



## Analysis Methods and Tools (II)



*Ir Dr. Sam C. M. Hui*

Department of Mechanical Engineering

The University of Hong Kong

E-mail: [cmhui@hku.hk](mailto:cmhui@hku.hk)

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- Life cycle costing
- Carbon audit
- Zero carbon building
- Assess carbon footprints

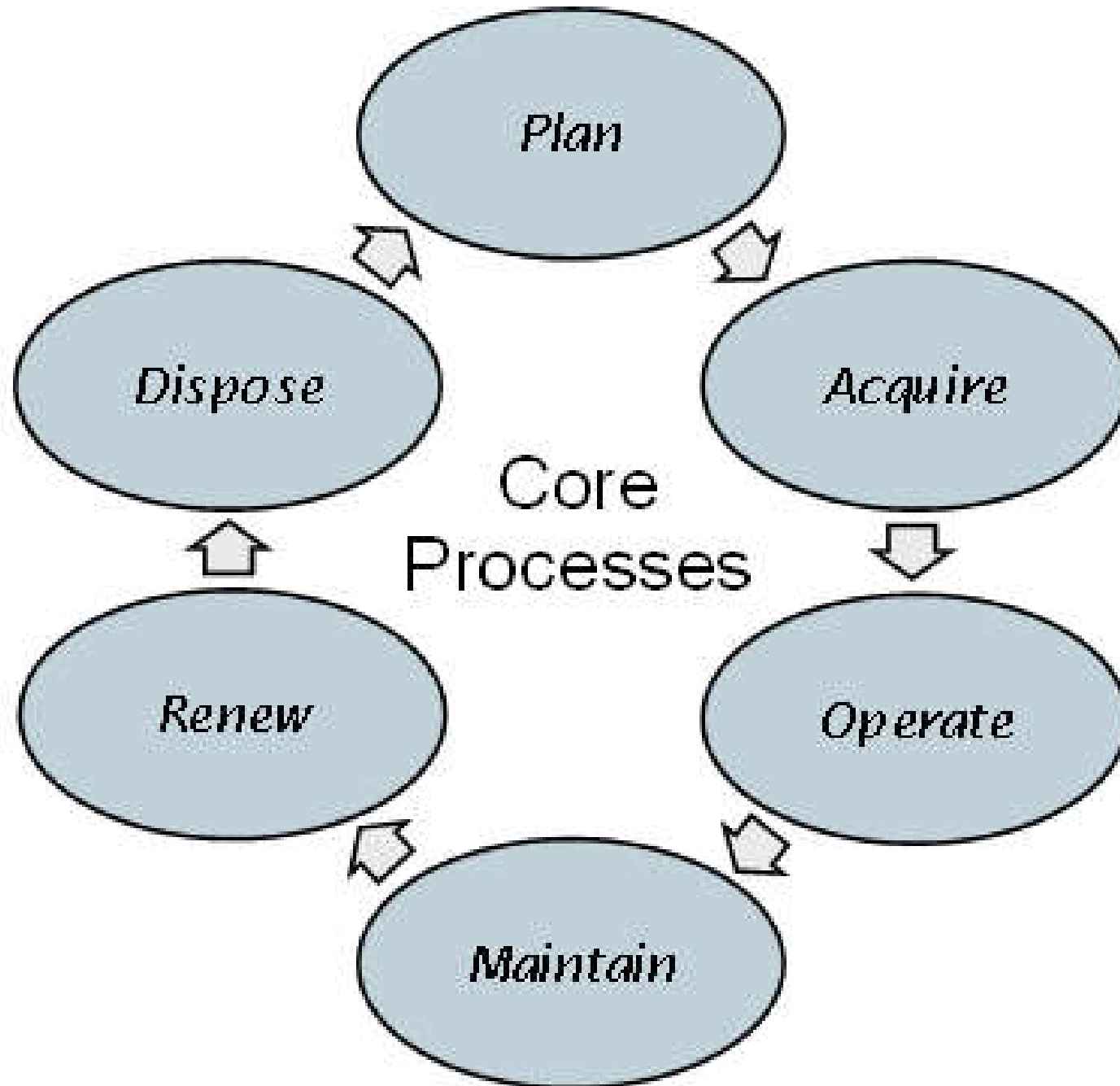


# Life cycle costing

- *Life cycle cost* is ‘cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements’ (ISO 15686-5)
- *Life cycle costing* is ‘methodology for the systematic economic evaluation of life cycle costs over a period of analysis, as defined in the agreed scope’ (ISO 15686-5)
  - It can address a period of analysis which covers the entire life cycle, or selected stage(s) or periods of interest therein

生命  
周期  
成本  
法

# Life cycle of an asset (ISO 15686 Buildings and constructed assets - Service life planning)



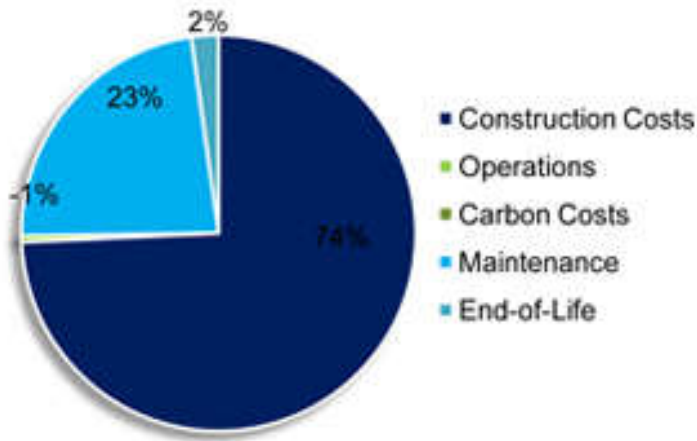


# Life cycle costing

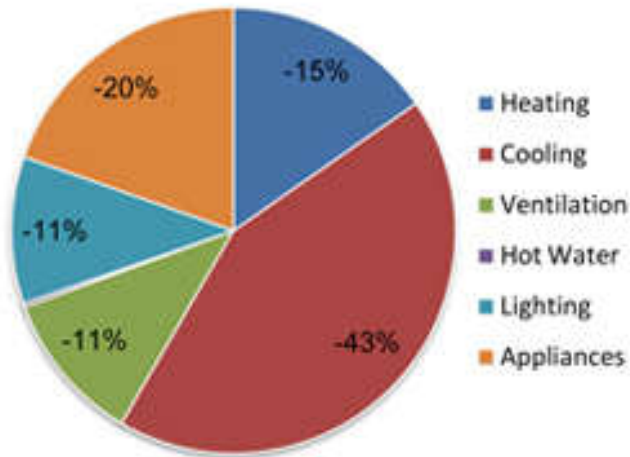
- Life-cycle costing (LCC) for buildings
  - Also known as whole life costing (WLC)
  - Analyses the design of building or building systems including initial costs, maintenance costs, repair costs, energy & water costs, and other significant costs over the assumed life of the facility or system (*total cost of ownership*)
  - Combines all costs into net annual amounts, discounts them to present value, and sums them to arrive at total LCC

# Why consider life cycle cost?

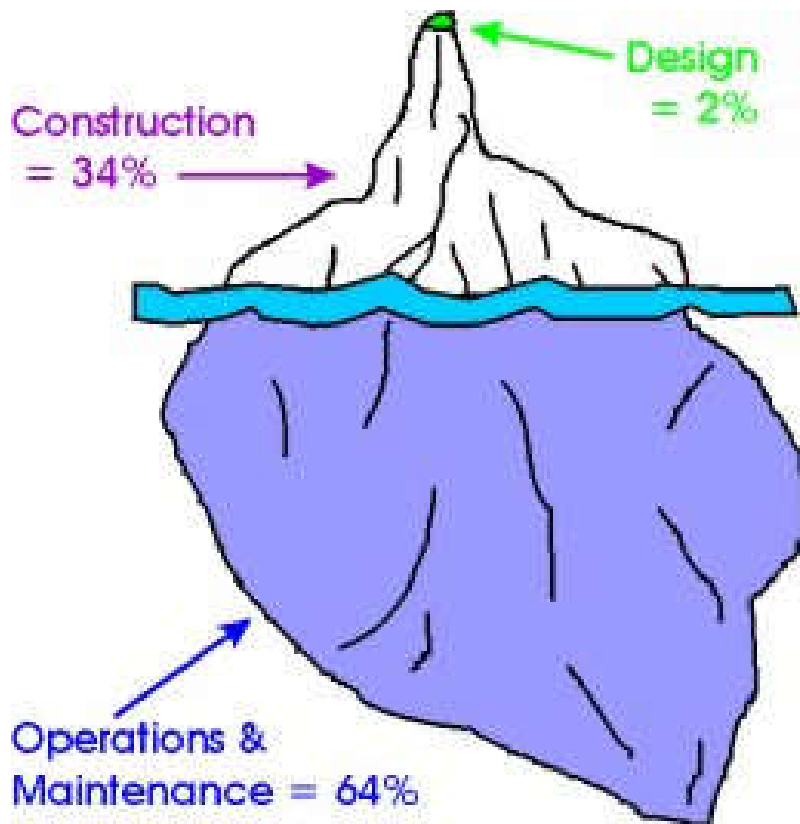
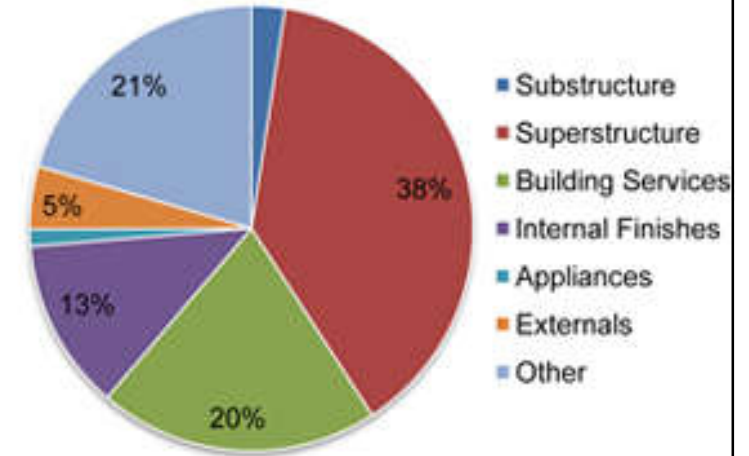
Costs by Lifecycle Stage



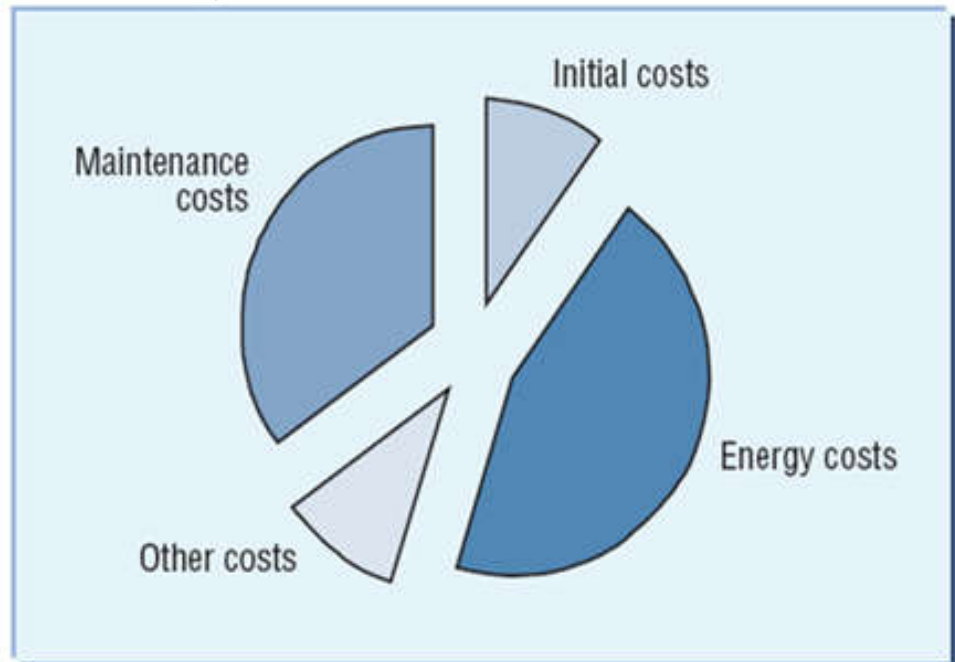
Operational Costs



Capital Costs



## Life cycle cost of electric motor



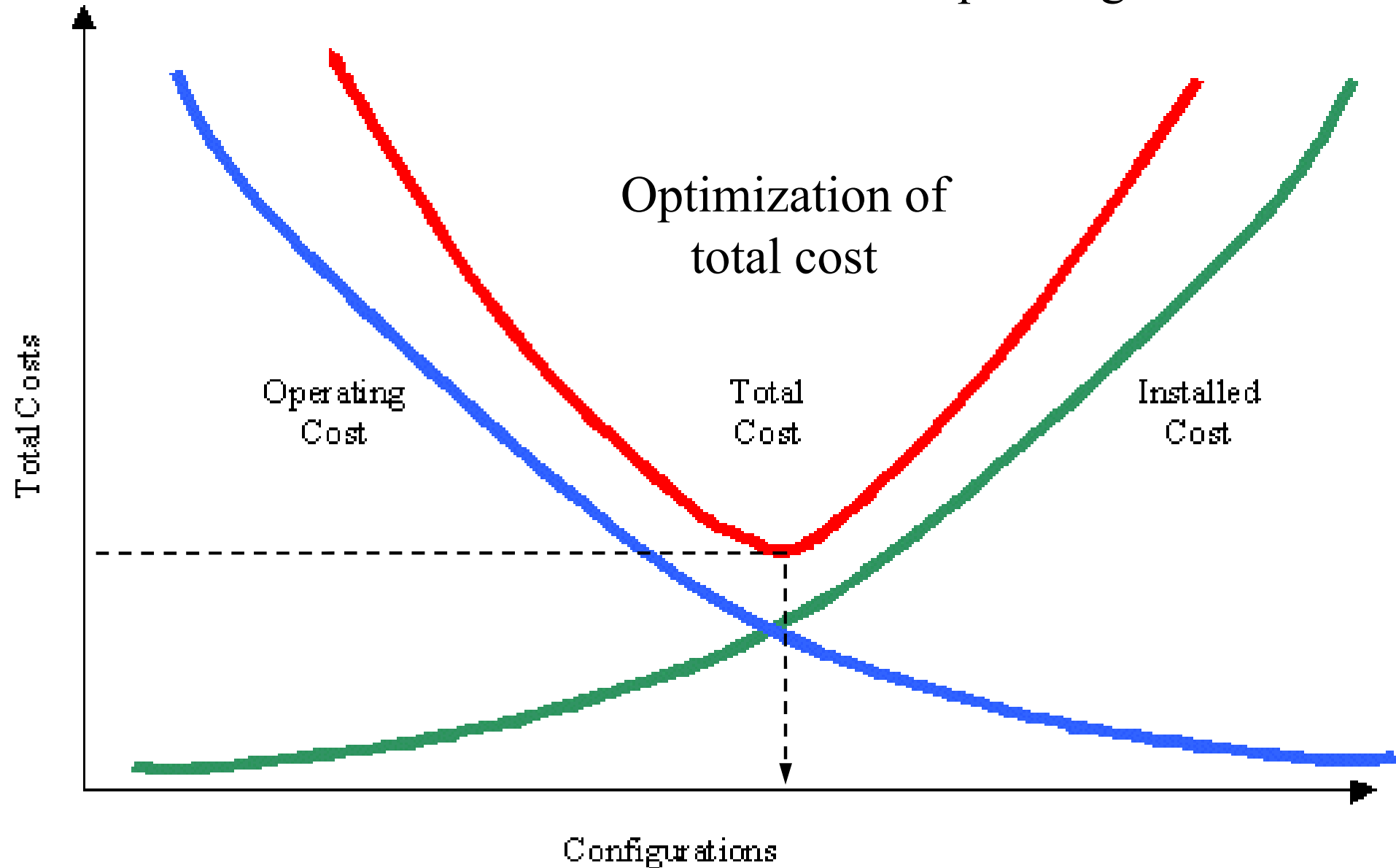


# Life cycle costing

- LCC is that it is not the same as life cycle assessment (LCA)
  - The two methodologies are complementary, but LCC focuses on the *dollar \$\$ costs* of building and maintaining a structure over its life cycle, while LCA focuses on *environmental performance*
  - Performance is measured in the units appropriate to each emission type or effect category

# Concept of total cost or life cycle cost

$$\text{Total cost} = \text{Installed cost} + \text{Operating cost}$$





# Life cycle costing



- Basic steps of LCC analysis
  - 1. Gather basic financial data
  - 2. Estimate annual energy costs
  - 3. Estimate first costs
  - 4. Estimate ongoing costs
  - 5. Calculate life-cycle costs
  - 6. Compare life-cycle costs



# Life cycle costing



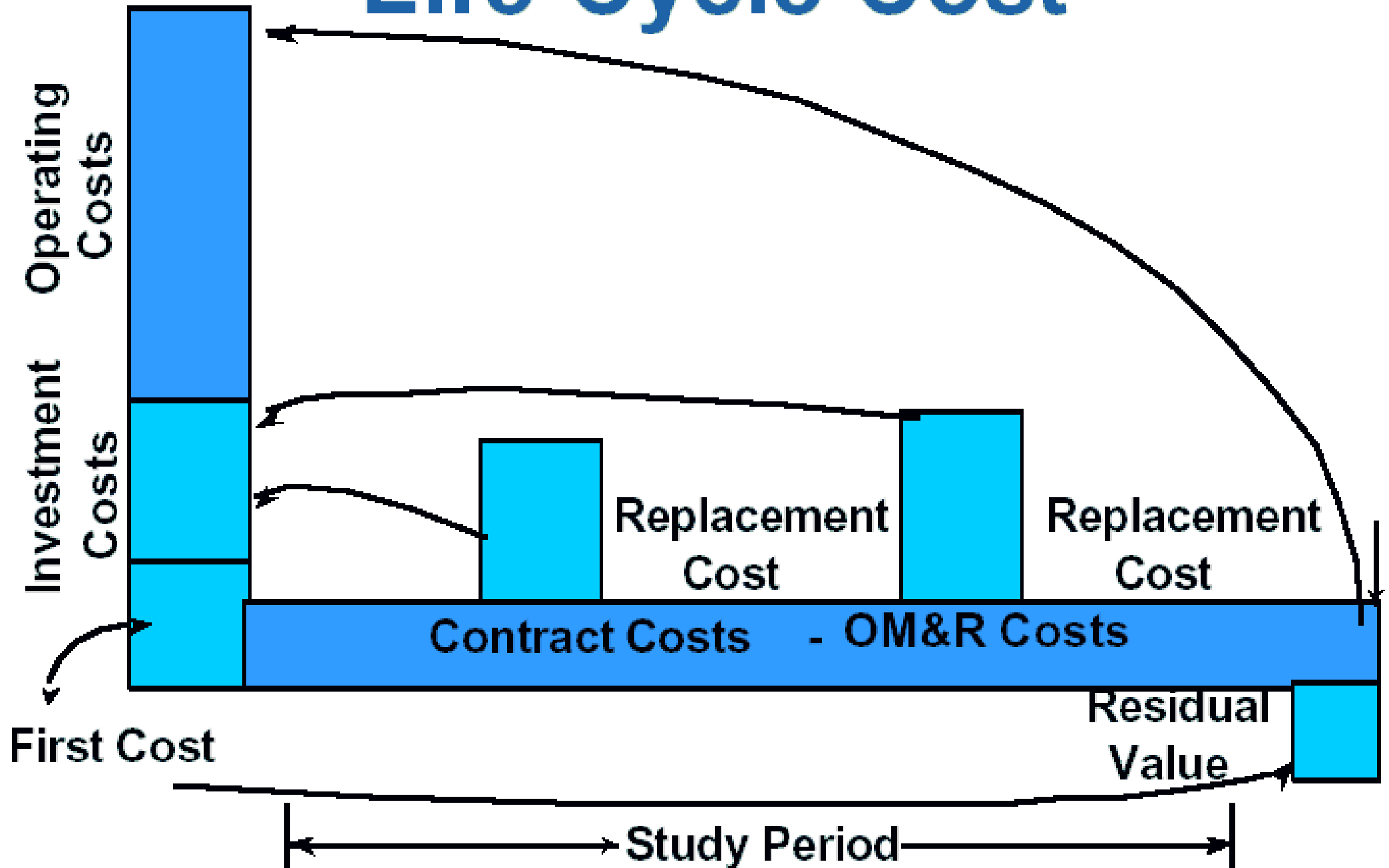
- General life cycle cost (LCC) equations

$$LCC = \sum_{t=0}^N \frac{C_t}{(1+d)^t} \quad PWF = \frac{\left[ 1 - \frac{1}{(1+d)^N} \right]}{d}$$

- $C_t$  = sum of all relevant costs occurring in year  $t$
- $N$  = number of years in the study period
- $d$  = discount rate used to adjust cash flow to present value
- $PWF$  = present worth factor



# Life-Cycle Cost





# Life cycle costing

- LCC calculation
  - $LCC = I + Repl - Res + E + W + OM\&R + O$ 
    - LCC = Total LCC in present-value (PV) dollars
    - I = PV investment costs
    - Repl = PV capital replacement costs
    - Res = PV residual value less disposal costs
    - E = PV of energy costs
    - W = PV of water costs
    - OM&R = PV of non-fuel operating, maintenance and repair costs
    - O = PV of other costs (e.g. contract costs)

## An example of life cycle cost calculation

	Building A	Building B
<b><i>Construction Year</i></b>	1950	2010
<b><i>Useful Life (years)</i></b>	20	20
<b><i>Purchase Price (P)</i></b>	\$35,000,000.00	\$45,000,000.00
<b><i>Interest (I)</i></b>	\$49,409,990.87	\$63,527,131.12
<b><i>Replacement Cost (re)</i></b>	\$20,500,000.00	\$20,500,000.00
<b><i>Resale/Salvage Value (Rs)</i></b>	\$20,000,000.00	\$40,000,000.00
<b><i>Disposal Cost (D)</i></b>	\$5,000,000.00	\$0.00
<b><i>Energy Costs (E)</i></b>	\$2,450,000.00	\$400,000.00
<b><i>Water Costs (W)</i></b>	\$60,000.00	\$32,000.00
<b><i>Maintenance (M)</i></b>	\$2,200,000.00	\$750,000.00
<b><i>Other (O)</i></b>	\$100,000.00	\$100,000.00
<b>Life Cycle Cost</b>	<b>\$59,720,010.87</b>	<b>\$45,309,151.12</b>

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## Cost Considerations for Design

Direct and indirect: initial, life cycle, and environmental

### **Initial:**

Construction: supply and installation

Design

### **Life cycle:**

Daily, weekly and annual maintenance including cleaning, repair, redecoration

Replacement, including removal, waste disposal, replacement

Running cost for energy consuming components

### **Environmental:**

Resource depletion and environmental pollution

Extraction, manufacture, transport, use and disposal: to air, ground and water

Indoor environmental quality

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# Life cycle costing

- Typical life-cycle cost analysis include:
  - Acquisition costs (or design & development costs)
  - Financing costs (e.g. interest rate on a loan)
  - Energy savings
  - Equipment replacement costs
  - Operations, maintenance and repair costs
  - Tax implications
  - Impacts of inflation

# Core process of life cycle costing (LCC)

1

- Defining the objective of the proposed LCC analysis

2

- Preliminary identification of parameters and analysis requirements

3

- Confirmation of project and facility requirements

4

- Assembly of cost and performance data

5

- Carry out analysis, iterating as required

6

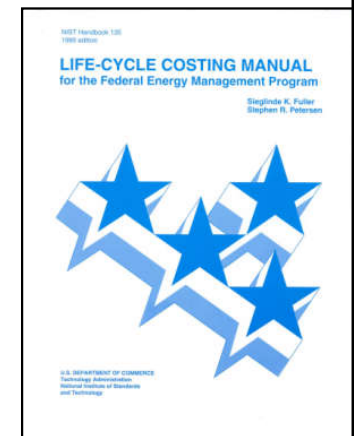
- Interpreting and reporting results



# Life cycle costing



- Useful references and tools:
  - ISO 15686-5:2008 Buildings and Constructed Assets. Service Life Planning. Life Cycle Costing  
[https://en.wikipedia.org/wiki/ISO\\_15686](https://en.wikipedia.org/wiki/ISO_15686)
  - NIST Handbook 135 Life-Cycle Costing Manual,  
[https://www.wbdg.org/FFC/NIST/hdbk\\_135.pdf](https://www.wbdg.org/FFC/NIST/hdbk_135.pdf)
  - Building Life-Cycle Cost (BLCC) software,  
<http://www.wbdg.org/tools/blcc.php>





# Carbon audit

- What is a **carbon audit**? 碳審計
  - It is a means of measuring and recording the green house gas (GHG) emissions of an organization or building within a defined system boundary
  - Sometimes called a ‘carbon footprint’
  - Includes:
    - Direct power usage (from fuel-powered sources)
    - Fuel-powered transport (haulage & travel)
  - The wider footprint may include:
    - Waste and recycling, carbon saving arrangements

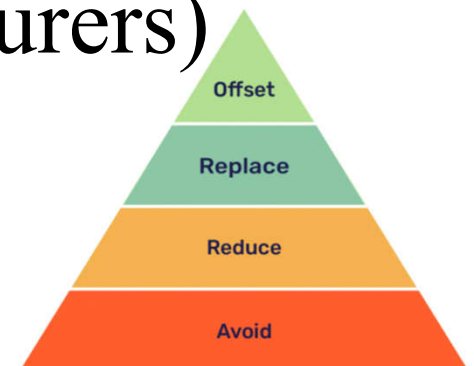




# Carbon audit

- Carbon audit is the first step in developing a carbon strategy
- Carbon strategy: A long term action plan to manage and reduce the carbon emissions of the organisation and its clients
- Carbon strategy is compulsory in certain industries (e.g. steel and car manufacturers)

CO<sub>2</sub>



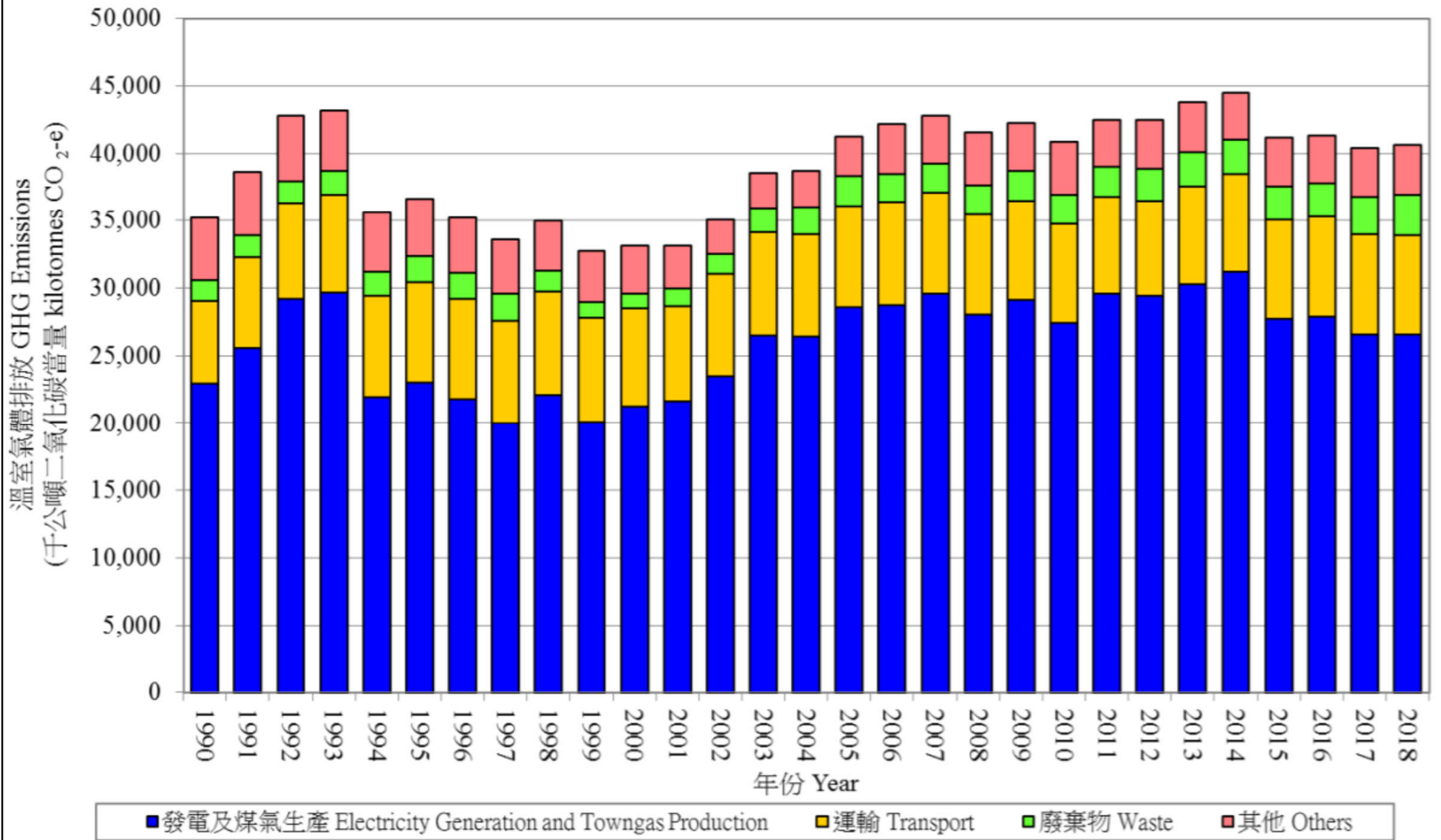


# Carbon audit

- Why should we do a carbon audit?
  - Some countries has set targets to cut carbon emissions under the Kyoto Protocol
  - Related local legislation
  - Corporate social responsibility policies
  - Employee & customer expectations
  - Brand value & corporate image
  - Carbon reporting provides good management data
  - Savings in energy consumption

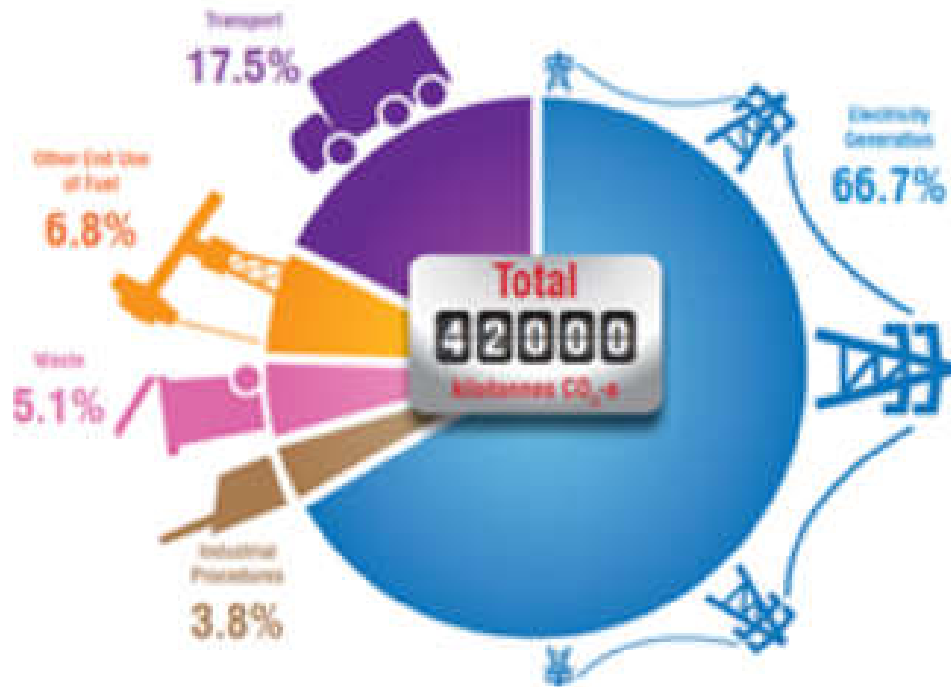


# Greenhouse gas (GHG) emission trends of Hong Kong 1990-2018



# Greenhouse gas (GHG) emission of Hong Kong 2008

Hong Kong's greenhouse gases emission by sectors in 2008<sup>14</sup>



Note: Other end use of fuel including use of fuel for combustion in commercial, industrial and domestic premises



Hong Kong's electricity consumption by sectors in 2008<sup>15</sup>





# Carbon audit

- EPD and EMSD, 2010. *Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong*, 2010 Edition, Environmental Protection Department (EPD) and Electrical and Mechanical Services Department (EMSD), Hong Kong
  - [https://www.epd.gov.hk/epd/sites/default/files/epd/english/climate\\_change/files/Guidelines\\_English\\_2010.pdf](https://www.epd.gov.hk/epd/sites/default/files/epd/english/climate_change/files/Guidelines_English_2010.pdf)



# Carbon audit

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- Purpose of the guidelines: Assist the building user and managers to:
  - Measure their greenhouse gas (GHG) performance
  - Identify areas of improvement
  - Conduct voluntary programmes to reduce and/or offset emissions
- Voluntary participation and self-reporting
- Compile the GHG inventory

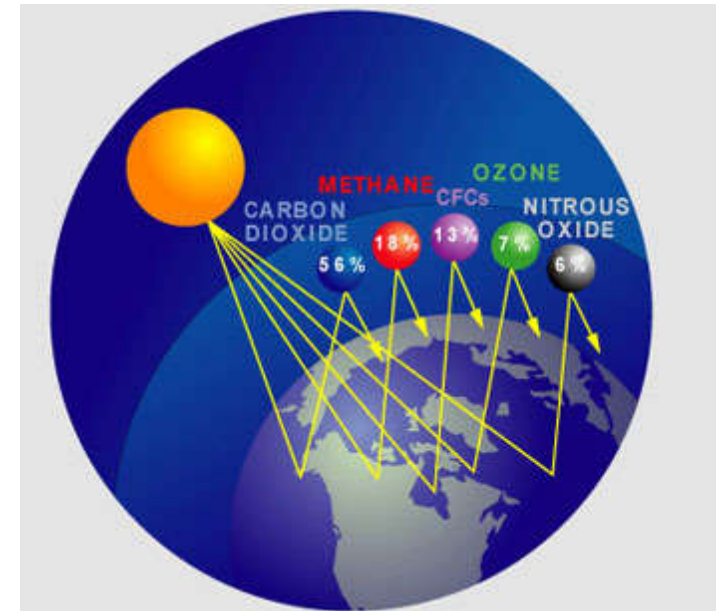




# Carbon audit

- Principles to ensure true and fair reporting

- Relevance
- Completeness
- Consistency
- Accuracy
- Transparency



- Include 6 types of GHG: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF<sub>6</sub>)

# Carbon audit



- Typical steps:

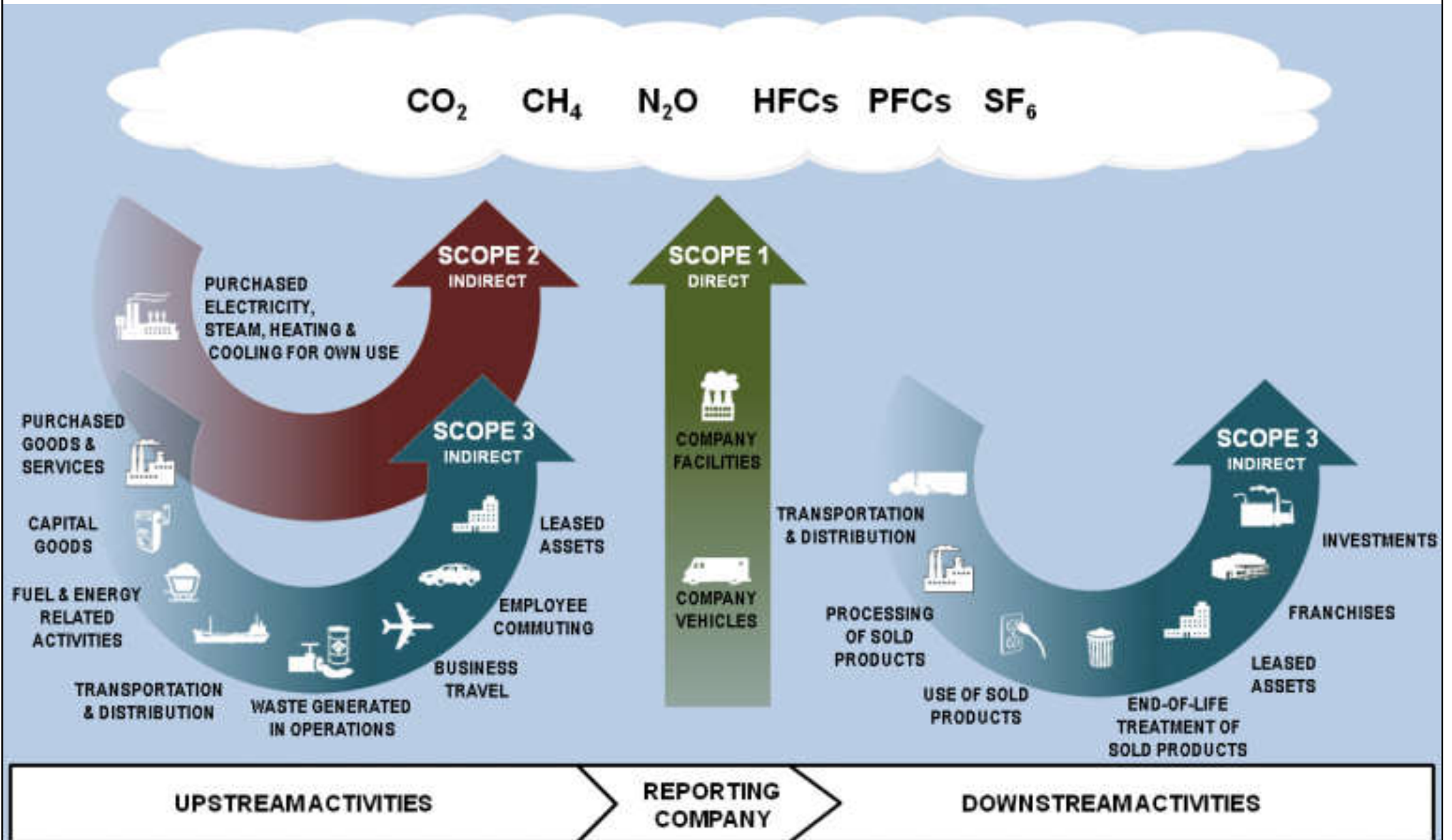
- 1. Determine the physical boundaries (e.g. site boundaries of building)
- 2. Determine the operational boundaries (identify and classify the activities to determine the scope)
- 3. Determine the reporting period (e.g. one year)
- 4. Collect necessary data and information and to quantify the GHG performance
- 5. Prepare the report



# Carbon audit

- *Physical boundaries* (e.g. site boundaries)
- *Operational boundaries*
  - Operational activities which will result in GHG emissions or removals
  - **Scope 1** – direct emissions and removals
  - **Scope 2** – energy indirect emissions
  - **Scope 3** – other indirect emissions (optional)

# Carbon audit and scope of greenhouse gas (GHG) emissions





# Carbon audit

- Scope 1 – direct emissions and removals
  - Combustion of fuels in stationary sources to generate electricity, heat, or steam, e.g. electricity generators, boilers, gas cooking stoves, etc.
  - Combustion of fuels in mobile sources (e.g. motor vehicles and ships), for example, shuttle bus
  - Intentional or unintentional GHG releases from equipment and systems, e.g. HFCs and PFCs from HVAC&R equipment



# Carbon audit

- Scope 1 – direct emissions and removals
  - Assimilation of CO<sub>2</sub> into biomass through e.g. planting of trees
  - Any other physical and chemical processing in the physical boundary which will emit or remove GHG. For example, on-site waste or sewage processing facilities

**Emission (CO<sub>2</sub>) =  $\Sigma$  Amount of Fuel Consumed x Emission Factor of CO<sub>2</sub>**

**Emission (CH<sub>4</sub> / N<sub>2</sub>O) =  $\Sigma$  Amount of Fuel Consumed x Emission Factor of (CH<sub>4</sub> / N<sub>2</sub>O) x Relative Global Warming Potential**



# Carbon audit

- Scope 2 – energy indirect emissions
  - Electricity purchased from power companies
  - Towngas purchased from the Hong Kong and China Gas Company
- Scope 3 – other indirect emissions (optional)
  - Methane gas generation at landfill in Hong Kong due to disposal of paper waste
  - GHG emissions due to electricity used for fresh water processing by Water Services Department



# Carbon audit

- Scope 3 – other indirect emissions (optional)
  - GHG emissions due to electricity used for sewage processing by Drainage Services Department
  - Other examples of GHG emissions
    - Extraction & production of purchased materials & fuels
    - Transportation of purchased materials or goods, fuels, products, waste, employees, occupants and guests, to and from the concerned buildings
    - Business travel by employees

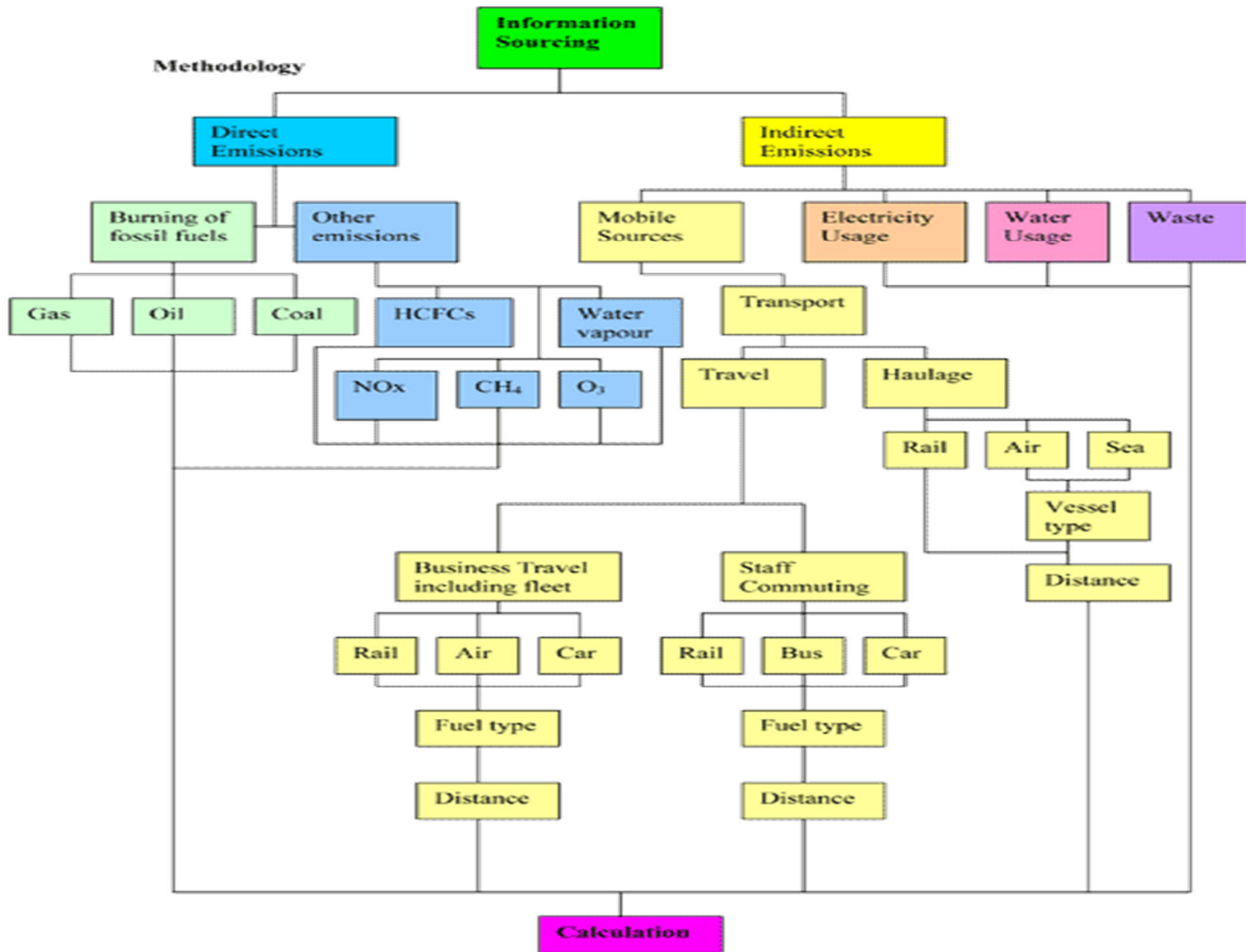




# Carbon audit

- Scope 3 – other indirect emissions (optional)
  - Other examples of GHG emissions (cont'd)
    - Emissions from outsourced activities or other contractual arrangements
    - Use of sold products and services
    - Waste disposal other than those covered in the above list
- Links with international emissions reporting framework, e.g. ISO14064-1

# The carbon audit methodology



# Carbon audit



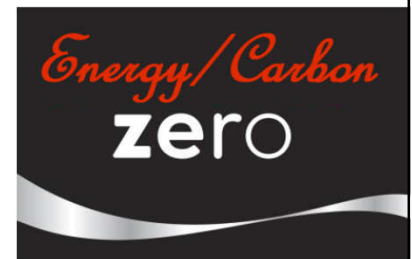
- Implications to sustainable building design
  - Future green building assessment might include the GHG indicators
  - Building projects that aim at “zero energy”, “zero carbon” or “zero emission” must demonstrate their compliance by carbon audit
  - Possibility of trading off GHG emission and allow carbon trading



# "0"

## Zero carbon building

- Zero carbon building (ZCB) 零炭建築
- Zero energy building (ZEB) 零能耗建築
  - A building that produces as much energy on-site as it consumes on an annual basis
  - “Net” zero energy building 淨零能耗建築
- In recent years, many researchers and governments investigated the definitions of ZEB and ZCB to develop an internationally agreed and consistent definition



# Terms and definitions of ZEB and ZCB

Terms	Definitions/Meanings
Zero energy building (ZEB) or net zero energy building (NZEB)	A building that produces as much energy on-site as it consumes on an annual basis
Net zero site energy building (site ZEB)	Amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building
Net off-site zero energy building (off-site ZEB)	Similar to previous one, but consider purchasing of energy off-site from 100% renewable energy sources
Net zero source/primary energy building (source ZEB)	It produces as much energy as it uses in a year, when accounted for the source. For electricity, only around 35% of the energy used in a fossil fuel power plant is converted to useful electricity and delivered. Site-to-source conversion multipliers are used to calculate a building's total source energy
Net zero energy cost building (cost ZEB)	The cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site
Net zero energy emissions building, zero carbon building (ZCB), zero emission building	The carbon emissions generated from the on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production

# "0"

## Zero carbon building

- Zero energy building (ZEB)
  - A building that produces as much energy on-site as it consumes on an annual basis
  - “Net” zero energy building
- Advantages of ZEB:
  - Reduce energy consumption and costs
  - Reduce carbon emissions
  - Reduce dependence on fossil fuels



# "0"

## Zero carbon building

- Video: Achieving Net-Zero-Energy Buildings - ASHRAE (2:05)
  - [http://youtu.be/pQFJr5E7\\_R0](http://youtu.be/pQFJr5E7_R0)
  - By American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)
    - 1. Building envelope measures
    - 2. HVAC, service water heating and lighting measures
    - 3. Renewable energy measures



# "0"

## Zero carbon building

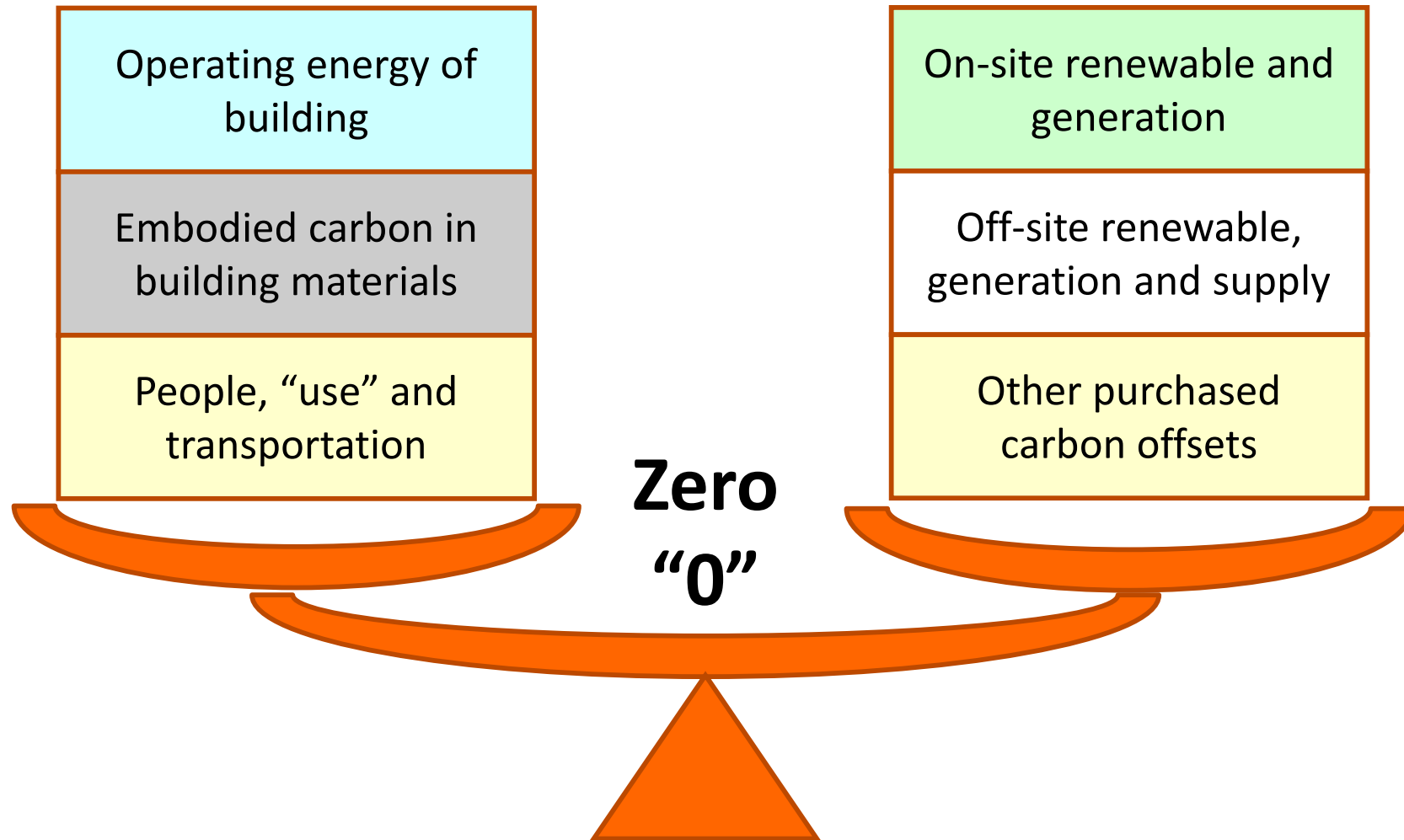
- ZEB is often used in conjunction with ZCB
  - ZEB: reduce the operating energy requirements  
→ zero fossil energy
  - ZCB: use renewable and low-carbon energy sources to offset or balance carbon emissions
- **Balancing** carbon concept for ZCB
  - Two major types of balance:
    - Import/export balance (e.g. for ZCB)
    - Load/generation balance (e.g. for ZEB)





# Balancing carbon emissions for zero carbon buildings (ZCB)

## Balancing Carbon



## Sources of difference between definitions of ZCB

- a. The metric of the balance (e.g. primary energy, final energy, carbon emission)
- b. The balancing period (monthly, seasonal, operation year, life cycle)
- c. The type of energy use included in the balance (e.g. HVAC, lighting, appliances)
- d. The type of energy balance (import/export and load/generation)
- e. The accepted renewable energy supply options
- f. The connection to the energy infrastructure (grid connected or standalone)
- g. Other requirements relating to energy efficiency, the indoor climate and building-grid interaction

# "0"

## Zero carbon building

- Australia has developed a definition for ZCB
  - “A **zero carbon building** is one that has no net annual Scope 1 and 2 emissions from operation of building incorporated services.
    - Include building envelope, water heater, built-in cooking appliances, fixed lighting, shared infrastructure and installed renewable energy generation
    - ZCB must meet specified standards for energy efficiency and on-site generation
    - Compliance is based on modelling or monitoring of greenhouse gas emissions in kg CO<sub>2</sub>-e/m<sup>2</sup>/yr.”



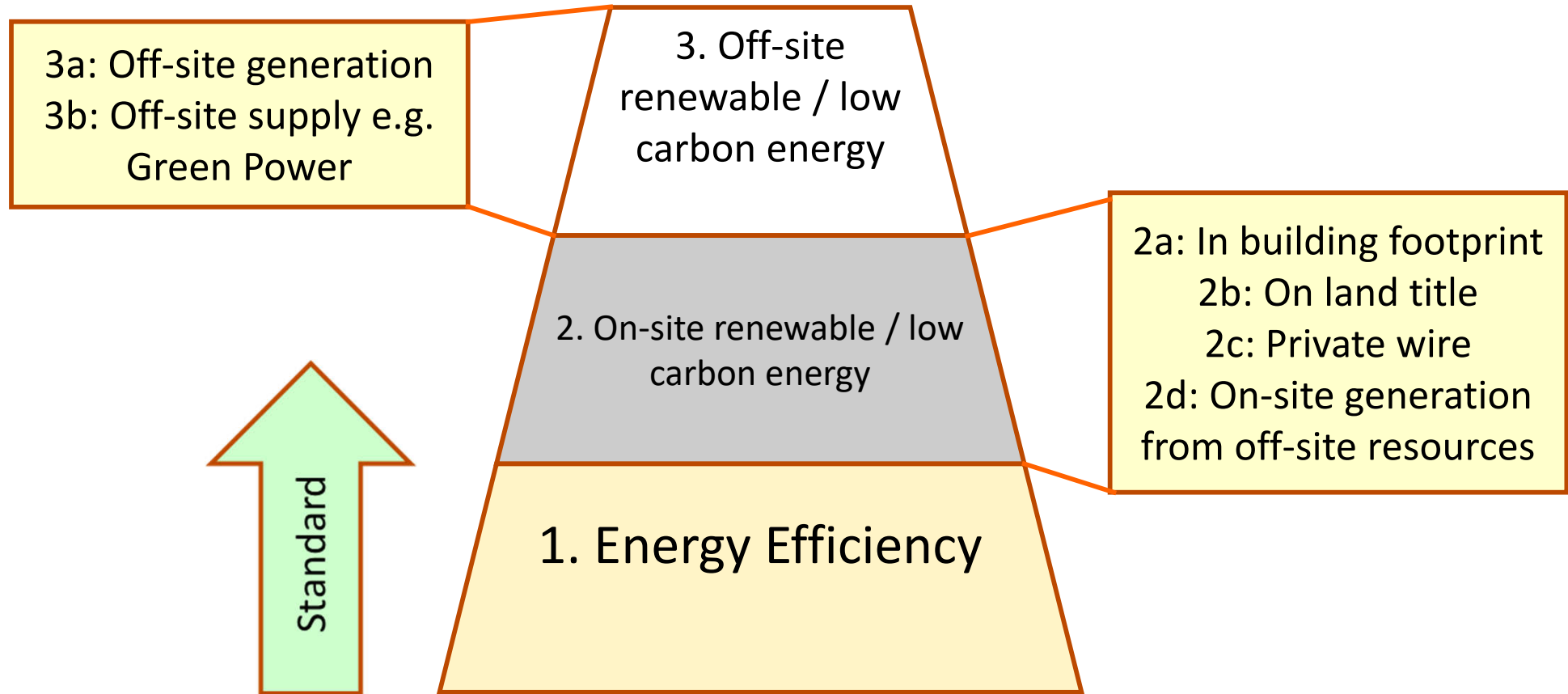
## Variations of ZCB [adapted from ASBEC (2011)]

Zero carbon occupied building	Include occupant emissions
Zero carbon embodied building	Include embodied emissions
Zero carbon life-cycle building	Include all emission sources in the building life cycle
Autonomous zero carbon building	No grid connection
Carbon positive building	Achieves less than zero emissions

Zero carbon  
Zero energy  
Zero waste  
Zero-carbon transport  
Zero-carbon energy  
Zero-carbon home  
Zero-carbon city



# Allowable emission reduction options for zero carbon buildings



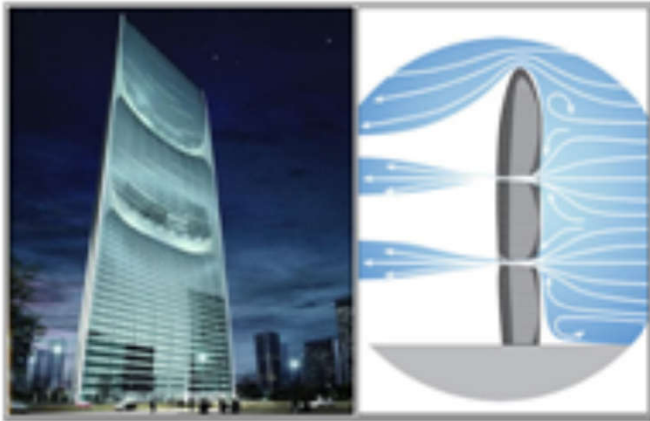
- ‘**Zero carbon**’ demands a numerical assessment and validation of the building design
- ZCB compliance requires designers to numerically validate the effectiveness of their approaches

# Comparison of low energy, zero energy/carbon and green buildings

[adapted from ECEEE (2009)]

	<b>Pros</b>	<b>Cons</b>
Low energy building (LEB) (e.g. passive house)	Cost optimal; well established principles with thousands of buildings constructed	Does not achieve greatest energy/carbon saving potential
Zero energy building (ZEB)/ Zero carbon building (ZCB)	Greatest energy/carbon saving	More expensive; limited practical experience
<b>Green Building (GB)</b>	Takes account of wider sustainability and resource use issues	May not be realistic across all new buildings

# Examples of zero energy/carbon building projects in the world



Pearl River Tower, Guangdong, China [2010]



Self-sufficient solar house, Freiburg, Germany [1992]



Pusat Tenaga Malaysia's ZEO Building, Malaysia [2007]



BCA Academy, Singapore [2009]



Beddington Zero Energy Development (BedZED), London [2002]



The Barratt Green House in Watford, UK [2008]



# Beddington Zero Energy Development (BedZED), UK



Energy design features:

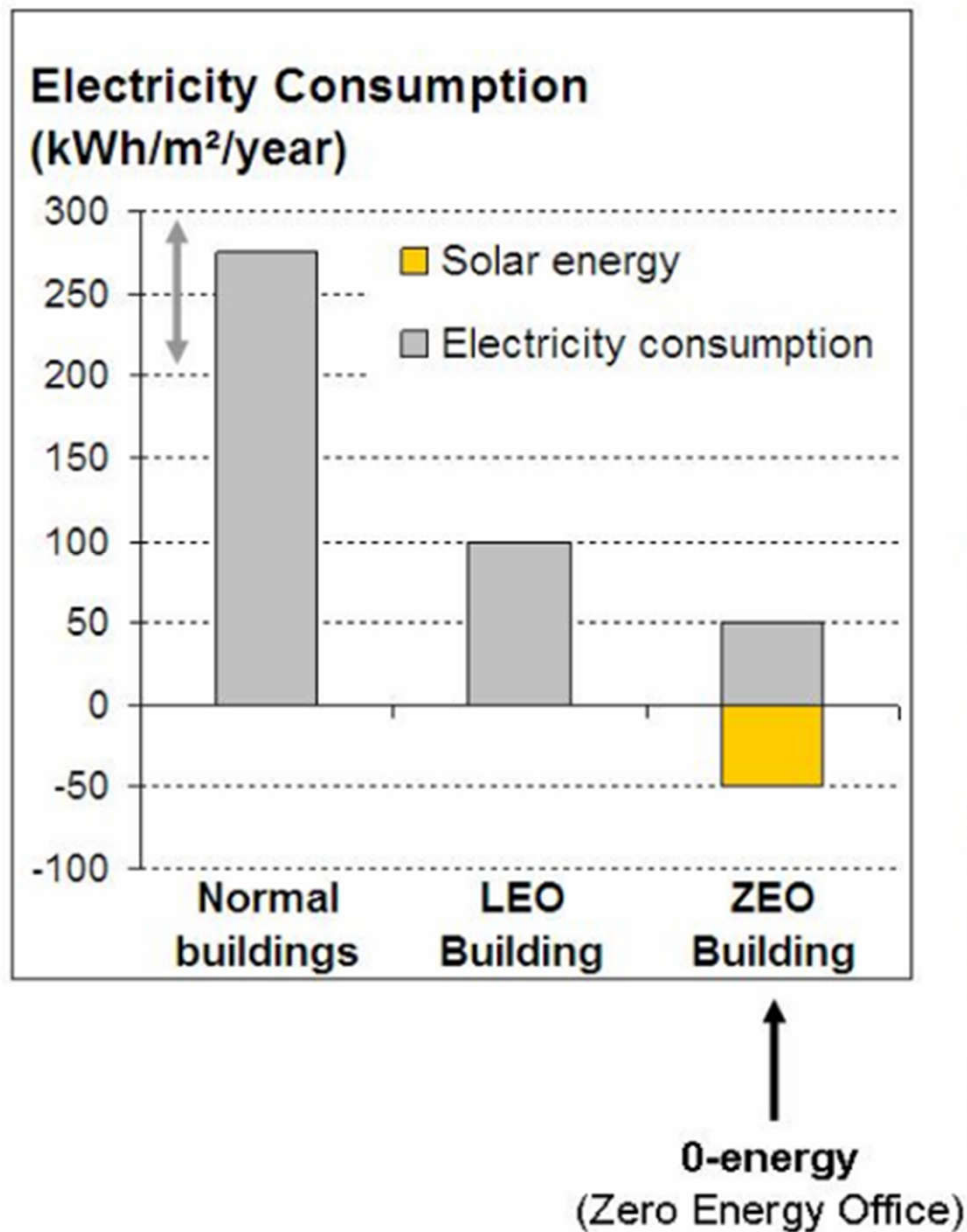
- Triple glazed
- High thermal insulation
- 777 m<sup>2</sup> of solar panels
- Co-generation
- District heating & electricity



Wind catcher



# Malaysia low energy building and zero energy building



# Zero energy office building in Guangdong, China (Pearl River Tower, for Guangdong Tobacco Company)



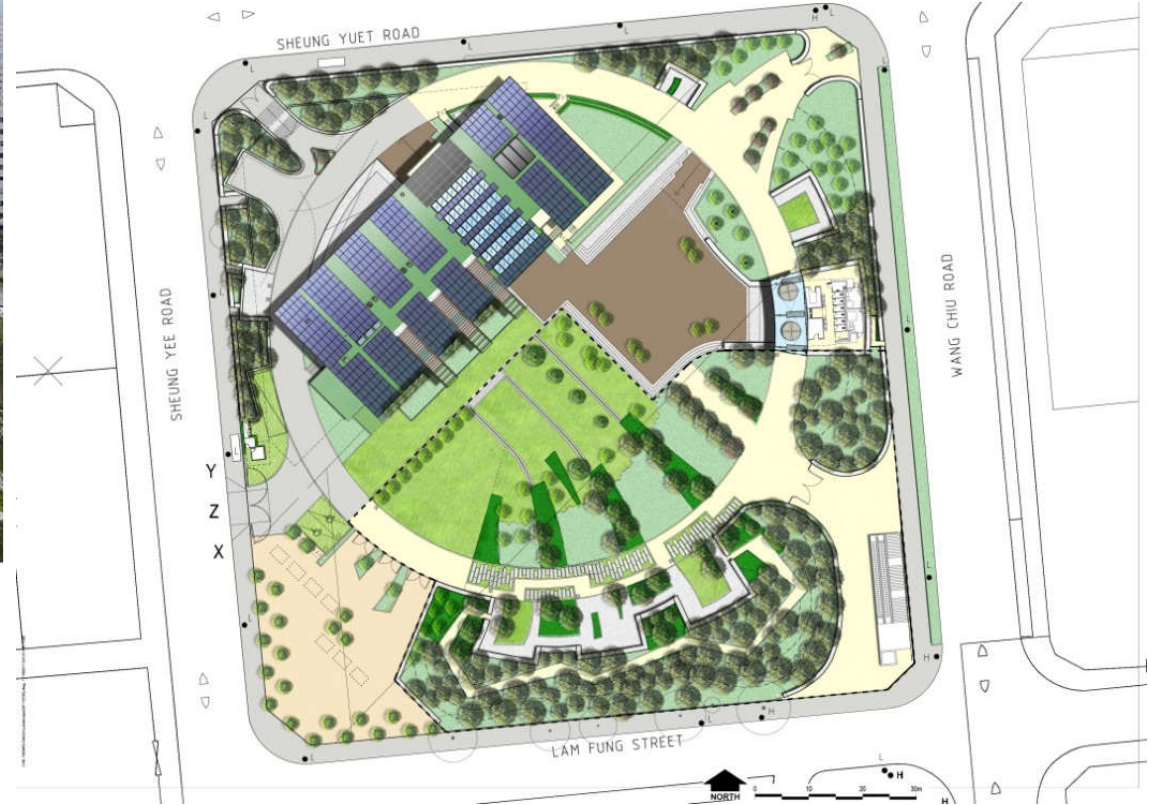
(completed in 2011)

Main features:

- Orientation of the building
- Low-E-glass
- Double-layer curtain-wall
- Chilled slab concrete ceilings
- Lighting efficiency
- Geothermal heat sink
- Energy storage
- Wind
- Integrated photovoltaics
- Microturbines

(Further info: [http://www.som.com/projects/pearl\\_river\\_tower\\_sustainable\\_design](http://www.som.com/projects/pearl_river_tower_sustainable_design))

# Zero Carbon Park (ZCP) <https://zcp.cic.hk/eng/story-of-zcb>



建造業零碳天地



- Hong Kong's first zero carbon building (2013) (3:45) <https://youtu.be/pFRx-8xmvbE>
- Zeroing in on Green-Building (3:20) <https://youtu.be/oiUkoJMhdvw>
- 環保基金 綠色建築教育短片系列 - 綠色建築網上導賞團 (7:23) <https://youtu.be/8JkTfb0H9u0>

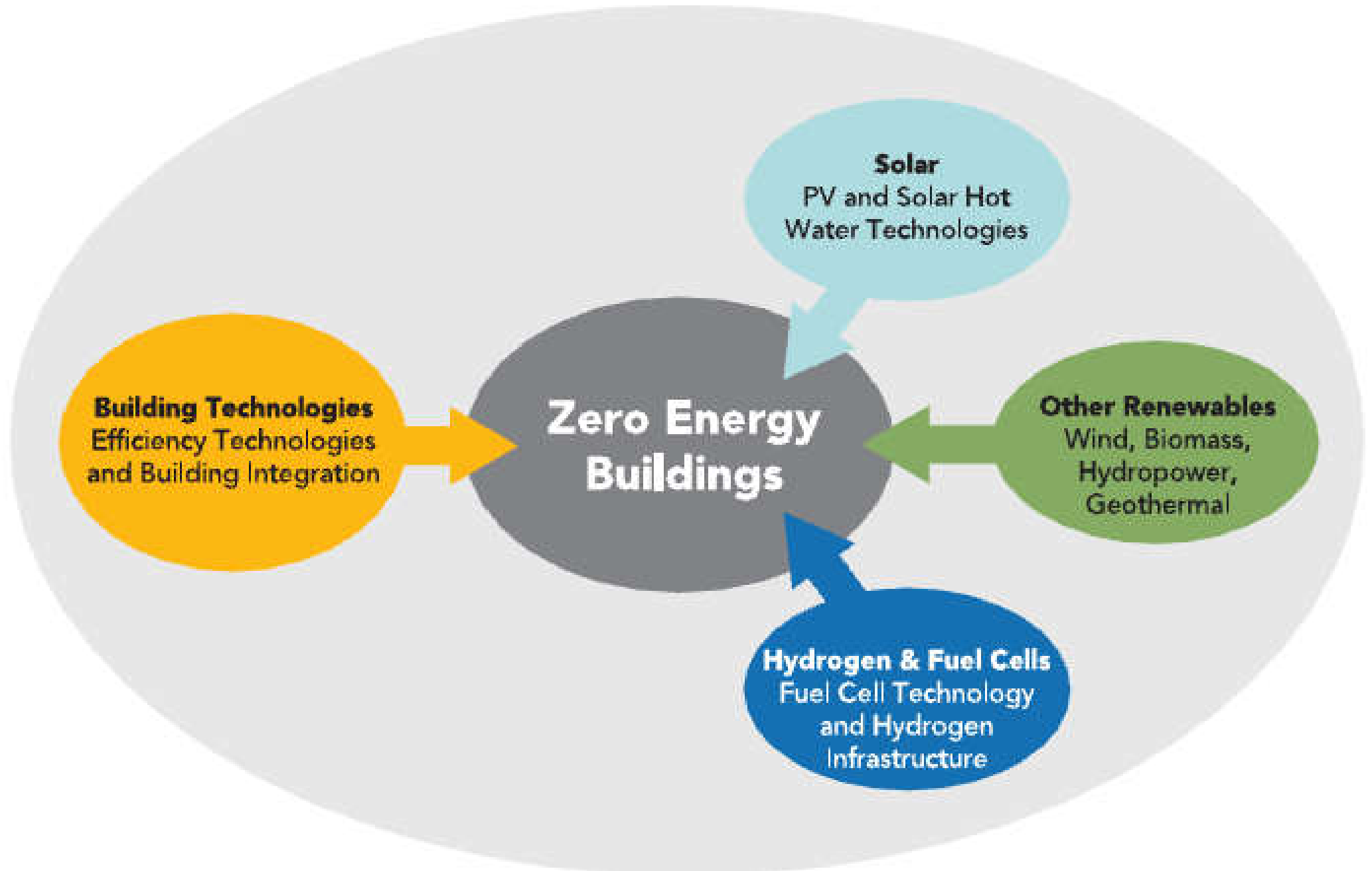
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# Zero carbon building

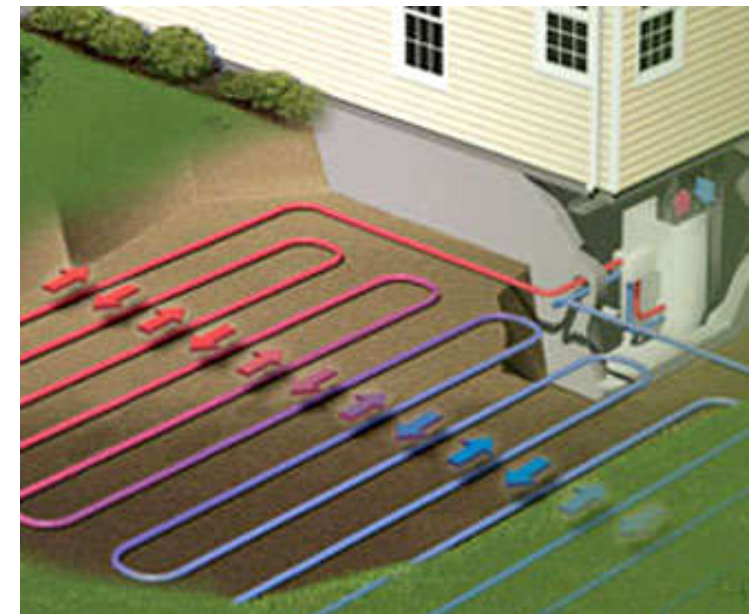
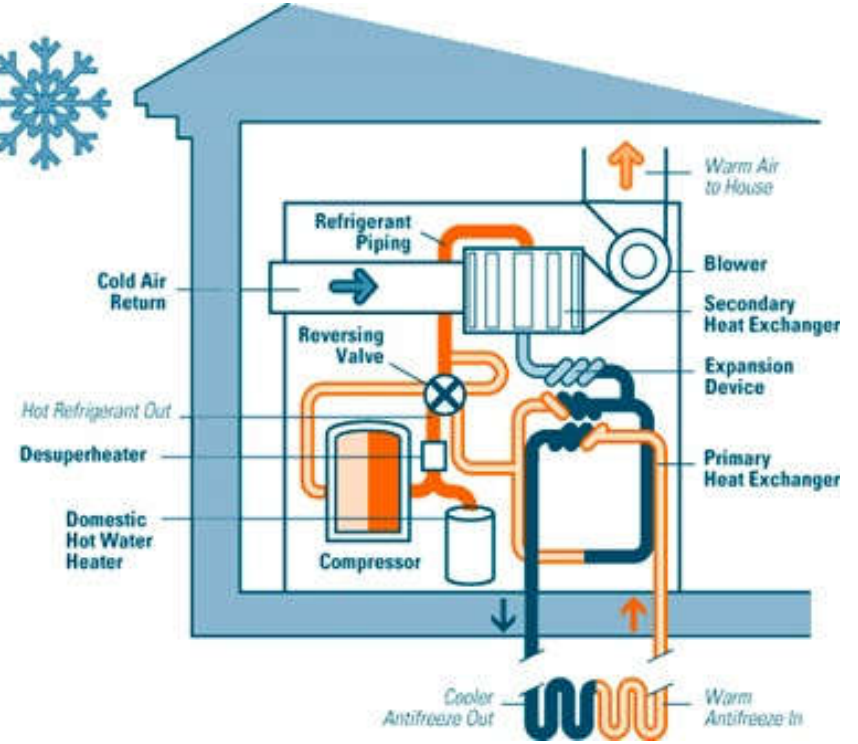
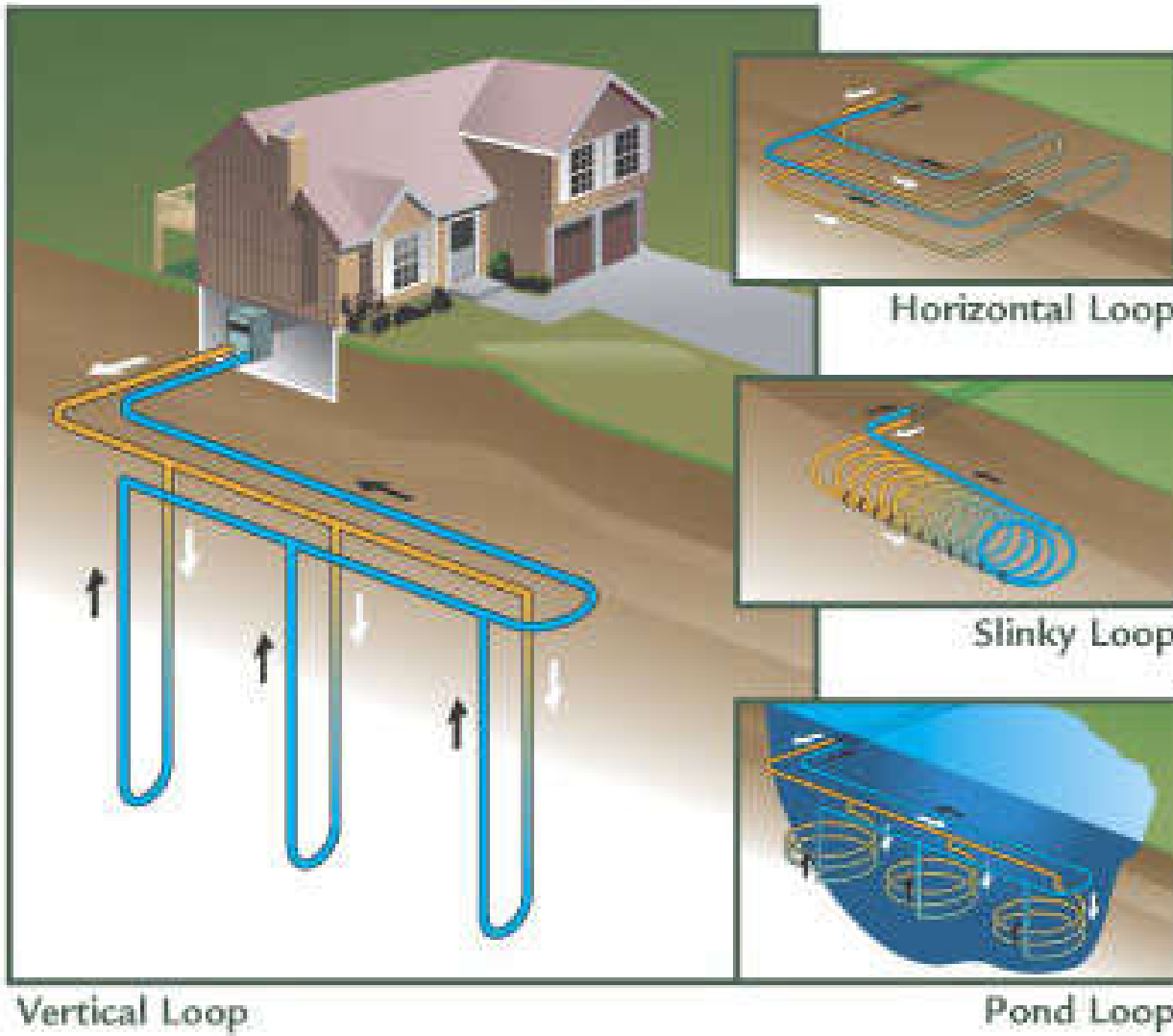


- How to achieve zero energy/carbon building?
  - High energy efficiency
  - On-site carbon reduction measures
    - Such as renewable energy systems, water efficiency
  - Methods to offset the remaining emissions, e.g.
    - Large scale off-site renewable energy facilities (unconnected)
    - Investment in local energy efficiency measures
    - Energy efficient appliances

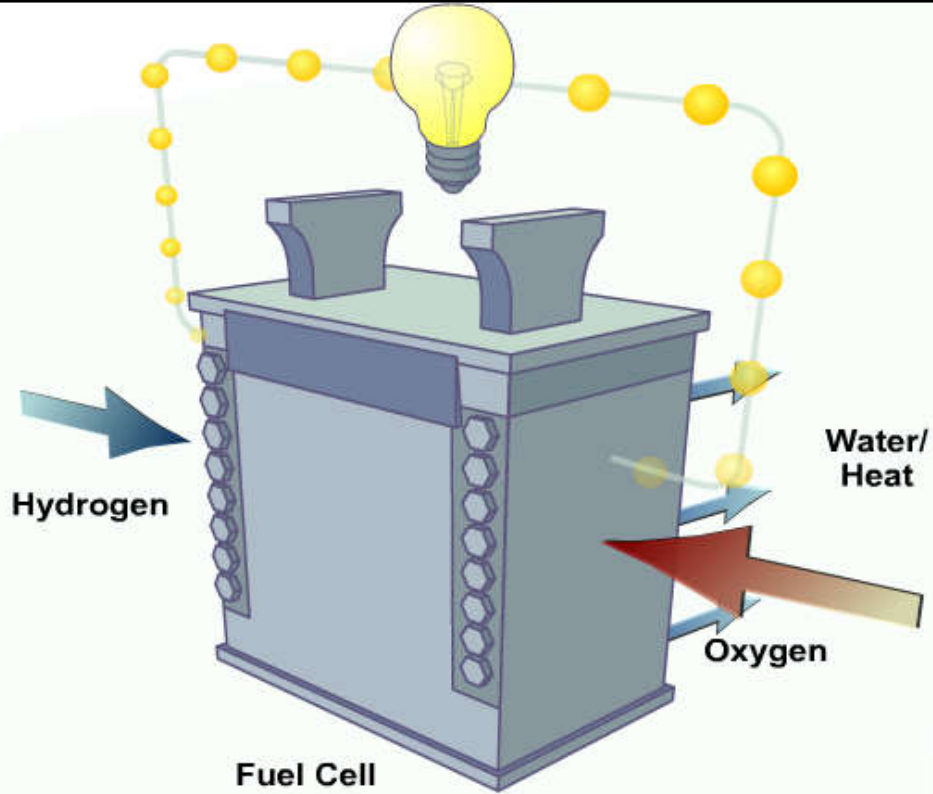
# Strategies for net zero energy building [Source: NSTC (2008)]



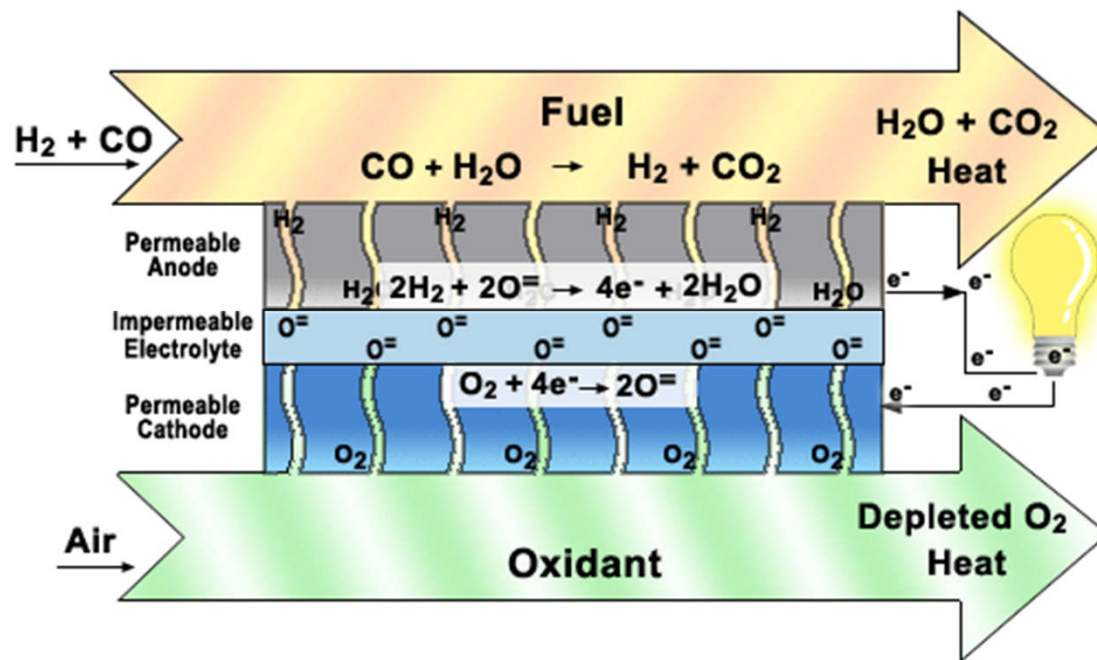
(Source: NSTC, 2008. *Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings*, Subcommittee on Buildings Technology Research and Development, Committee on Technology, National Science and Technology Council (NSTC), Washington, DC. <https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/nstc-netzero-2008.pdf>)



Geothermal heat pumps

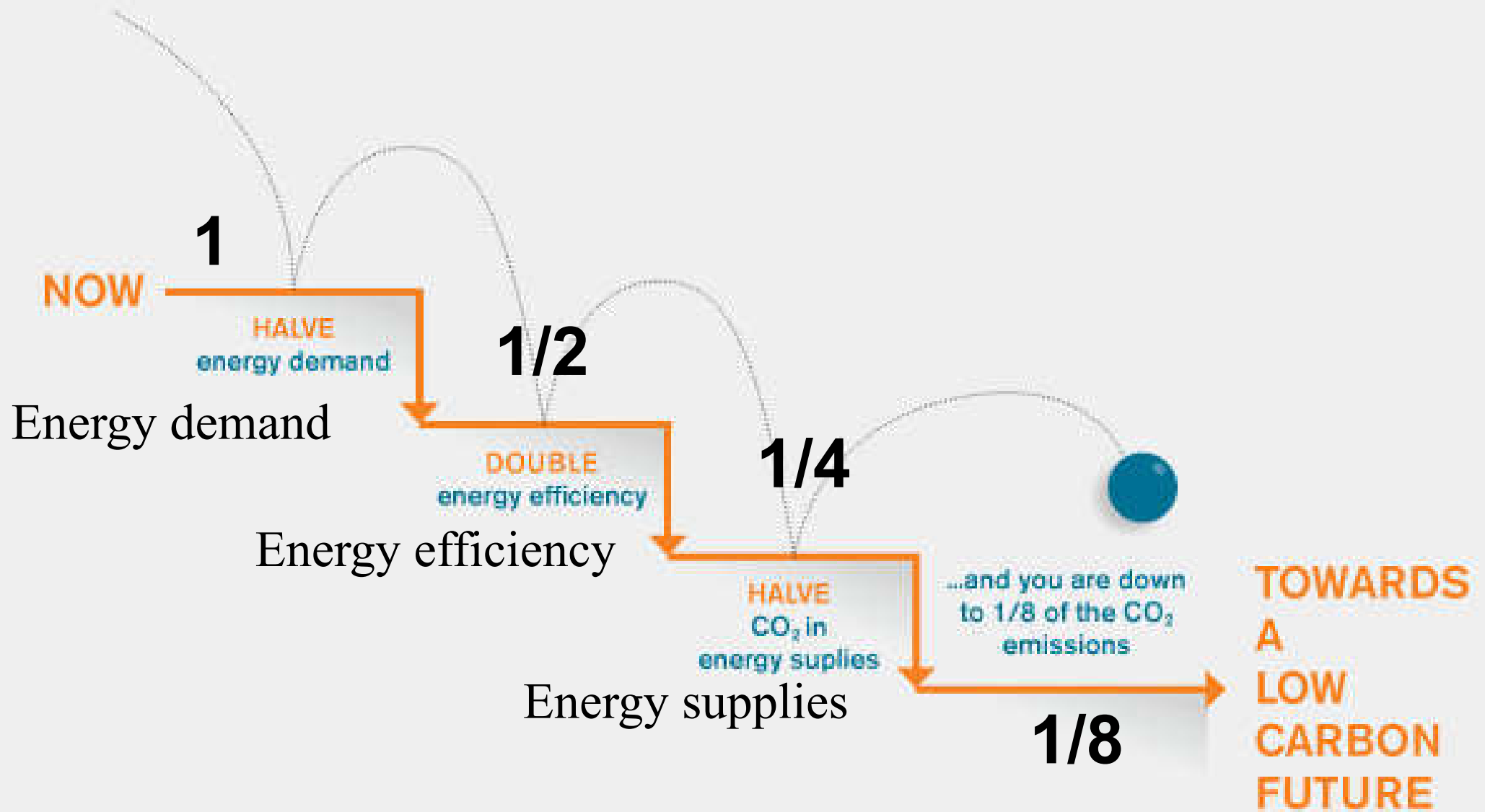


### Solid Oxide Fuel Cell





# The first steps to a low carbon future



## Energy reduction action plan

**1** **ENGAGE**  
users in energy  
consumption

to

- reduce carbon/energy
- save money
- enhance service efficiency

**2** **REDUCE**  
energy demand

through

- good passive design
- energy conscious behaviour
- responsible use

**3** **DRIVE OUT**  
waste with  
efficient equipment

by

- simple & effective controls
- reducing ICT heat & power
- low energy equipment

**4** **DECARBONISE**  
energy supplies

with

- low carbon fuels/biomass
- on-site/near-site renewable  
energy sources
- recovering useful heat

**5** **NEUTRALISE**  
energy supplies

with

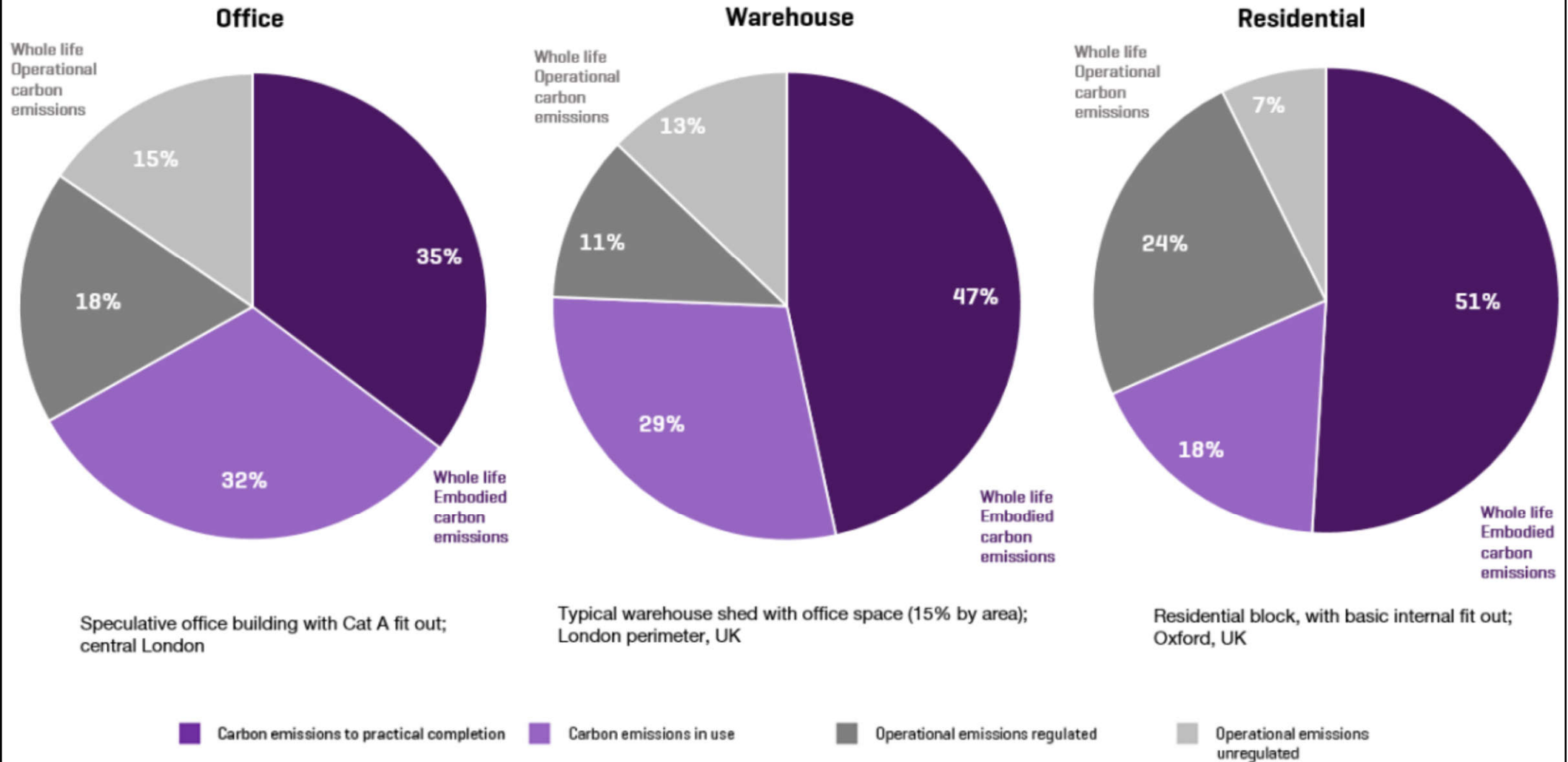
- off-site renewable energy
- other green electricity supplies
- distribution of surplus heat and energy  
through a neighbourhood network

"0"

# Zero carbon building

- How to achieve net zero carbon building?
  - 1. Establish net zero carbon scope
  - 2. Reduce construction impacts
  - 3. Reduce operational energy & carbon impacts
  - 4. Increase renewable energy supply
  - 5. Carbon offset the remainder of emissions
- As a rough rule of thumb:
  - “The embodied carbon of most buildings will fall in the range 400-1,000 kg CO<sub>2</sub>e per m<sup>2</sup>”

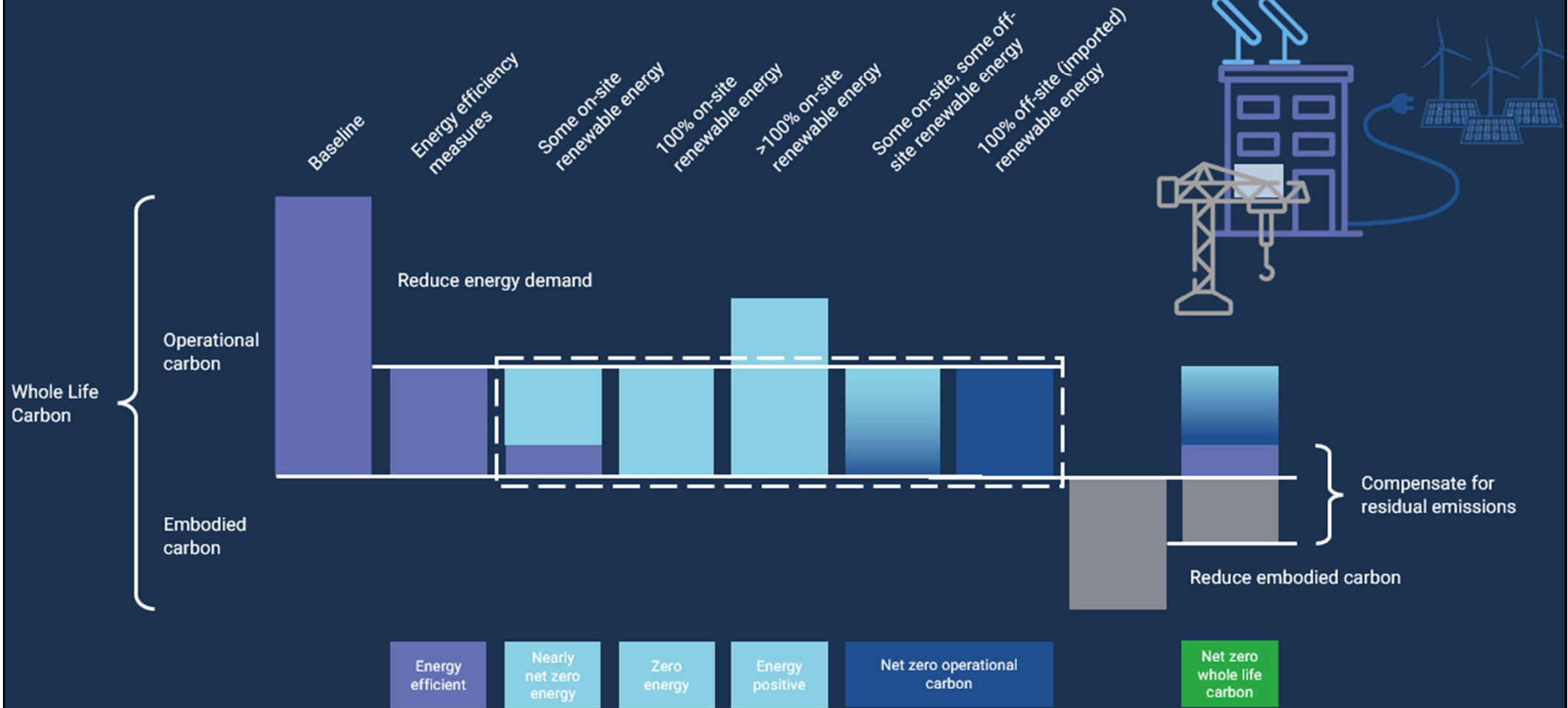
# Total whole life carbon emissions breakdown for different building types



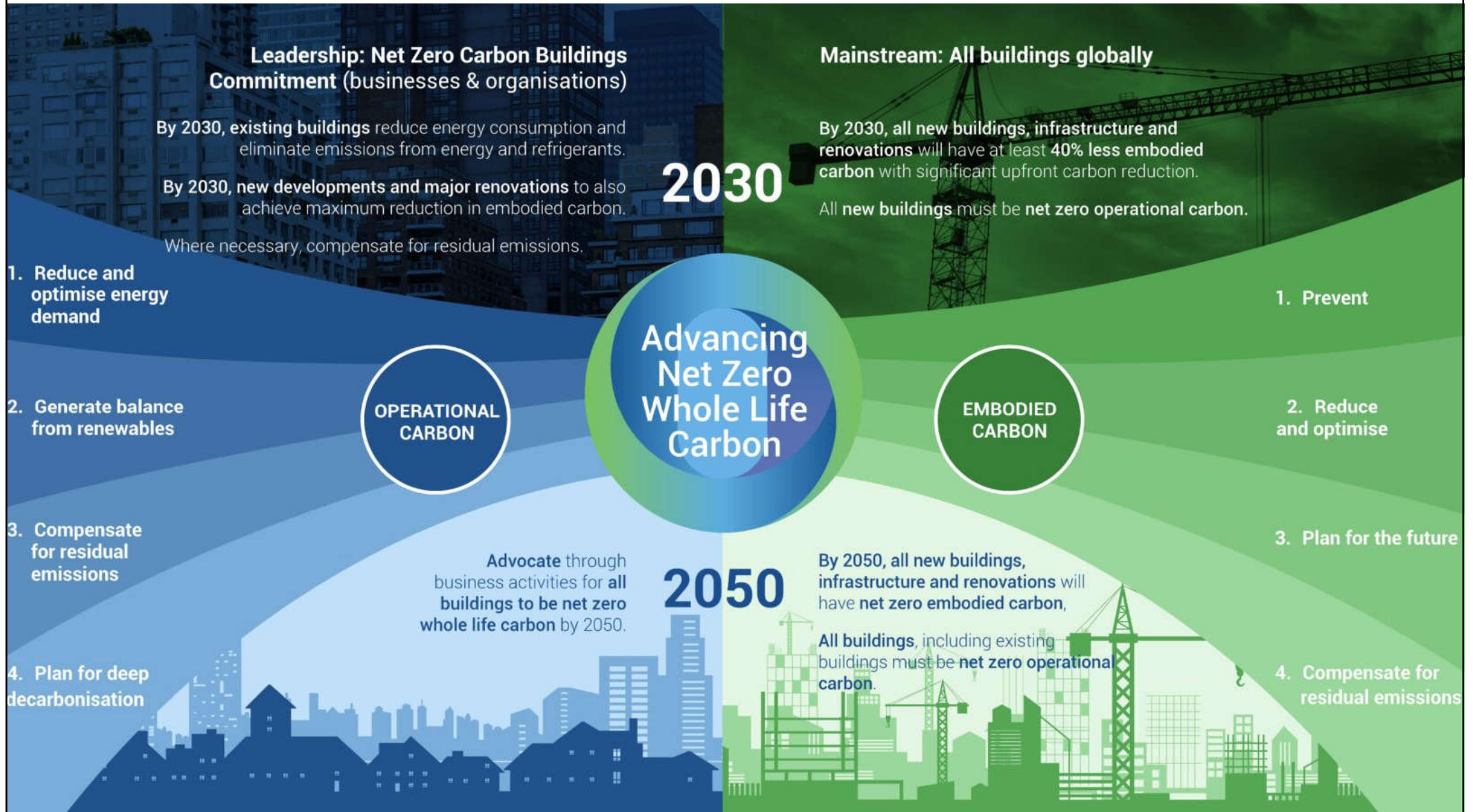
(Source: RICS Whole Life Carbon Assessment for the Built Environment <https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf>)

# What is a net zero carbon building?

## Definitions: Net Zero Carbon Buildings



# Whole Life Carbon Vision

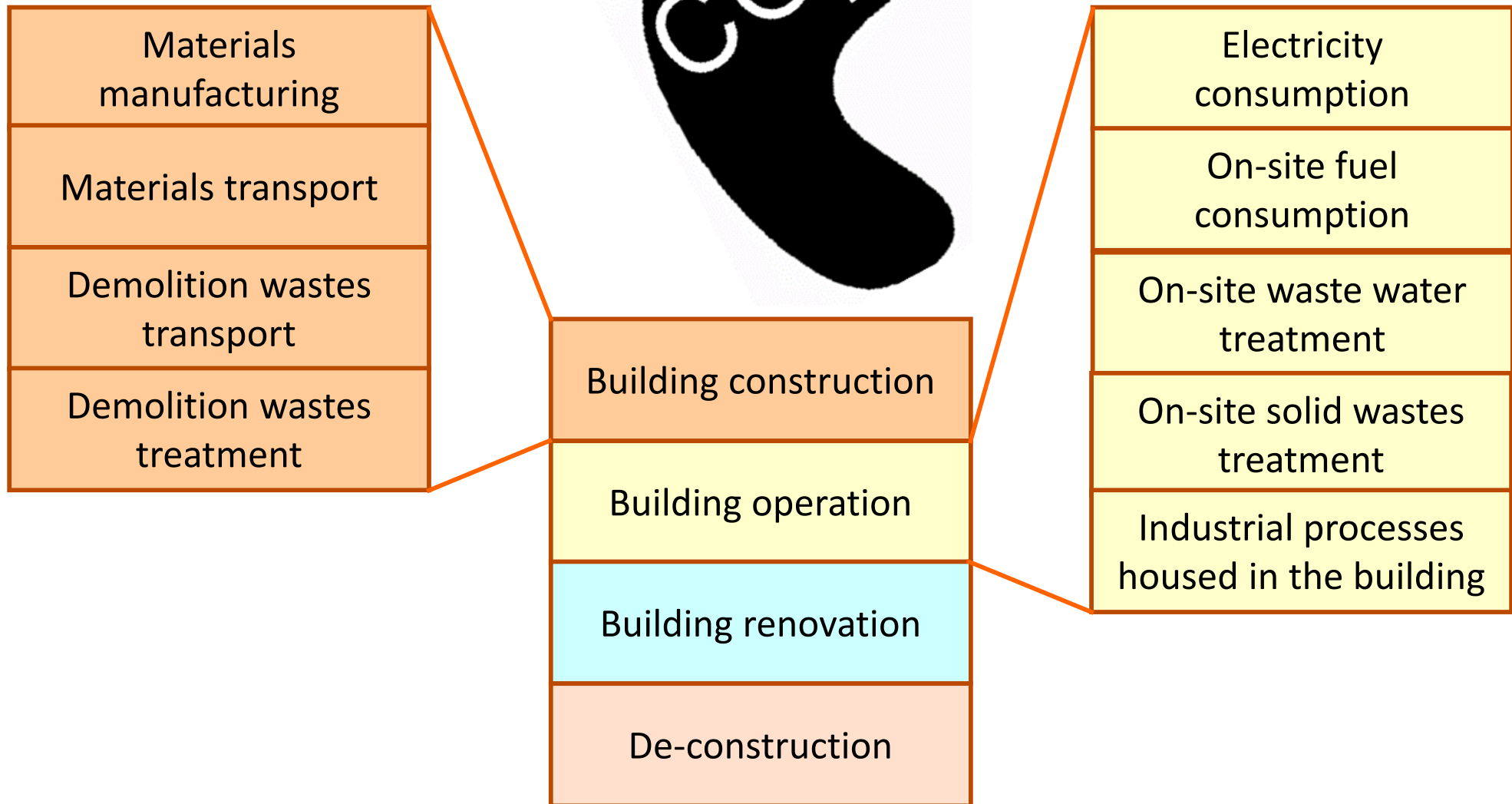


# Assess carbon footprints



- **Carbon** is frequently used as shorthand for either carbon dioxide ( $\text{CO}_2$ ) or carbon dioxide equivalents ( $\text{CO}_2\text{-e}$ ) of greenhouse gases
  - Used as an indicator for environmental impact or sustainability level
- **Carbon footprint**
  - Measure the exclusive direct (on-site, internal), and indirect (off-site, external, embodied, upstream, and downstream)  $\text{CO}_2$  emissions of an activity, or over the life cycle of a product, measured in kg

# Carbon footprint of a building and its components



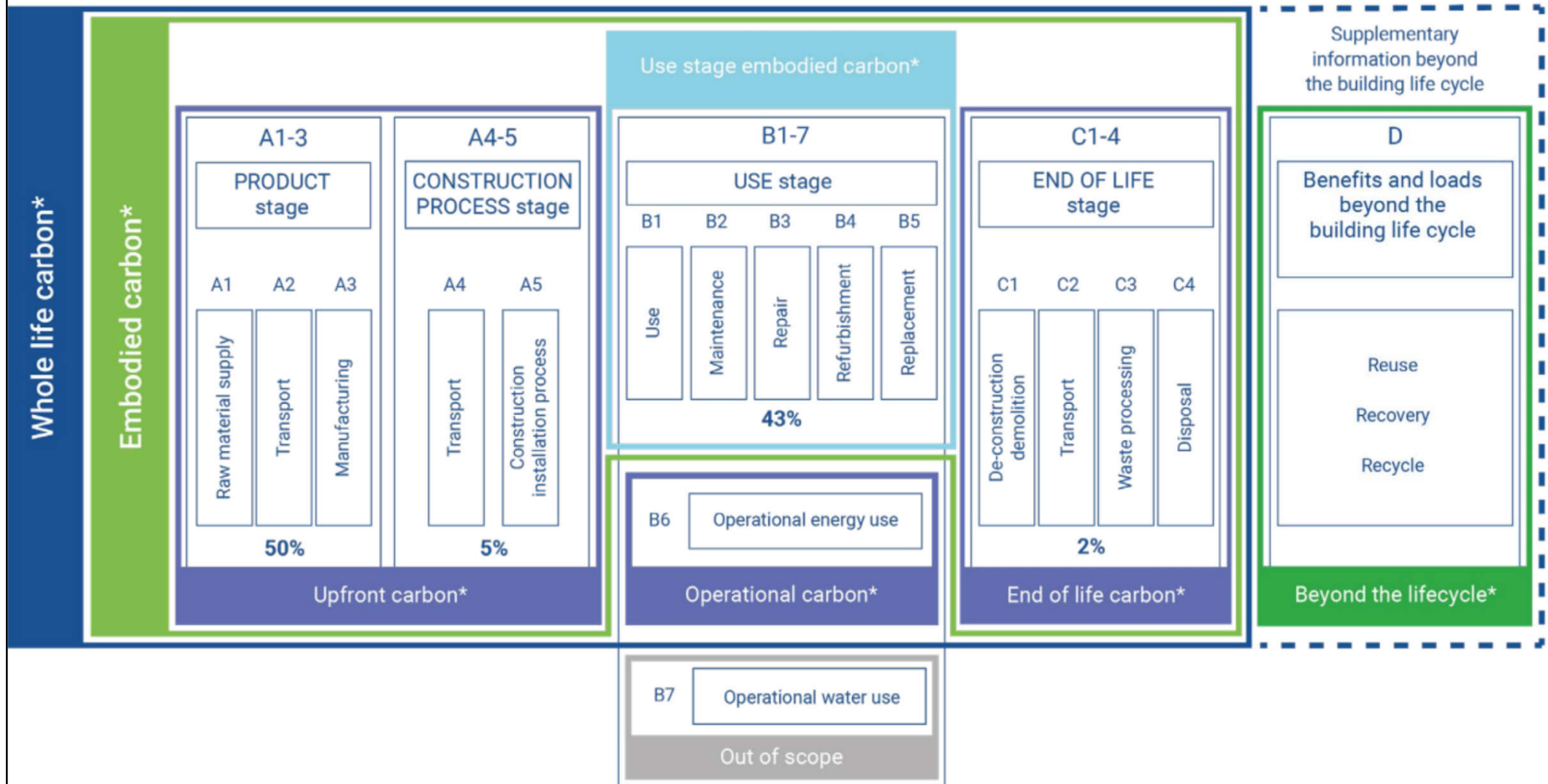


# Assess carbon footprints

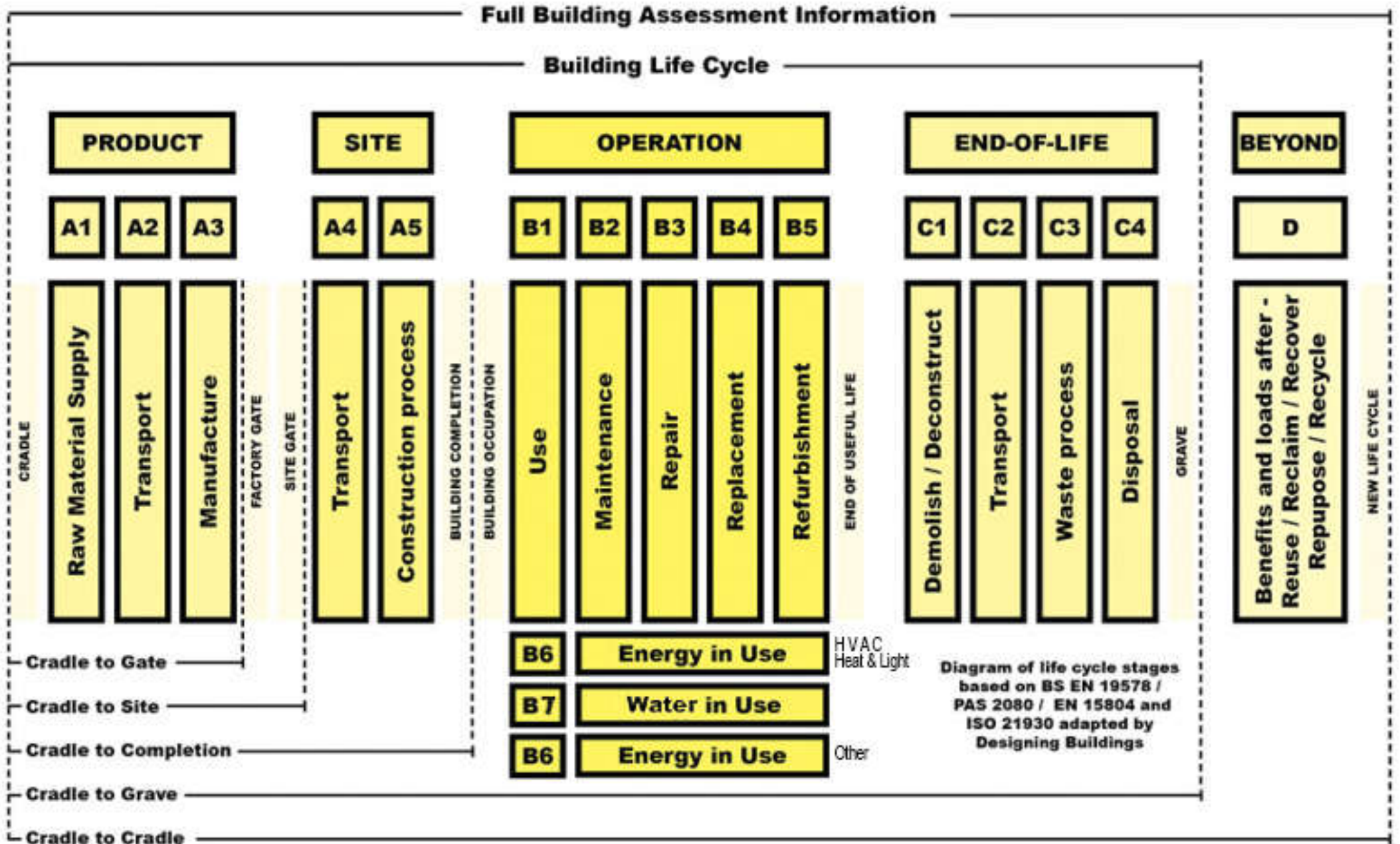


- International standards for carbon footprint calculation and analysis
  - ISO 14040: Life Cycle Assessment - Principles and Framework
  - BSI: PAS 2050 - Specification for the Assessment of Life-Cycle GHG Emissions of Goods/Services
  - WRI/WBCSD: Greenhouse Gas Protocol
  - IPCC: 2006 Guidelines for National Greenhouse Gas Inventories

# Life cycle stages and modules according to EN 15978 and the estimated (according to the Institution of Structural Engineers) distribution of emissions for a medium-scale residential building



# The sustainability of construction works

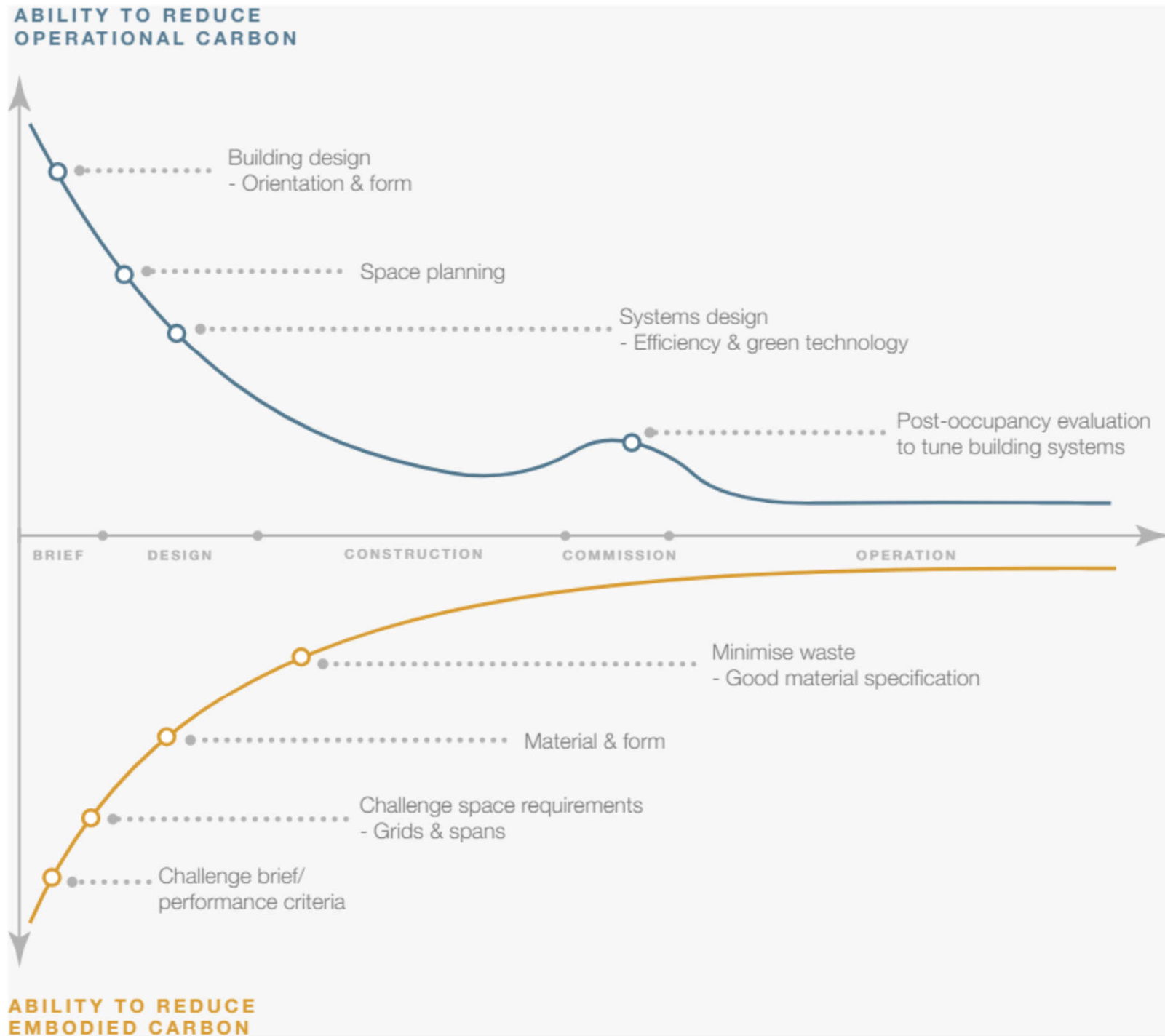


# Assess carbon footprints

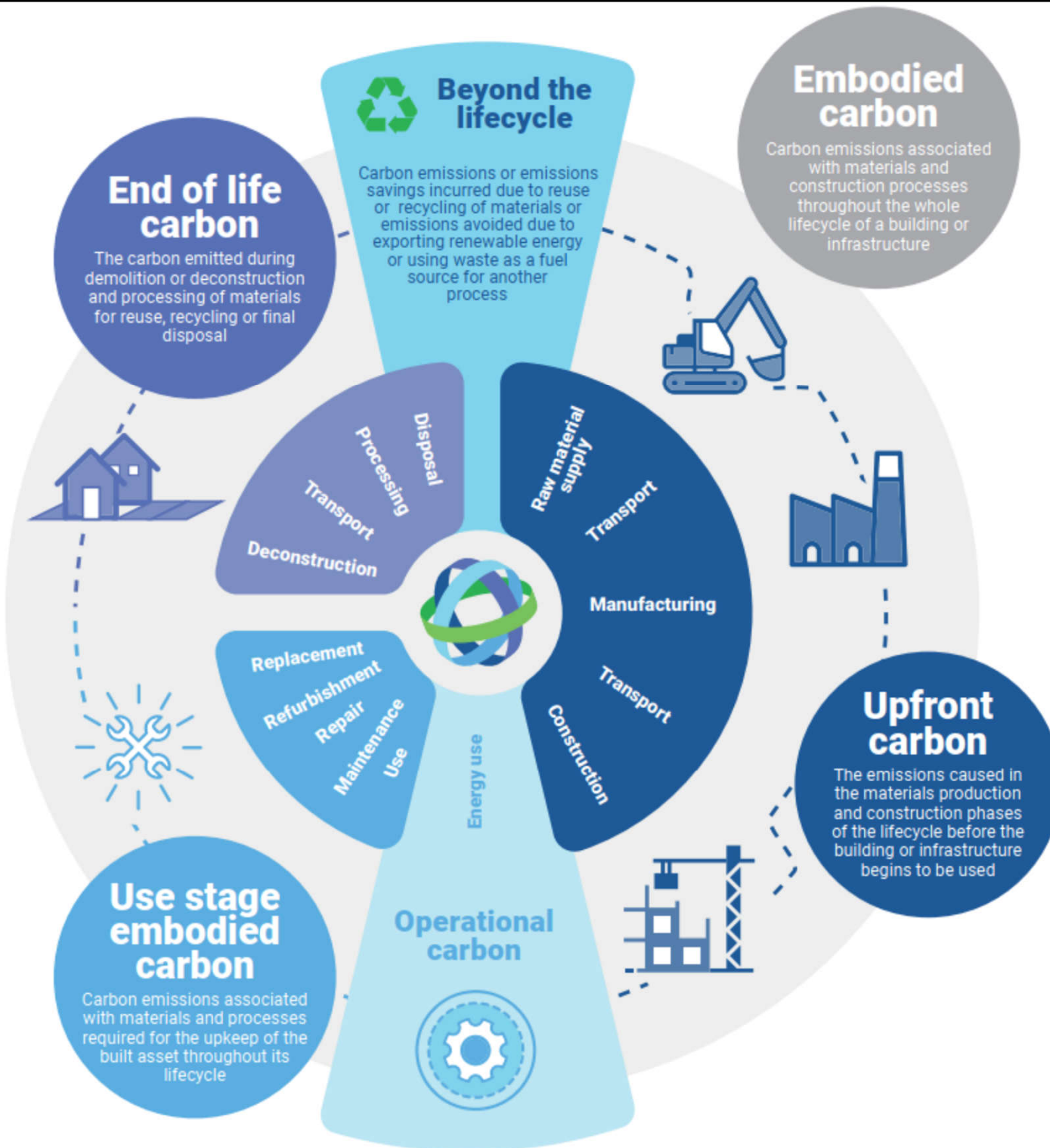


- **Embodied carbon**
  - Carbon emissions associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure
- **Operational carbon**
  - The emissions associated with energy used to operate the building or in the operation of infrastructure
- **Whole life carbon**
  - Emissions from all lifecycle phases

# Approach to reduce operational carbon and embodied carbon



(Source: <https://www.arup.com/perspectives/publications/research/section/net-zero-carbon-healthcare>)



Project lifecycle showing both the scope of the definition and need for whole life consideration

## Different carbon reduction approaches

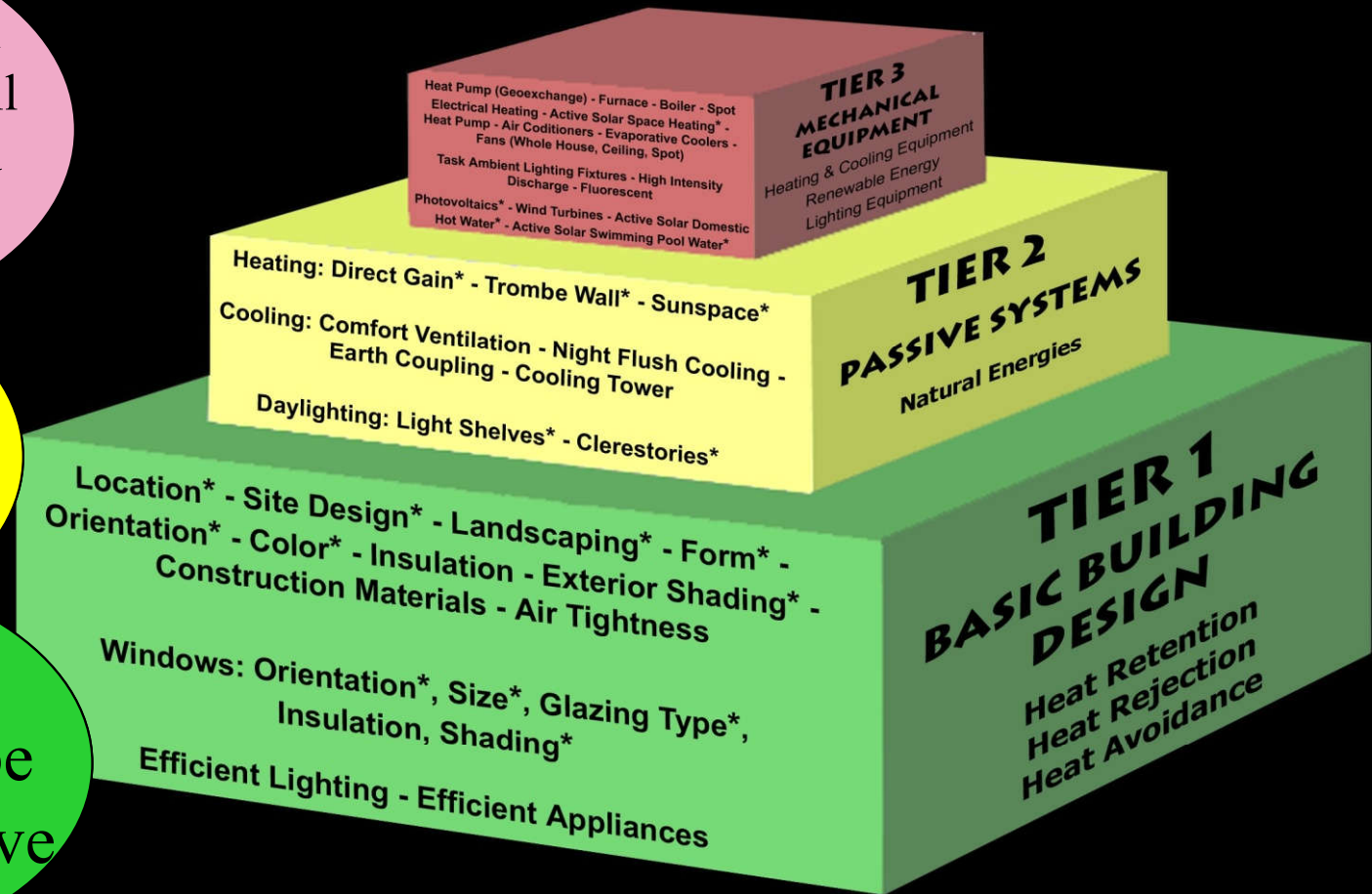
<b>Strictly zero carbon</b>	No carbon is emitted within Scopes 1 and 2; neither balancing nor offsets are allowed.
<b>Net zero carbon</b>	All carbon emissions within emissions Scope 1 are eliminated, and emissions within Scope 2 are balanced through export of low or zero carbon goods, internal or external sequestration, or import substitution of Scope 3 emissions.
<b>Carbon neutral</b>	Any and all emissions for which the building is responsible under Scopes 1 and 2 can be managed through the purchase of offsets from third parties that lie outside the building's boundaries.
<b>Low carbon</b>	Emissions under Scopes 1, 2 and 3 are reduced compared to a baseline. The reduction level is often not clearly specified.

# Carbon Reduction: The Tier Approach

...and the Mechanical Systems won't be small enough to be powered by renewable energy

...or the Passive Systems won't work

Basic building design **MUST** be climate responsive



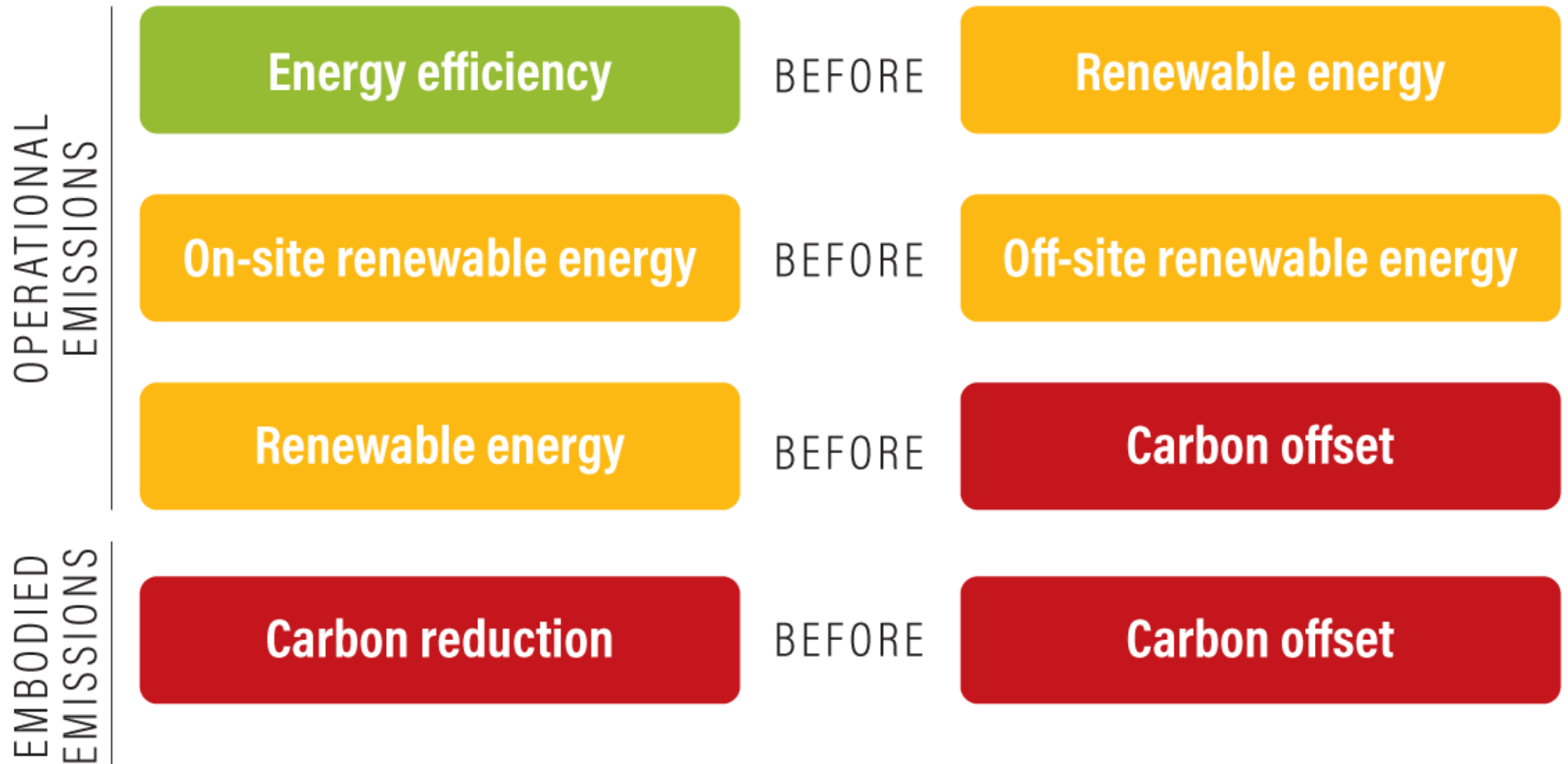
**THE 3 TIER APPROACH TO SUSTAINABLE HEATING, COOLING, AND LIGHTING OF BUILDINGS**

\* PART OF SOLAR RESPONSIVE DESIGN

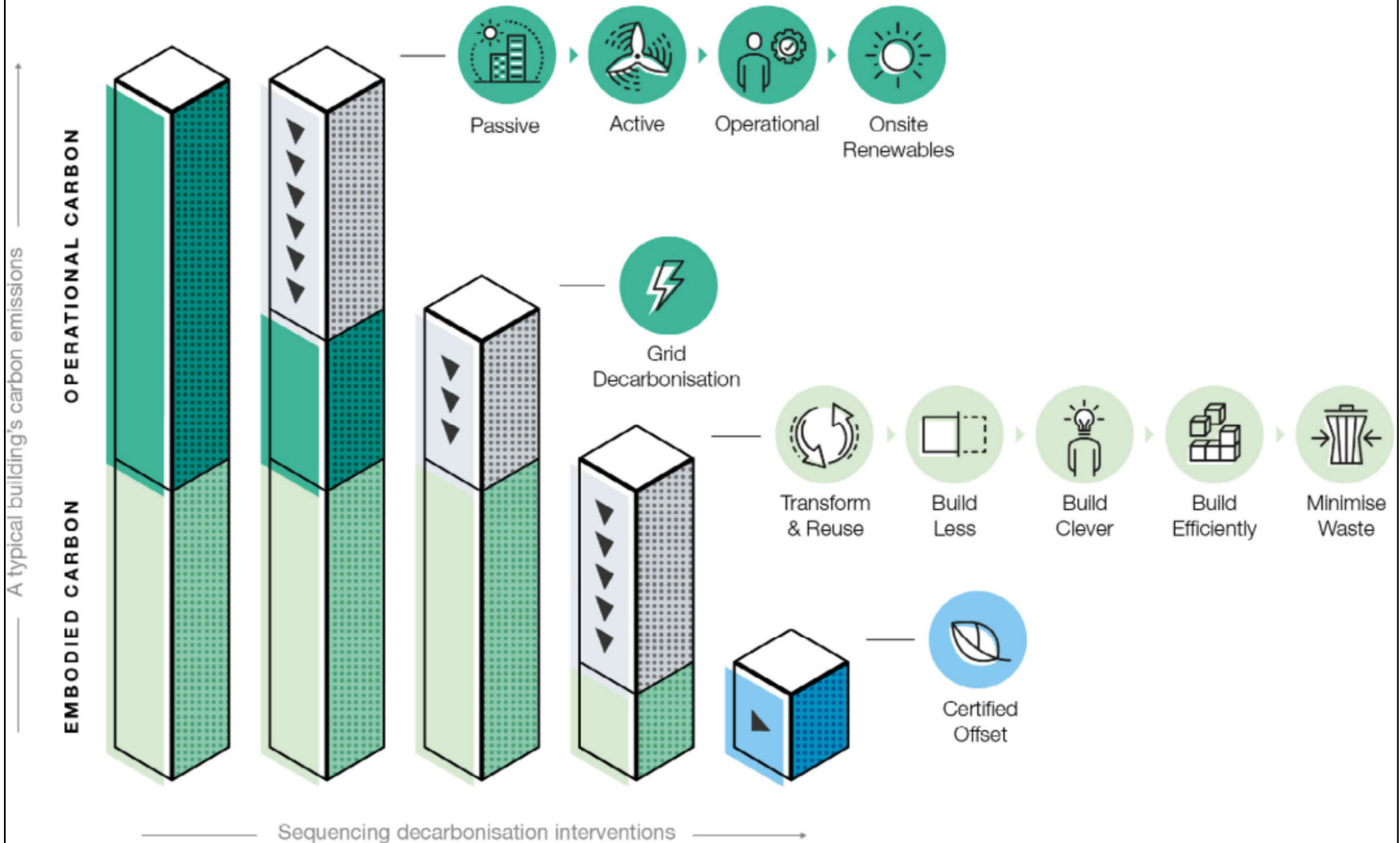
Drawn by Barbara Jo Agnew at Auburn University



# How to achieve Zero Carbon Buildings (ZCBs)?



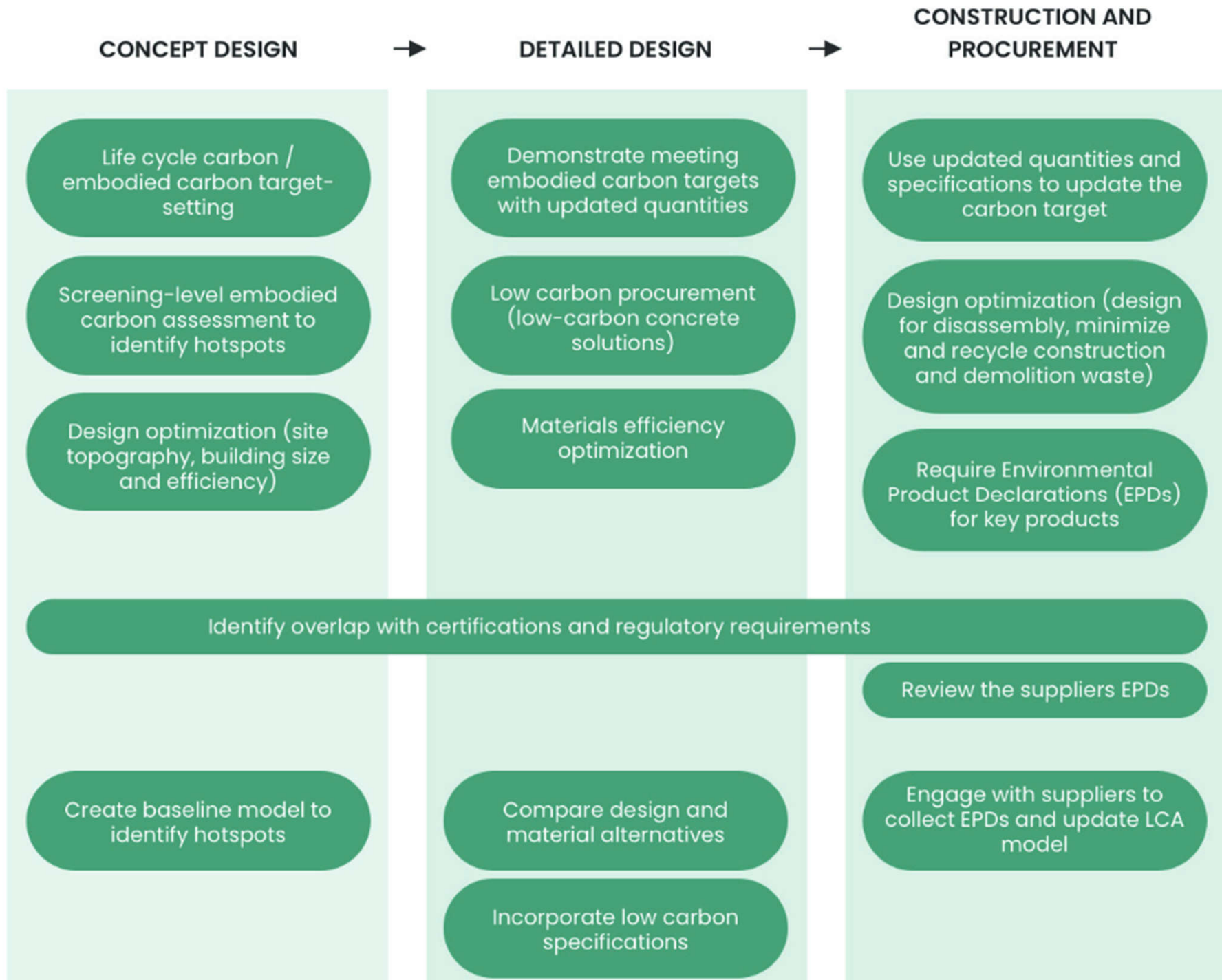
# Route to Net Zero: Getting the Sequencing Right



## Recommended design strategies for ZCB

- At the outset, the building project should take into account **building energy efficiency** and use of **renewable energy**
- Select the appropriate building site; allow opportunity to apply renewable energy and to **reduce transportation and food production needs**
- Optimise **passive design strategies** to protect the natural and comfortable environment in order to reduce energy demand
- Conserve **water** and reduce the demand for hot water
- Appropriately select **materials** in order to reduce the environmental impacts
- Reduce **energy use** in all aspects of the building operation
- Consider building energy efficiency first before introducing renewable energy offsets

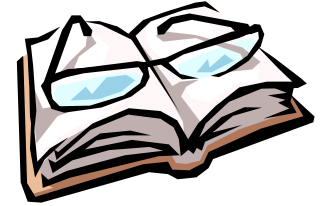
# Measures to reduce embodied carbon at each project stage



# Six-step approach to cost-effective zero net energy+carbon design

<p><b>1. Load reduction</b> Reduce building energy demands through passive strategies. Example measure: improved insulation</p>	<p><b>4. Energy recovery</b> Supply energy by recovering energy from existing energy losses. Example measure: wastewater heat recovery system</p>
<p><b>2. Passive strategies</b> Implement passive design measures that harness environmental conditions to meet building loads. Example measure: natural ventilation</p>	<p><b>5. Renewables</b> Supply demands of energy consumption with renewable energy generation. Example measure: solar thermal panels</p>
<p><b>3. Efficient systems</b> Reduce energy losses by increasing energy efficiency of active systems (ie, systems that use energy). Example measure: heat pump with a high coefficient of performance</p>	<p><b>6. Offsets</b> Offset remainder of the energy budget if necessary. Example measure: energy efficiency project investment</p>

# Further Reading



- Life-Cycle Cost Analysis (LCCA) [WBDG]  
<https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca>
- Carbon Footprint Management Toolkit for Sustainable Low-Carbon Living (CityU)  
<http://www.cityu.edu.hk/aerc/cft/>
- Arup, 2019. *Five Minute Guide to Zero Net Energy and Carbon*, Arup, London.  
<https://www.arup.com/perspectives/publications/promotional-materials/section/five-minute-guide-to-net-zero-energy-in-buildings>