L (mildly flammable)
R454b	466	A2L (mildly flammable)
R513A	631	A1 (non-flammable)
R32	675	A2L (mildly flammable)
R410A	2088	A1 (non-flammable)

Future influences:

- Achieving low-carbon buildings
- Growth of hydronic technologies and low GWP- refrigerants
- Advanced control and monitoring systems
- Retrofit balance
- Balance what’s possible and what’s practical

Zero Net Carbon Buildings

Smart Meters & Grid Mix Emission Factors

ISO 52000-3:2023

- Net-Zero Energy ≠ Net-Zero Carbon
- Belgium has a 15 min – grid mix factor

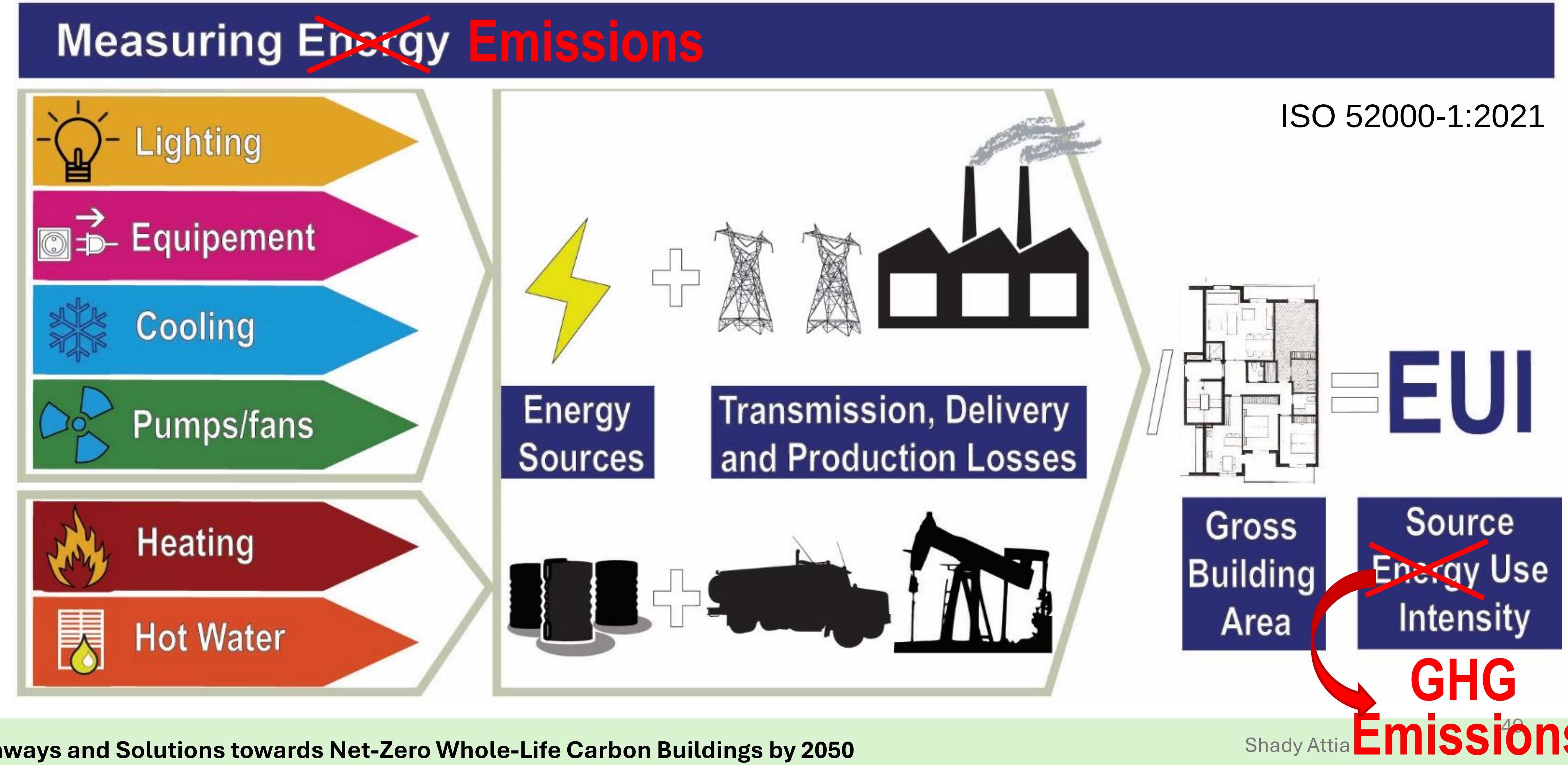
- Annual operational emissions calculations based on dynamic factors and export/import fluctuations

EMISSION FACTOR [g/kWh]

2023	MONTH											
HOUR of the day	1	2	3	4	5	6	7	8	9	10	11	12
1	411	517	487	484	500	543	580	544	512	470	480	383
2	406	516	484	473	474	534	561	532	509	472	479	380
3	402	516	478	467	475	534	563	529	506	472	479	379
4	400	517	483	464	480	533	566	529	506	473	480	380
5	403	519	485	467	487	533	570	533	509	476	483	383
6	415	523	493	477	498	536	573	540	518	486	489	391
7	429	529	500	487	502	535	568	542	527	492	499	402
8	441	531	498	479	489	518	545	524	521	497	505	411
9	447	522	483	454	463	487	508	493	494	486	498	415
10	446	501	462	422	426	451	467	457	461	462	486	414
11	440	481	441	389	390	421	434	421	425	439	476	408
12	434	466	426	365	365	400	410	393	396	418	471	404
13	432	458	420	351	350	387	396	378	376	404	470	404
14	437	460	420	344	345	379	389	371	368	401	479	409
15	447	473	430	344	348	379	391	372	372	411	495	420
16	460	494	448	356	360	389	401	384	391	433	516	429
17	468	521	473	381	383	408	420	408	424	466	520	430
18	469	540	499	425	416	440	456	450	475	505	511	426
19	464	540	513	478	459	481	498	498	526	521	502	421
20	457	530	512	517	497	519	541	540	549	513	495	415
21	448	523	505	522	518	546	572	562	547	502	491	407
22	440	520	500	511	511	556	580	563	537	493	486	399
23	434	520	500	500	499	551	575	554	529	487	486	396
24	425	518	496	487	489	540	570	545	519	477	482	386

Zero Net Carbon Buildings

Converting the primary energy use intensity to GHG emissions



Carbon Neutral Communities

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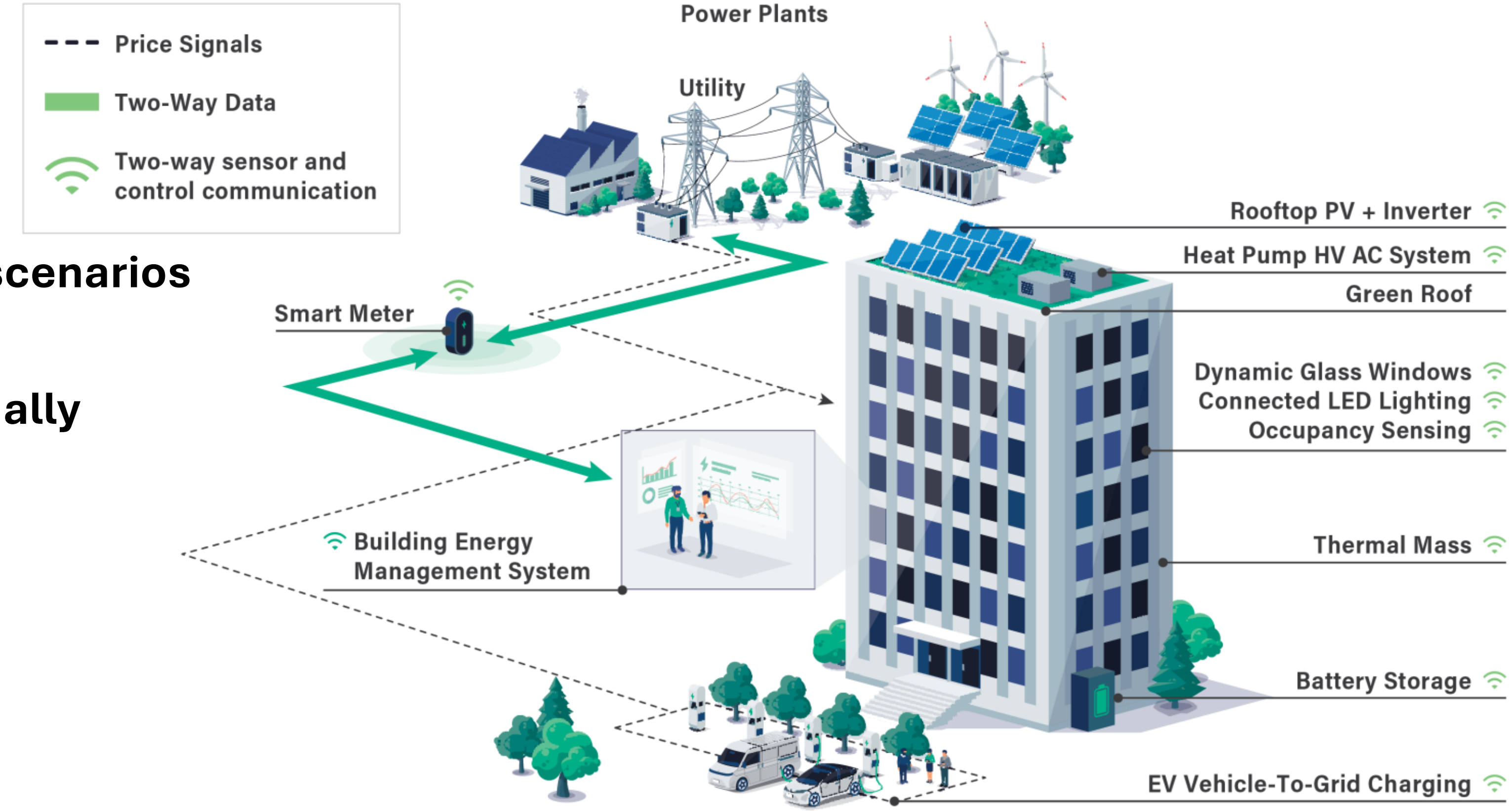
From Single Building to Community

Carbon Neutral Communities

From Single Building to Community



1. Either average or marginal grid mix scenarios are typically adopted
2. Environmental data sources are usually based on averages:
   - Real-time Generation Mix Data
   - Carbon Intensity of Each Source:
   - Power Demand and Grid Load:
   - External Data Sources:
   - Emissions Factor Calculation:
   - Updating the Signals through smart grids

Source: NREL.

WORLD RESOURCES INSTITUTE

Source: https://trellis.net/article/health-economic-and-community-benefits-zero-carbon-buildings/

Pathways and Solutions

The transition towards zero-emission buildings

PAST	TRANSITION	FUTURE
2021 nearly Zero-Energy low renovation rates	2030 nearly Zero Emission massive deep renovation	2050 zero-emission built environment

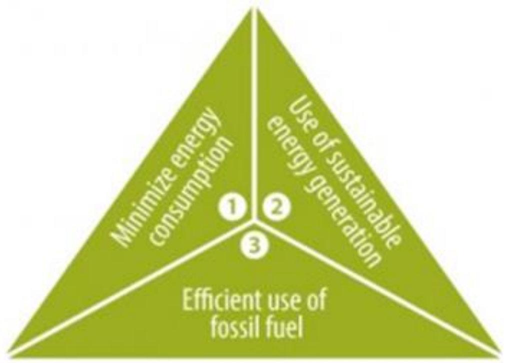


Figure 1a: Trias Energetica (Duijvestein, 2010)

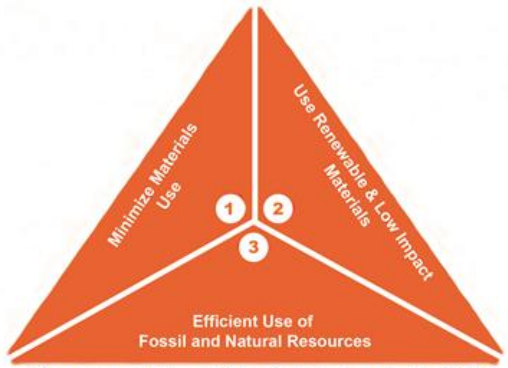


Figure 1a: Trias Materia (Duijvestein, 2010)

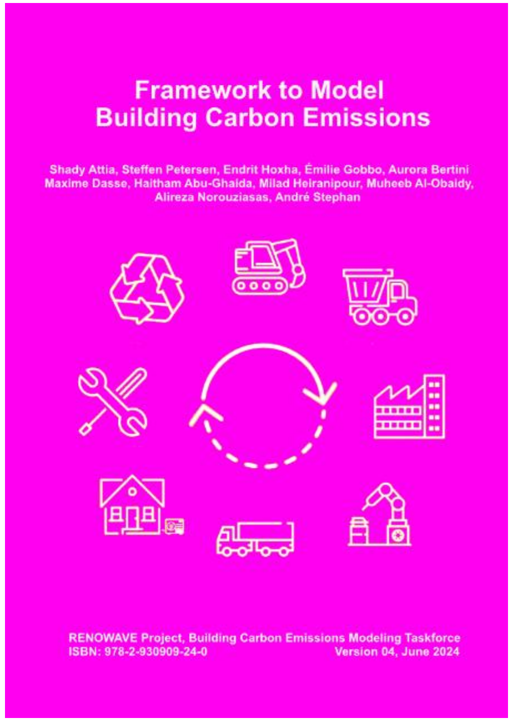
Framework for Building Modelling

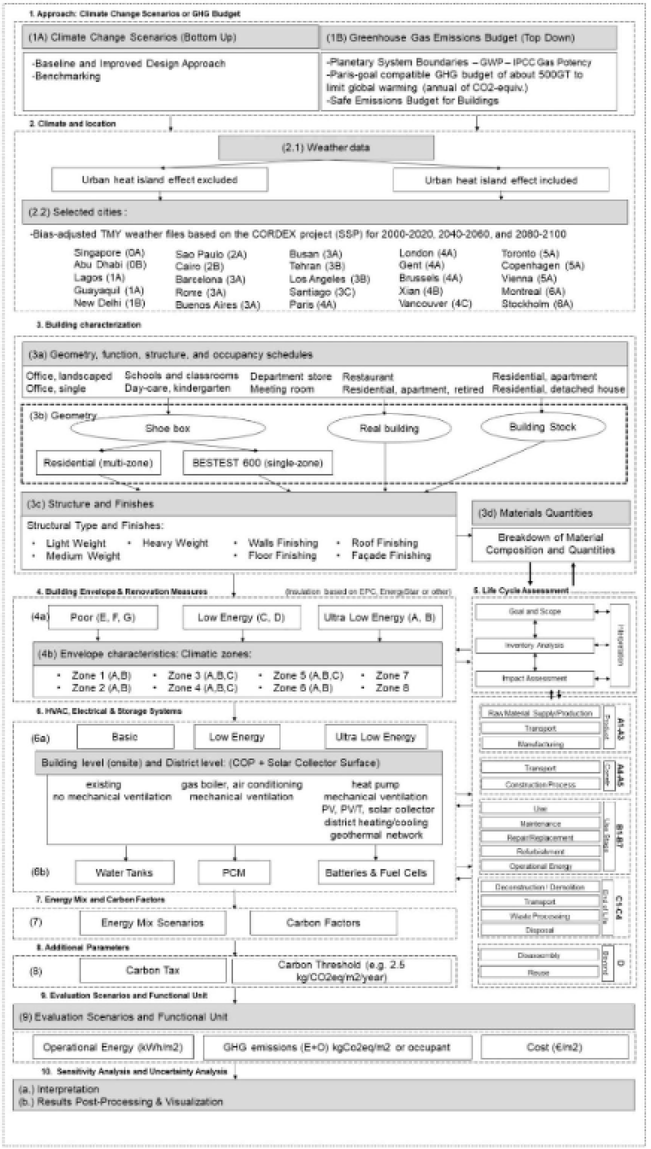
For Zero Carbon Buildings

10 Modules

Paris-goal-compatible assessment method

- evaluate the assessment methods proposed or required by current climate policies, aiming to check their compatibility with meeting the science-based carbon targets and budgets





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Conclusion

What should be focused on:

- Adopt the new indicators of GWP and Module A-B-C + (D)
- Get experienced with carbon numbers through EPDs (databases)
- Use consistent methodology and software

Zero Carbon Emissions Buildings Ingredients:

> Reduced building area
> Minimized car parking
> High-Performance envelope
> Electric heating & cooling
> Biogenic materials
> 40% window-to-wall ratio
> Plug-in batteries
> Solar PV on roof and facades

Directions:

Begin by setting a decarbonization performance goal and limit for your project. Start by mixing the smallest building area with the minimal parking. Next, add a high-performance building envelope alongside an electric heating and cooling system. Add a pinch of solar PV and a large scoop of biogenic materials and run the energy and life cycle impact assessment simulations.

Questions?

The Sixth International Conference on Efficient Building Design

Materials and HVAC Equipment Technologies

Pathways and Solutions towards Net-Zero Whole-Life Carbon Buildings by 2050

Beirut, Lebanon
| October 4, 2024

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