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construction materials, CO_2e, and their sustainability measurement

Dr. Alex Amato

Global construction consultants

construction materials, CO_2e, and their sustainability measurement

contents:

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the three rules of 'green materials'

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the three rules of 'green materials'

1. 'there is **NO** such thing as a green material.'
2. '**ALL** materials result in environmental and often social impacts, but some cause more or less impacts than others.'
3. 'to properly assess the true impact of a material, a life cycle view **MUST** be taken.'

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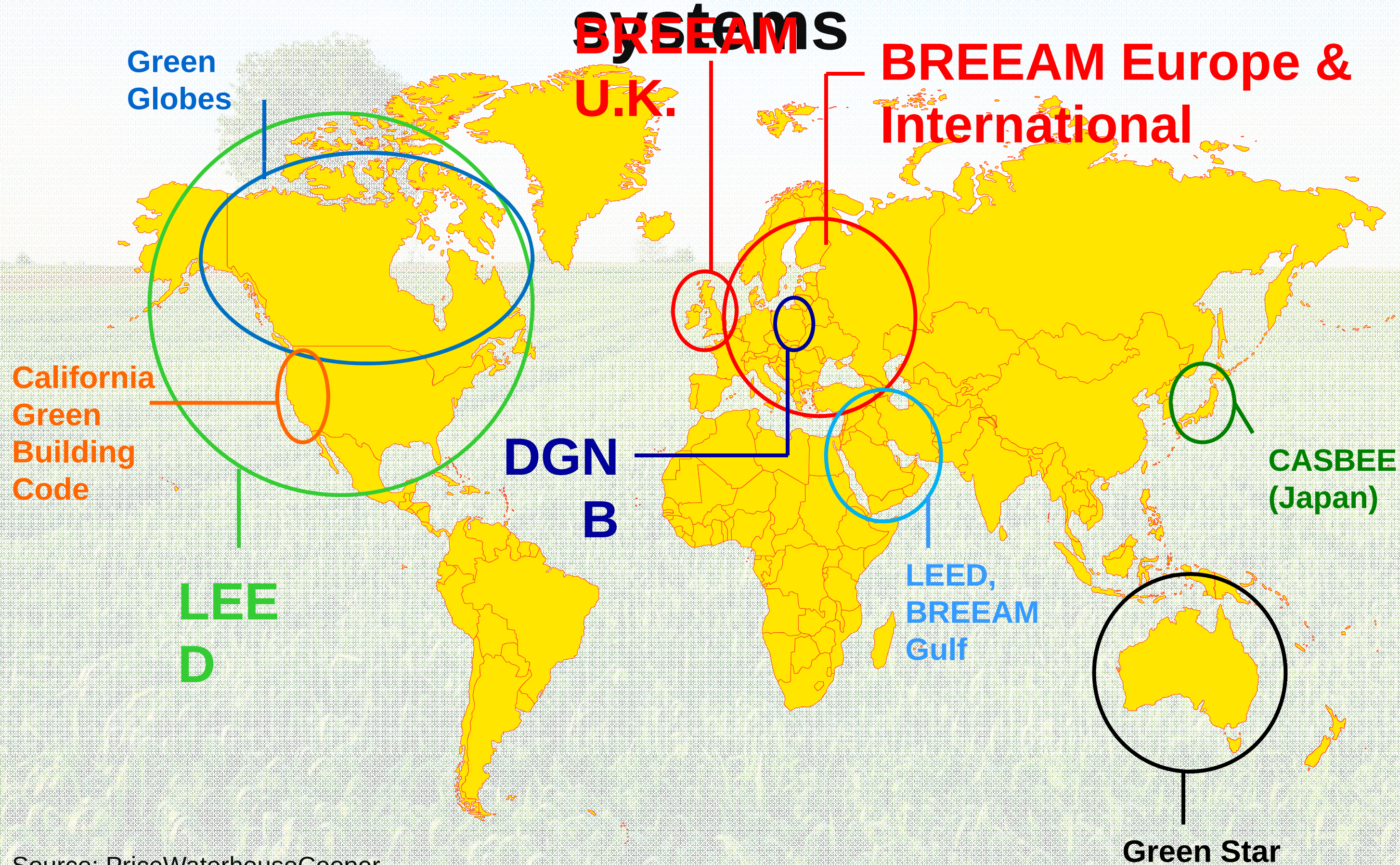
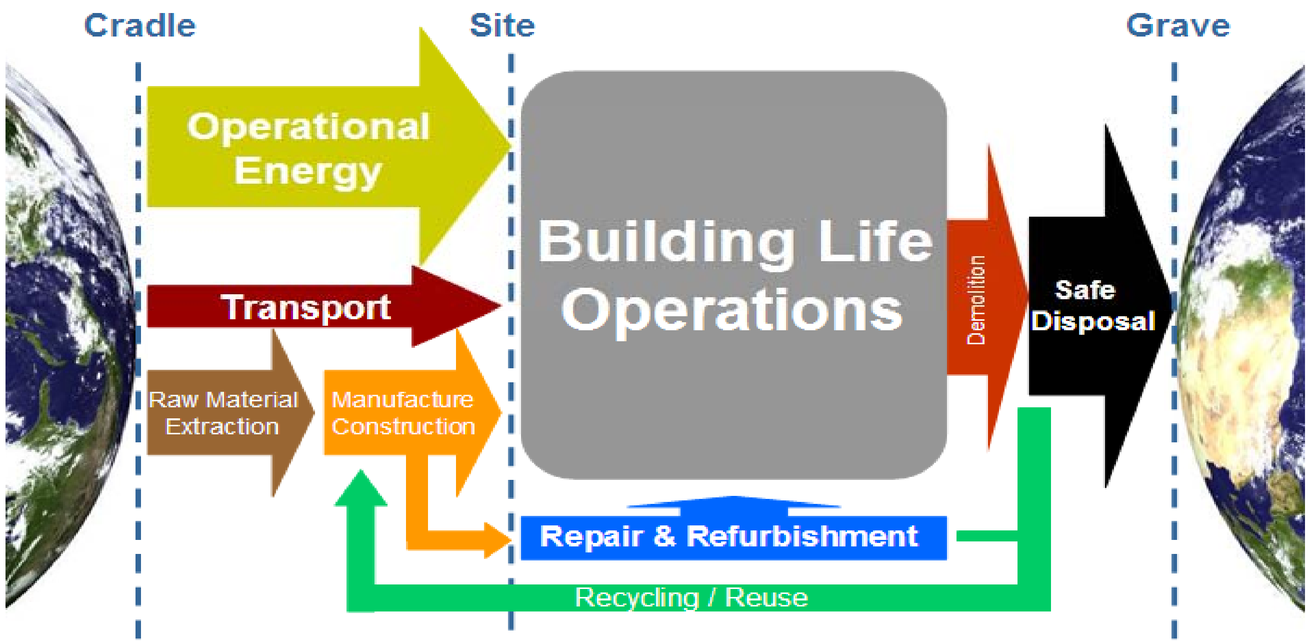
Current green building certification systems



Source: PriceWaterhouseCooper

why a life cycle approach?

because impacts and mitigation occurs throughout the **life cycle** of most construction materials and because any assessment must take into account the **repair and maintenance regime** of any material or product.



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typical material information in the public realm for designers to consider

given the following information, which material appears to be the most **'green'?**

- steel hot rolled sections made from primary raw materials at 25 - 30 GJ/tonne

or

- reinforced concrete at 1 - 4 GJ/tonne dependant on mix and quantity of reinforcement

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environmental comparisons of materials what to consider........

to be effective, comparisons need to be made between equivalent functional units e.g.

- complete superstructure systems
- complete roofing and façade system

they also need to take into account consequential adjustments to the building design e.g.

- changes in foundation design
- fire proofing
- different thermal performance i.e. thermal mass

environmental comparisons cont.

- therefore to be valid, environmental comparisons of competing material/product systems have to be:
  - carried out over the life cycle of the building (not just the product) including end of life scenarios;
  - need to assess the consequent repair and maintenance and replacement regimes of each material/product; and
  - need to include all consequential design changes resultant from each alternatives so that each functional unit is compared equally

this is effectively a Life Cycle Assessment

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early work, steel vs. concrete offices UK 1992 - '96

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environmental comparisons cont.

results of the steel vs. concrete comparative office study carried out '92 - '96 …….energy

INITIAL BUILDING EMBODIED ENERGY COMPARED WITH TOTAL LIFE-CYCLE BUILDING ENERGY										
	BUILDING TYPE A									
A Initial building Emodied Energy (ibee) C % of L.C. ee to Total L.C. building Energy (L.C. bee + L.C. boe)	Slimfloor Beams & Precast Slabs		Composite Beams & Composite Slabs		Reinforced Concrete Beams & Slabs		Cellular Beams & Composite Slabs		Precast Concrete & Hollow Core Units	
	A GJ/ m²	C %	A GJ/ m²	C %	A GJ/ m²	C %	A GJ/ m²	C %	A GJ/ m²	C %
1. Naturally Ventilated Option	8.8	33.4	8.9	33.7	8.7	33.4	9.1	33.9	9.0	33.8
2. Supply/Extract Ventilation	9.1	25.5	9.2	25.6	9.0	25.4	9.4	25.7	9.2	25.6
3. Floor Supply/Extract Raised	9.0	25.4	9.1	25.5	8.9	25.3	9.3	25.7	9.2	25.8
4. Raised Floor Supply/ Extract Enhanced	9.0	25.3	9.1	25.5	8.0	25.8	9.3	25.6	9.2	25.8

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environmental comparisons cont.

results of the steel vs. concrete comparative office study carried out ‘92 - ‘96……..CO_2

INITIAL BUILDING EMBODIED CO2 EMISSIONS COMPARED WITH TOTAL LIFE-CYCLE BUILDING CO2 EMISSIONS										
	BUILDING TYPE A									
A Initial building Emodied CO2 (ibeCO2) C % of L.C. building eCO2 to Total L.C. building CO2	Slimfloor Beams & Precast Slabs		Composite Beams & Composite Slabs		Reinforced Concrete Beams & Slabs		Cellular Beams & Composite Slabs		Precast Concrete & Hollow Core Units	
	A kg/m²	C %	A kg/m²	C %	A kg/m²	C %	A kg/m²	C %	A kg/m²	C %
1. Naturally Ventilated Option	726	37.4	724	37.5	764	37.9	738	37.7	811	38.7
2. Supply/Extract Ventilation	746	28.9	743	28.9	784	29.4	758	29.1	831	29.9
3. Floor Supply/Extract Raised	741	28.8	739	28.8	780	29.3	754	29.0	826	30.0
4. Raised Floor Supply/ Extract Enhanced	741	28.8	739	28.8	780	29.2	754	28.9	826	30.0

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environmental comparisons cont.

lessons learned!

- LCA methodology is difficult to apply because it is complex and time consuming requiring several models to be constructed as follows:
  - an initial building model of the masses (not the quantities) of all the components/materials that make up the building. The model also needs to input the environmental impacts per mass of material to complete the initial building model.
  - an operational model of the building also needs to be created that estimates the operational energy usage of the building because of the interrelationship between material and energy requirement.
  - a refurbishment and repair and maintenance model needs to be constructed in a similar way as the initial model.
  - finally an end of life model needs to be constructed that deals with disposal - often with a sensitivity analysis of different scenarios.

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environmental comparisons cont.

lessons learned!

- although LCA methodology can be considered to be the most thorough and rigorous assessment method, delivering a quantitative result that makes comparison easy, it has not yet been widely adopted by the construction industry as a design tool.
- this is partly due to its complexity but also because it often requires detailed information about the building design that is only available in the latter stages of the design process.
- due to its complexity and detailed information requirement it has in the past not be able to deliver information in time to affect the design process.
- finally it does not deliver corresponding cost information to the design team.

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LCA development - the Hong Kong years HK 2001 - '07

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development of LCA since early use

the development of combined LCA / LCC practice in HK work carried out from 2001- '07 by Dr. Alex Amato, HKU: and Mr. Steven Humphrey, Davis Langdon & Seah:

- value over a building's life-cycle slowly becoming important
- better information / awareness in the market
- Kyoto and other initiatives raising importance of CO_2 and also data on other specific impacts is now available
- trend towards Corporate & Social Responsibility
- industry needs numbers and user-friendly ways to compare options and major/minor differences

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methodology - LCA overview

Life Cycle Assessment [LCA]

- Based around the requirements and principles of ISO14040
- Environmental impact of energy + material are assessed quantitatively over a building's life-cycle
- Impacts can be classified under the following categories:

  e.g. Energy, Climate Change, Ozone Depletion, Resource Depletion, Photochemical Smog, Acid Rain, Eco-Toxicity to Humans & Air, Waste & Water Consumption. That can be further categories.

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methodology - LCA life cycle inventory

- life cycle inventory results after quantification

No	Substance	Compartment	Unit	Steel ETH U Europe
1	Zr95 to water	Non mat.	mBq	13.1
2	Zr95 to air	Non mat.	nBq	169
3	Zr	Air	æg	6.5
4	Zn65 to water	Non mat.	mBq	2.09
5	Zn65 to air	Non mat.	µBq	11.3
6	Zn (ind.)	Soil	æg	49.9
7	Zn	Water	mg	14
8	Zn	Air	mg	18.3
9	zinc (in ore)	Raw	æg	441
10	zeolite	Raw	æg	509
11	Y90 to water	Non mat.	µBq	3.71
12	xylene	Water	æg	264
13	xylene	Air	mg	3.16
14	Xe138 to air	Non mat.	mBq	784
15	Xe137 to air	Non mat.	mBq	71.7
16	Xe135m to air	Non mat.	Bq	2.89
17	Xe135 to air	Non mat.	Bq	29.2
18	Xe133m to air	Non mat.	mBq	86.2
19	Xe133 to air	Non mat.	Bq	171
20	Xe131m to air	Non mat.	mBq	583
21	wood (dry matter) ETH	Raw	g	5.2
22	wood	Raw	mg	333
23	water	Raw	kg	21.7
24	waste heat to water	Non mat.	kJ	87.2
25	waste heat to soil	Non mat.	kJ	16.3
26	waste heat to air	Non mat.	MJ	12
27	W	Water	æg	7.39
28	VOC as C	Water	æg	839
29	vinyl chloride	Water	ng	2.15

Air emissions
Solid waste
Raw materials
Other emissions
Liquid waste

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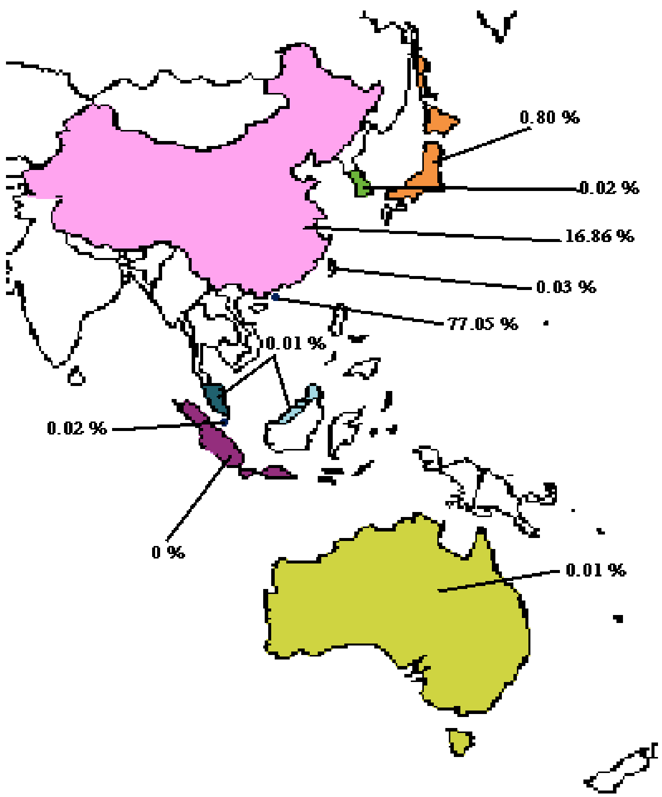
methodology - LCA regionalisation



Key Issues

- mode of transportation.
- distance traveled.
- energy source in country of manufacture; ie.fuel mix.
- process adopted in manufacturing; and fuel mix.

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LCA life cycle impact assessment

Includes

1. Classification

2. Characterisation

3. Normalisation, Weighting

Life Cycle Inventory (LCI) of 1 kg material e.g. SO_2, NO, HCl, etc.

LCI results assigned to impact categories (Energy, Climate Change, Ozone Depletion, Resource Depletion, Photochemical Smog, Acid Rain, Eco-Toxicity to Humans & Air, Waste & Water Consumption)

Impact Category Indicators

1. Energy **(MJ)**
2. Resource depletion (**kg Antimony (Sb) eq.)**
3. Water consumption **(litre)**
4. Waste **(kg)**
5. Climate change **(kg CO_2 eq.)**
6. Acid rain **(kg SO_2 eq.)**
7. Photochemical smog **(kg ethane eq.)**
8. Ozone depletion **(kg CFC-11 eq.)**
9. Toxicity to humans **(kg Tox eq.)**
10. Toxicity to ecosystems **(kg Tox eq.)**

Aggregated result by comparative seriousness

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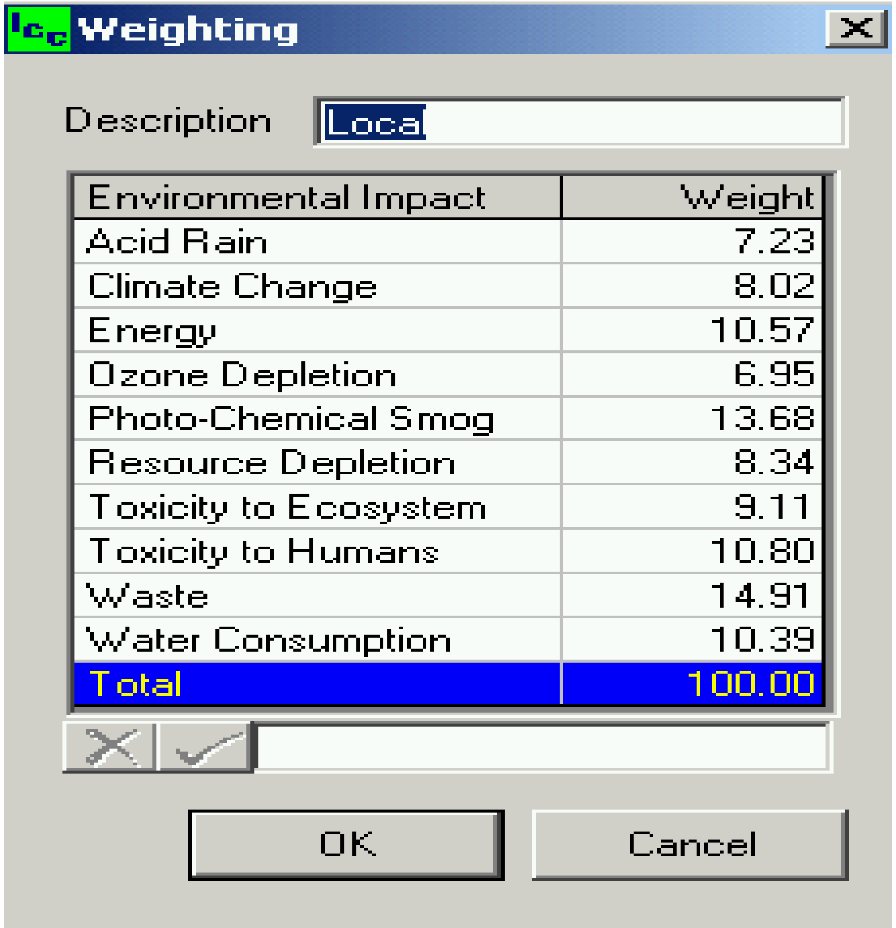
LCA; weighting environmental impacts



Environmental Impact	Weight
Acid Rain	7.23
Climate Change	8.02
Energy	10.57
Ozone Depletion	6.95
Photo-Chemical Smog	13.68
Resource Depletion	8.34
Toxicity to Ecosystem	9.11
Toxicity to Humans	10.80
Waste	14.91
Water Consumption	10.39
Total	100.00

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2^{nd} LCA + LCC study

HKHA new harmony block study

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2^{nd} LCA + LCC Study for HKHA

- New Harmony Block (Option 2)

- LCA - quantifies life-cycle environmental impacts.
- LCC – quantifies life-cycle cost implication.
- The decision-making tool quantitatively measures:
    1. environmental impacts; and
    2. cost implications
- of selecting from 110 alternative materials/ product specification choices.

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computer model – TASC

tool for the **a**ssessment of **s**ustainable **c**onstruction

- decision making tool
  - used by design teams for evaluating alternative proposals
  - allows cost and environmental impacts to be compared together
  - compares proposed alternatives against the “base building”
  - includes line of acceptability
  - delivers results in hours

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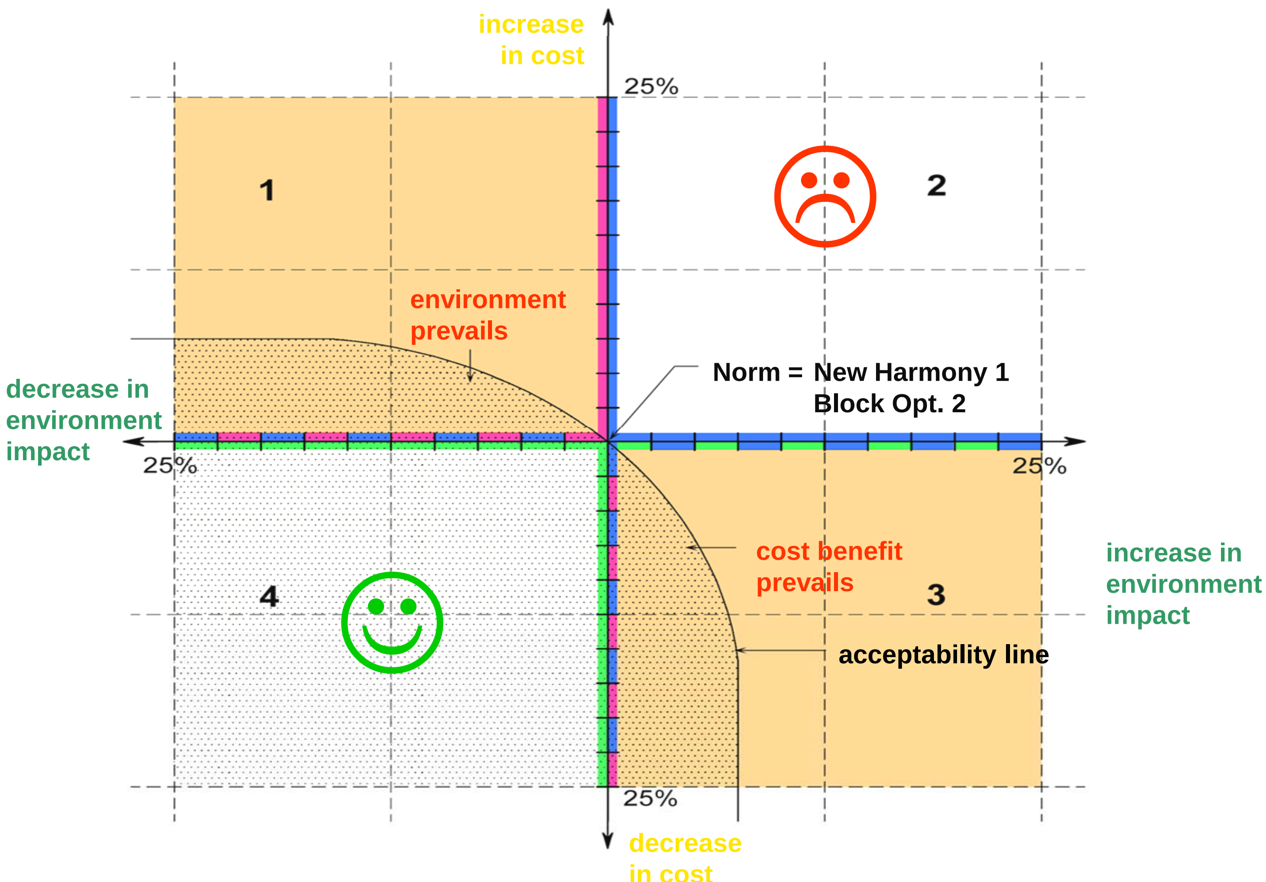
decision making tool



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LCA validation carried out

- **peer review**
  - LCA Methodology - Reviewed by DHV and BRE
  - LCA Data Treatment - reviewed by BRE
  - LCC Methodology - reviewed by BRE
  - weighting Methodology - Reviewed by DHV and HKU psychology dept.
  - operational Modeling - Reviewed by WSP

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findings

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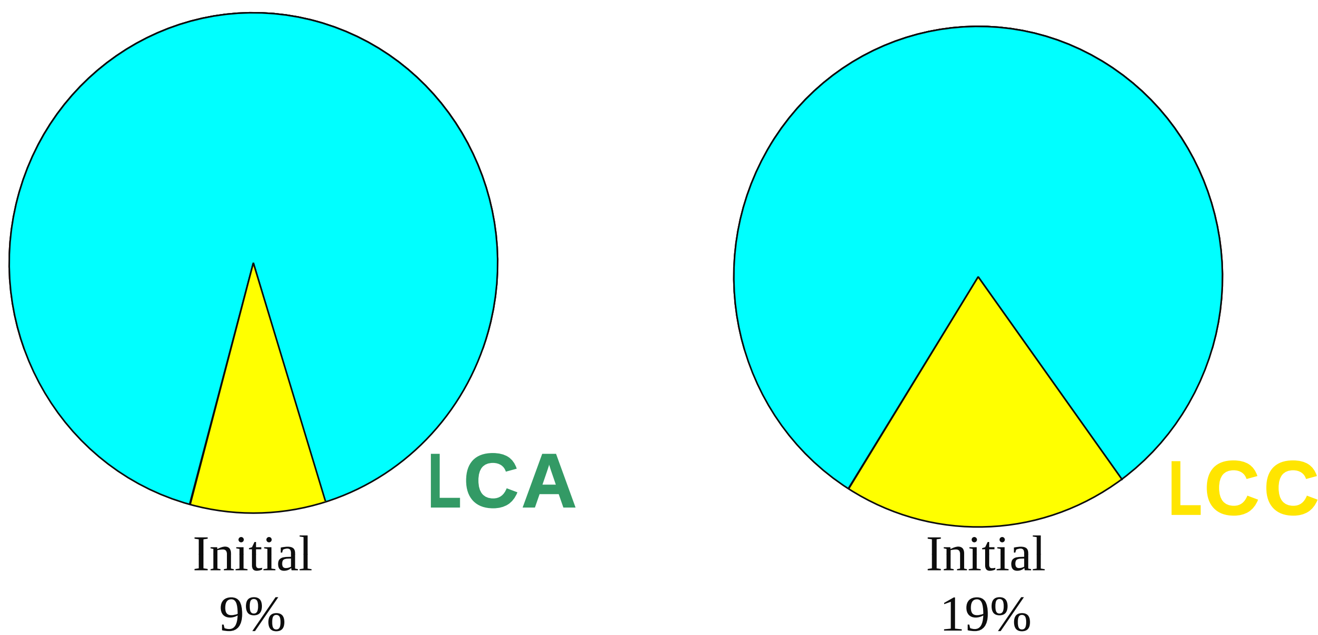
key findings

- The **initial environmental impact** at construction stage is about **9%** of the whole of the 55 years life span
- The **initial construction cost** is about **19%** of the total **LCC** profile



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key findings

- most costly elements for HKHA are the maintenance and refurbishment costs
- architectural items are of relatively low initial cost and environmental impact, but high recurring impact during the building's operational life
- tenant energy impacts are a large proportion of the total, but HKHA have little direct control over these areas…
- or do they?

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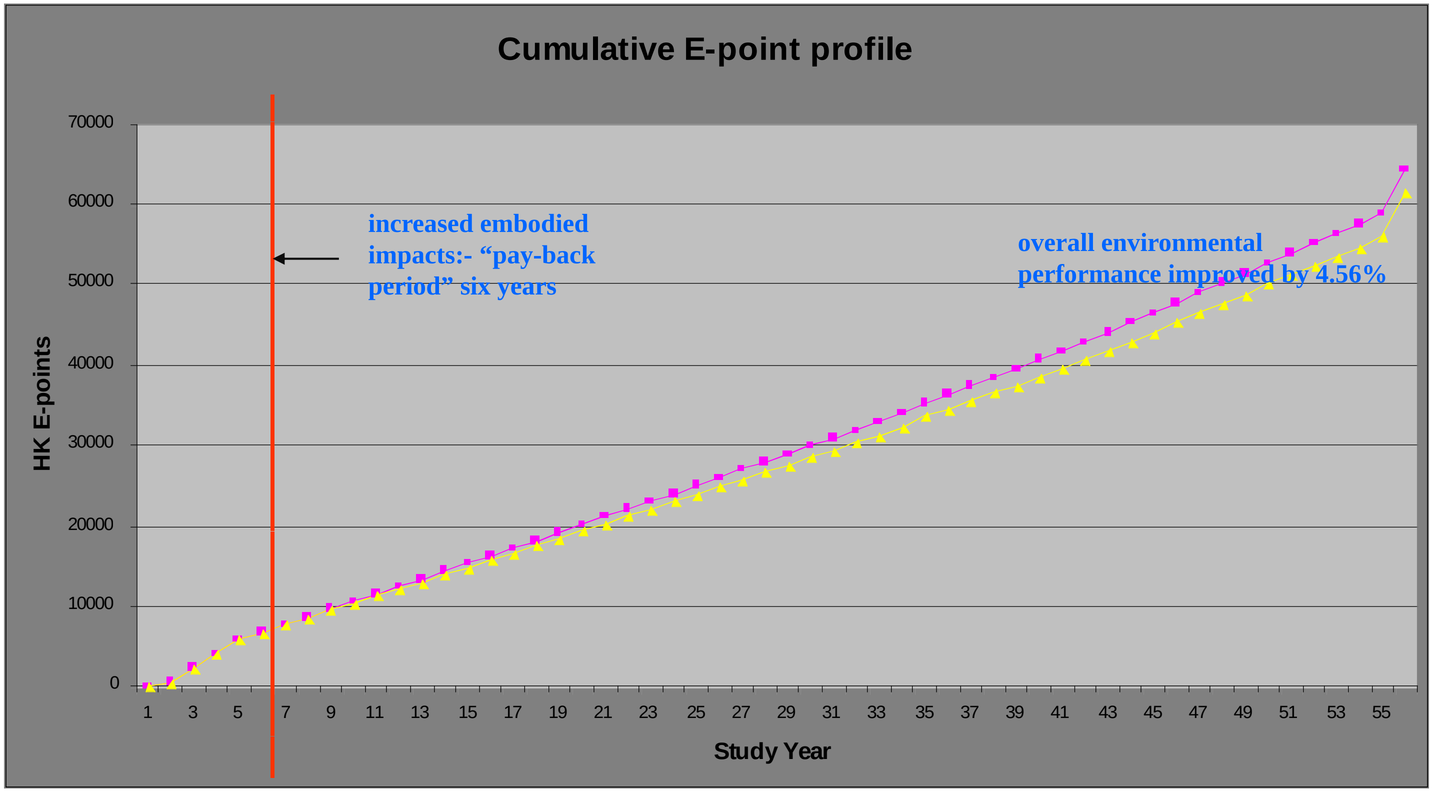
benefit of inclusion of 75mm external thermal insulation



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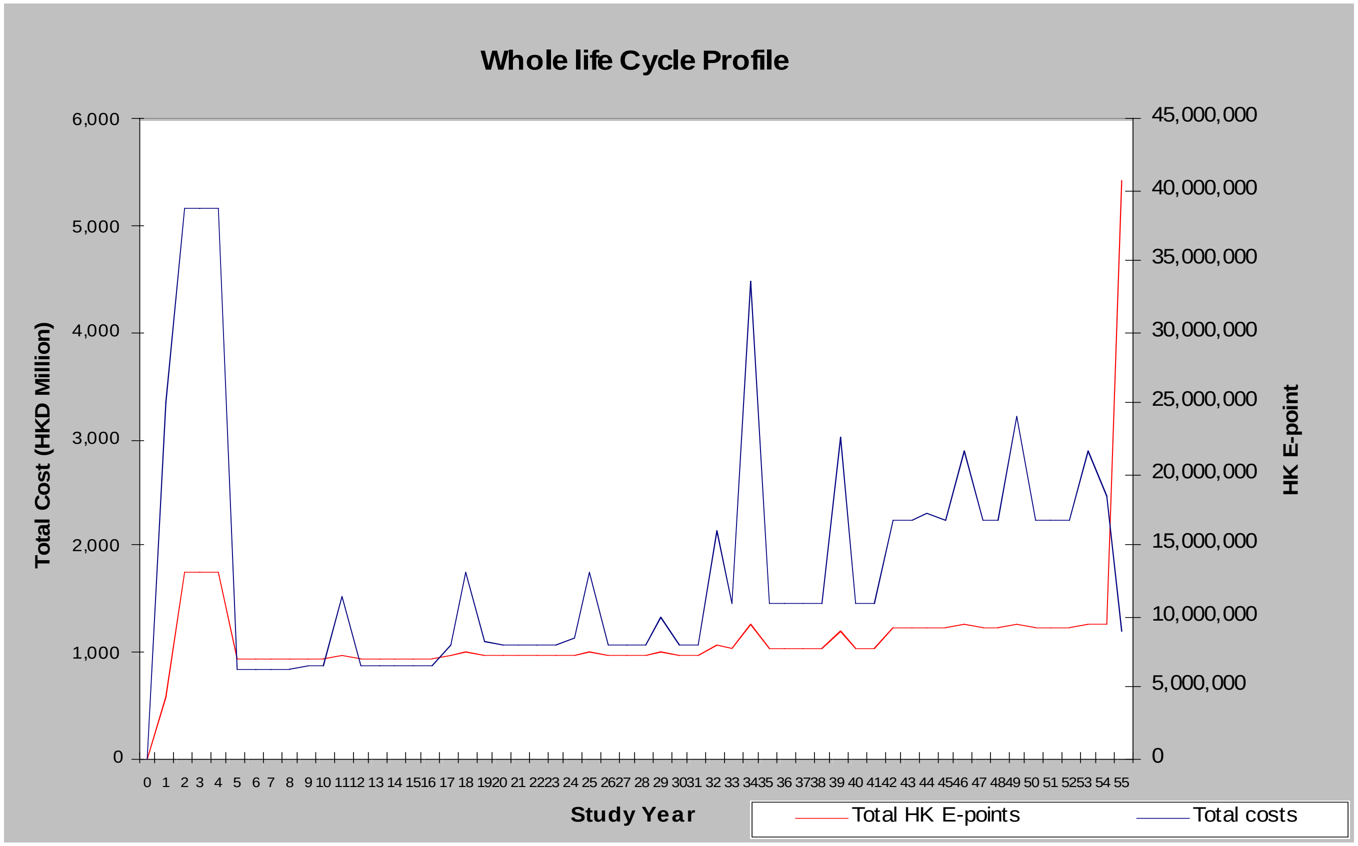
lifecycle profile of annual costs + environmental impacts



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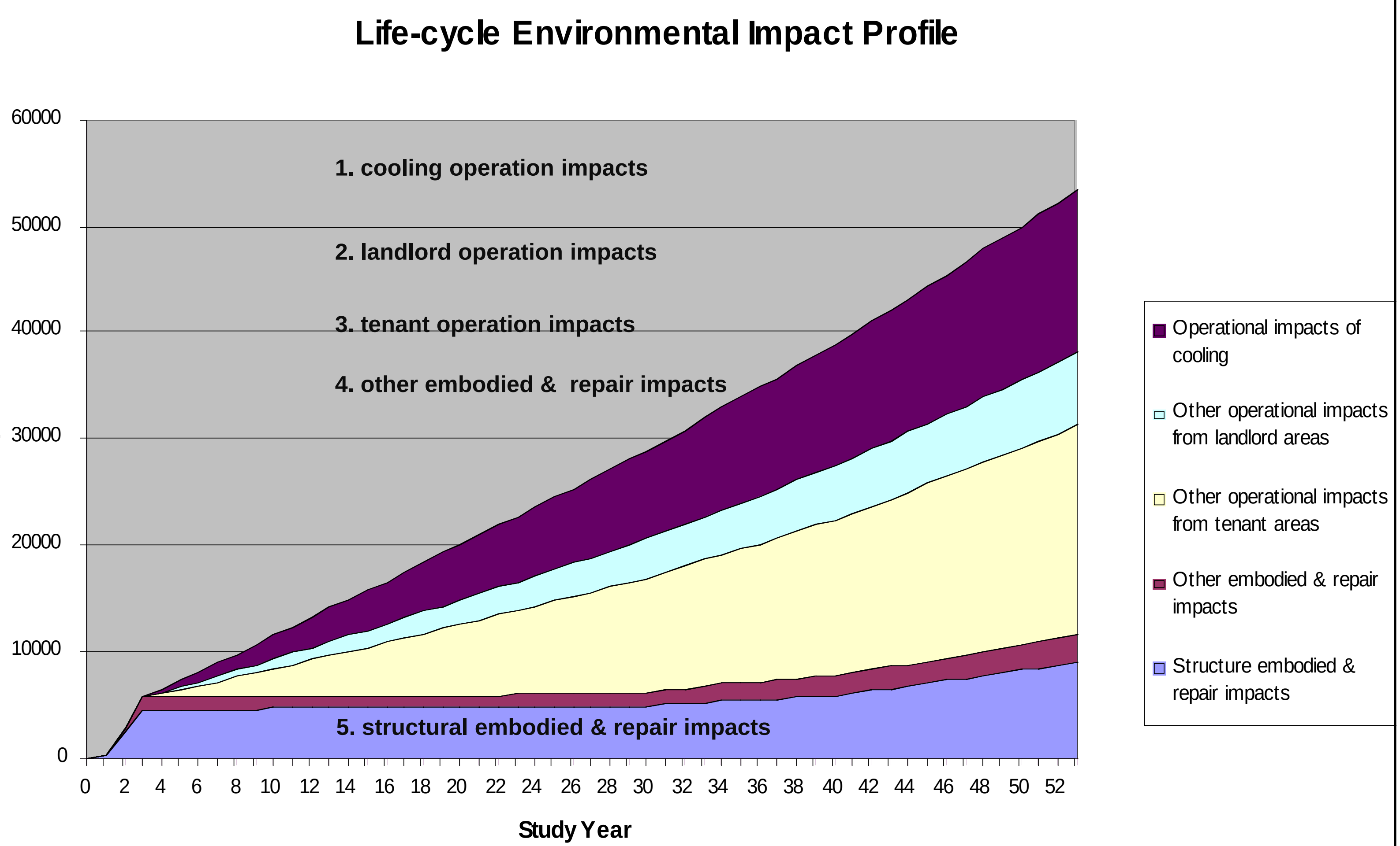
detailed analysis of HKHA block



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alternative designs / materials

non-viable alternatives studied or dubious alternatives

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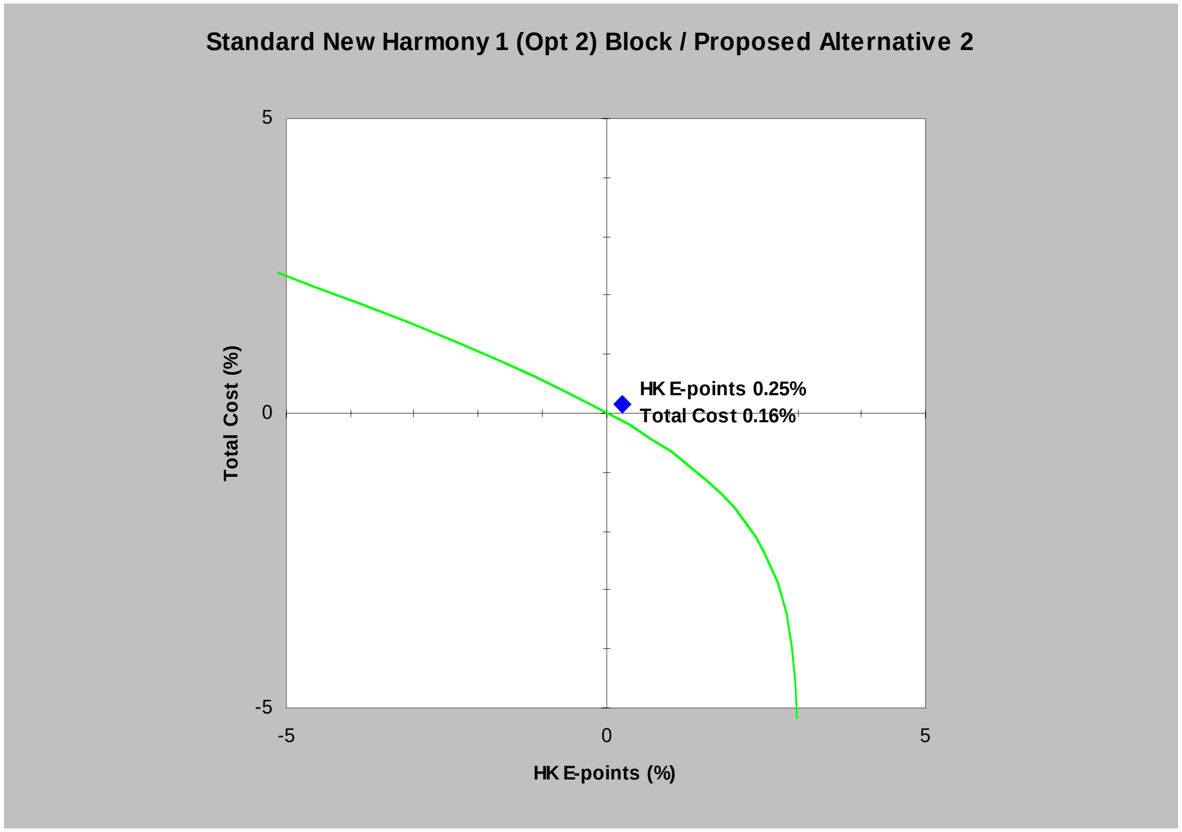
Ordinary Poland Cement Panel Wall to gypsum stud wall



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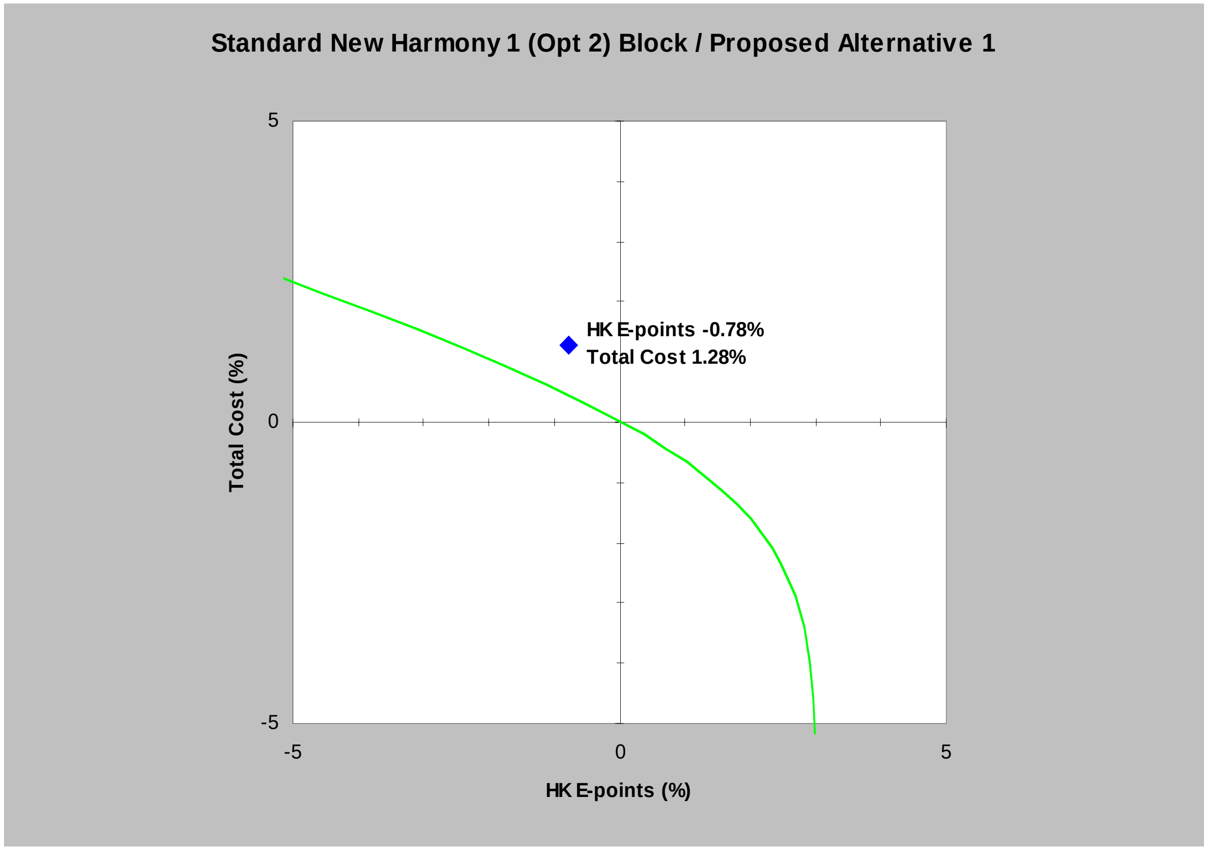
aluminium to PVC-u windows



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viable alternatives

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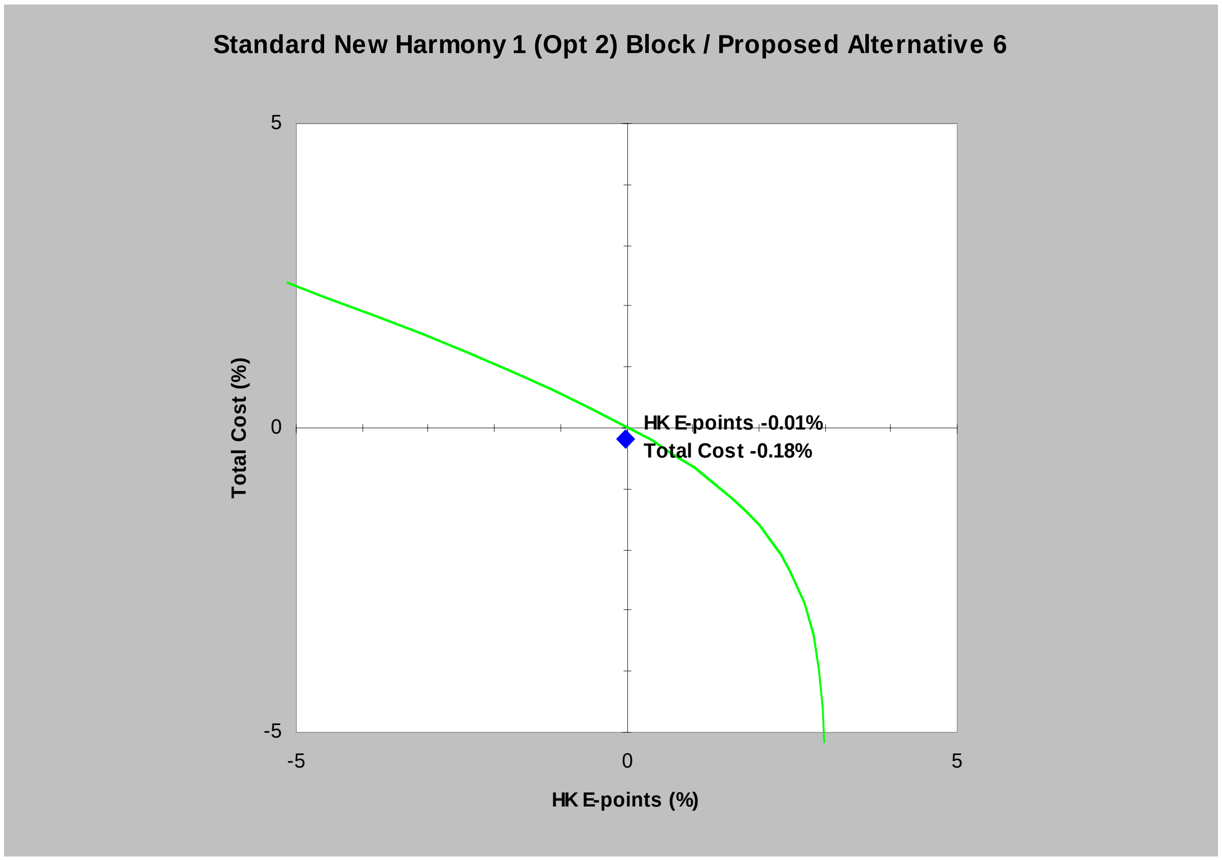
softwoods entrance doors & kitchen doors



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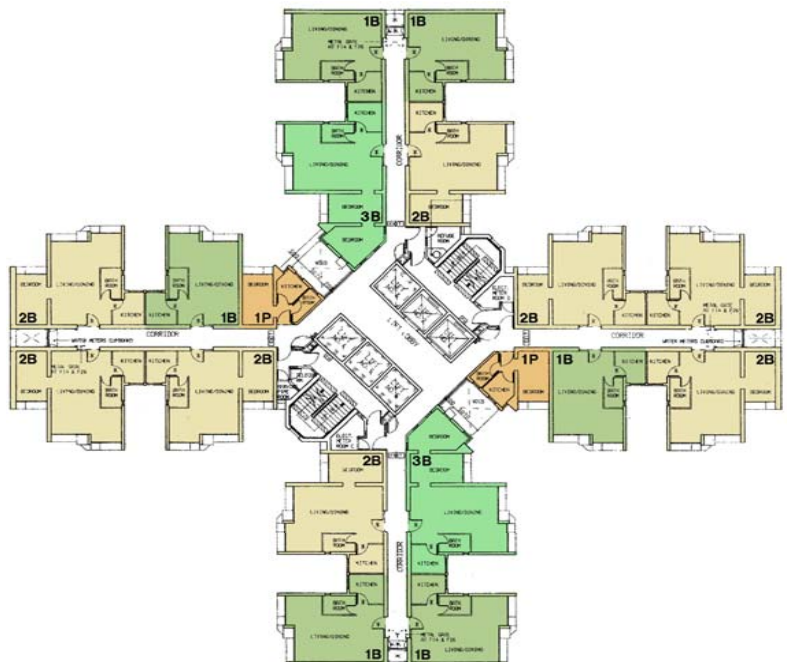
some conclusions

- optimizing structure key to reducing overall **LCA** impacts
- occupancy influences **operational energy**



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other applications

HK science park phase II
life cycle costing discussion paper

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PV systems

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PV system life cycle costing analysis

HK$	Roof PV System	Façade PV System
Capital Cost	**HK$15,800,000.00**	**HK$ 19,700,000.00**
Saving in electricity + carbon tax (per annum)	**HK$ -188,893.24**	**HK$-111,484.35**
Maintenance Costs (per annum)	**HK$10,000**	**HK$10,000**
Payback Period	**80 years**	**163 years**

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water recovery systems

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water recovery life cycle costing analysis (25 year period)

HK$	grey water system	rainwater & condensate system
Extra Capital Cost	**HK$3.5m**	**HK$4.0m**
Saving in Water (m^3)	**64,800m^3**	**155,000m^3**
Saving in Water (HK$)	**HK$-8.4m**	**HK$-19.9m**
Operating Cost	**HK$1.0m**	**HK$1.5m**
Maintenance Costs	**HK$0.2m**	**HK$0.3m**
Whole Life Cycle Costs	HK$-3.7m	HK$-14.1m
Payback Period	24 years	8 years

A Rainwater & Condensate System with a capital cost of HK$4m which saved 90,000m3 water per annum would have **a 10 year payback period.**

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the move to CO_2e + recent development

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the move to CO_2e + recent development

1. the move to CO2e as the main environmental impact measured
2. benchmarking of archetypes
3. the carbon ready reckoner
4. timber and other ‘natural products’

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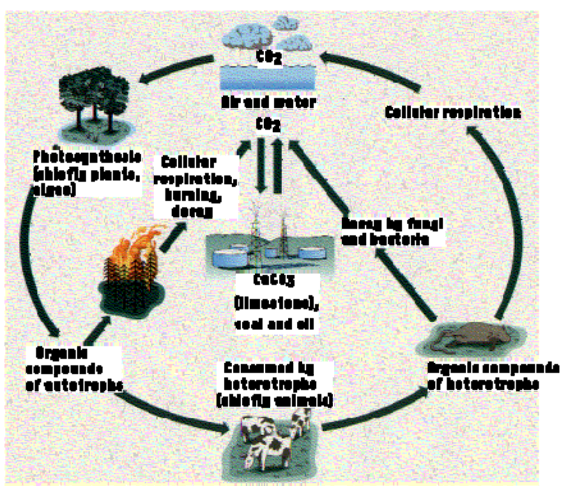
why carbon is important

climate change - now viewed as the single most important environmental impact

- climate change has already begun to affect our lives through increases in the frequency and severity of **extreme weather events**, global warming etc.
- the cost of coping with or **adapting to a new climate is greater than the cost of reducing carbon emissions**.
- this point is made by the Stern Report 2006, which provided robust economic evidence to support the need for action **now** to cut carbon emissions.



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construction CO_2e context

- UNEP have identified the **building sector** as a very important area to help reduce carbon.
- the UN consider the built environment to be responsible for **35 - 50% of total energy use** and associated GHG emissions in both developed and developing countries.
- energy is mainly consumed during the operational stage of buildings, for heating, cooling, ventilation, lighting, small power loads etc.
- a smaller percentage of energy, estimated to be 7.5 - 20% is used for material manufacturing, material transportation, construction and demolition of building and civil engineering.
- CO_2e is a very good proxy for other environmental impacts like acidification, smog etc. simplifying LCA methodology.

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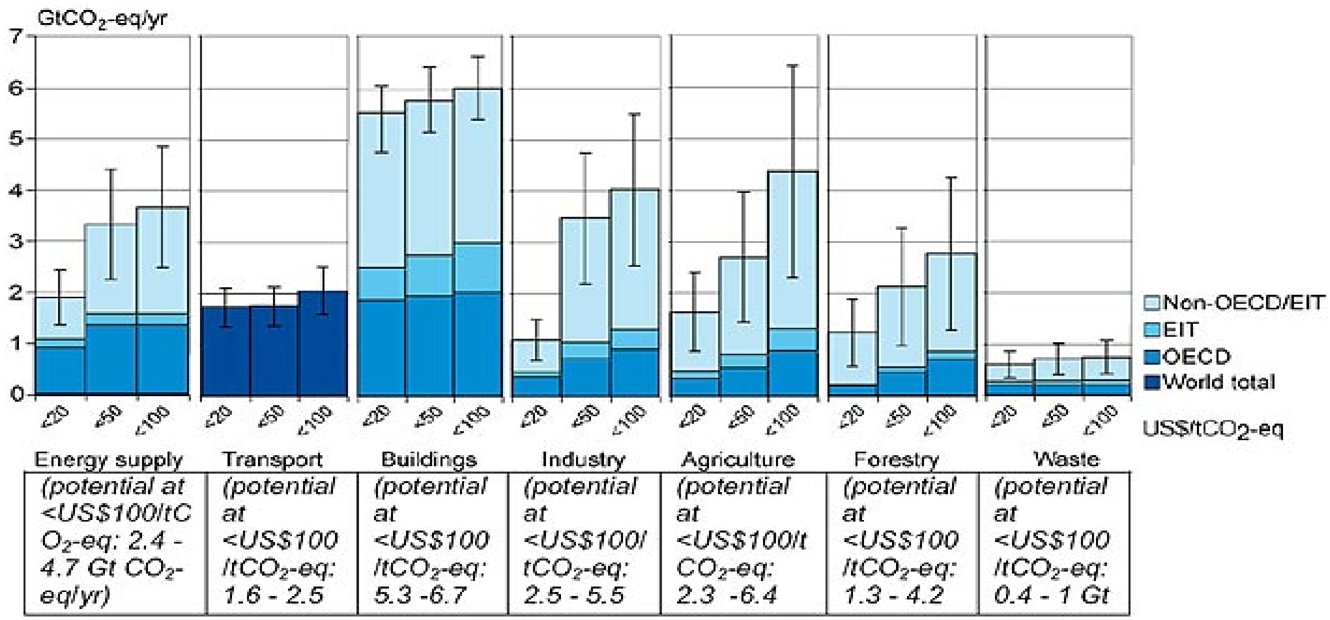
UNEP….1

- the diagram from IPCC AR-4 indicates that the significant potential for energy efficiency improvements and greenhouse gas emission reduction from buildings is common among developed and developing countries, as well as in economies in transition.
- the challenge is therefore to design mechanisms that will redirect the economic savings associated with emission reduction in buildings so as to offset the increased investment costs for energy emission reduction measures.



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UNEP….2

the UNEP report states there is not enough being done in the construction sector, due to the following:

- fragmentation of the building sector,
- split economic interests, design team, client, constructors, tenants, users etc.
- lack of information and understanding through out the industry,
- perceived high risk and under estimation of the lifecycle cost benefits from energy efficiency investments in buildings,
- energy costs are often a comparatively small part of the overall cost of the building operation
- procedural difficulties of apply for grants, advice etc.

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UNEP….3

a number of countries have however applied different policy tools with the explicit objective to reduce energy consumption and greenhouse gas emissions in buildings.

- the report assessed a number of of policy instruments for reducing greenhouse gas emissions from buildings (UNEP 2008) - 80 case studies in 52 countries comparing 20 types of policy instruments :
  - regulatory,
  - fiscal,
  - economic and capacity building measures.
- many achieved high savings at low or even negative costs for society.
- regulatory instruments such as building codes were revealed as the most effective and cost effective category of instruments in this study if enforcement can be secured.

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UNEP….4

- the CDM, defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries.
- it has been difficult to apply the CDM to the construction sector due to complexity and administrative cost e.g. only 6 of more than 3,000 projects in the CDM pipeline are related to energy efficiency in buildings.
- such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO2, which can be counted towards meeting Kyoto targets.
- the mechanism is the first global, environmental investment and credit scheme of its kind, providing a standardized emissions offset instrument, CERs.
- it is hoped that at the forthcoming UNFCC meeting of the parties in Copenhagen in December this year that the CDM procedures will be simplified to allow easy application of the CDM to construction projects.

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other initiatives around the world

recently various zero or low carbon initiatives have taken place around the world to combat the impacts of carbon emissions.

- concept for buildings to become carbon neutral through a transparent process of measuring/calculating emissions.
- the Code for Sustainable Homes, in the UK - zero carbon by, 2013 & 2016
- in many countries, new eco towns and cities have been built with the intention of producing zero carbon and creating a better quality of life for the occupants.
- some examples of projects built or underway are: BedZed, South London designed by Bill Dunster, Dongtan, China and Masdar, Abu Dhabi.

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Carbon as a measure of sustainability

- Building accreditation systems encourage sustainable aspects in the building design by point systems.

point systems do not quantify the environmental impacts of the buildings; really they signify the level of the environmental focus of the building design

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the move to CO_2e + recent development

benchmarking of archetypes

1. simple calculation of building or civil engineering footprints is rather meaningless without benchmarks that can easily establish good, average and poor performance

2. it may seem surprising but there are approximately only 20 - 25 building/civil engineering structures that can be used to represent a large city such as Hong Kong

3. carbon benchmarks for each archetype can be established for both embodied and operational impact assessment of new and existing buildings providing targets for designers and FM operators

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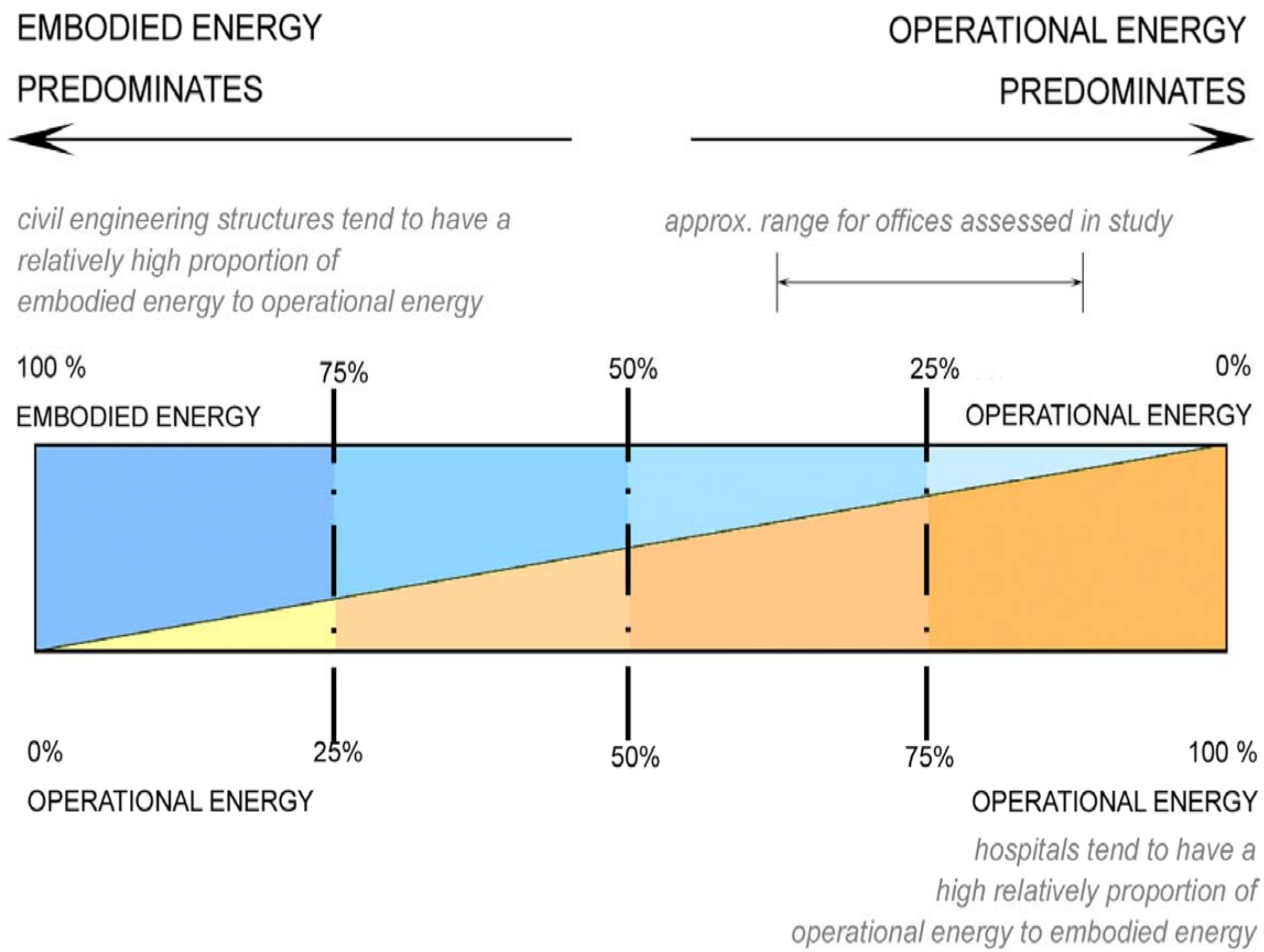

Proportional relationship between embodied and operational energy for building types

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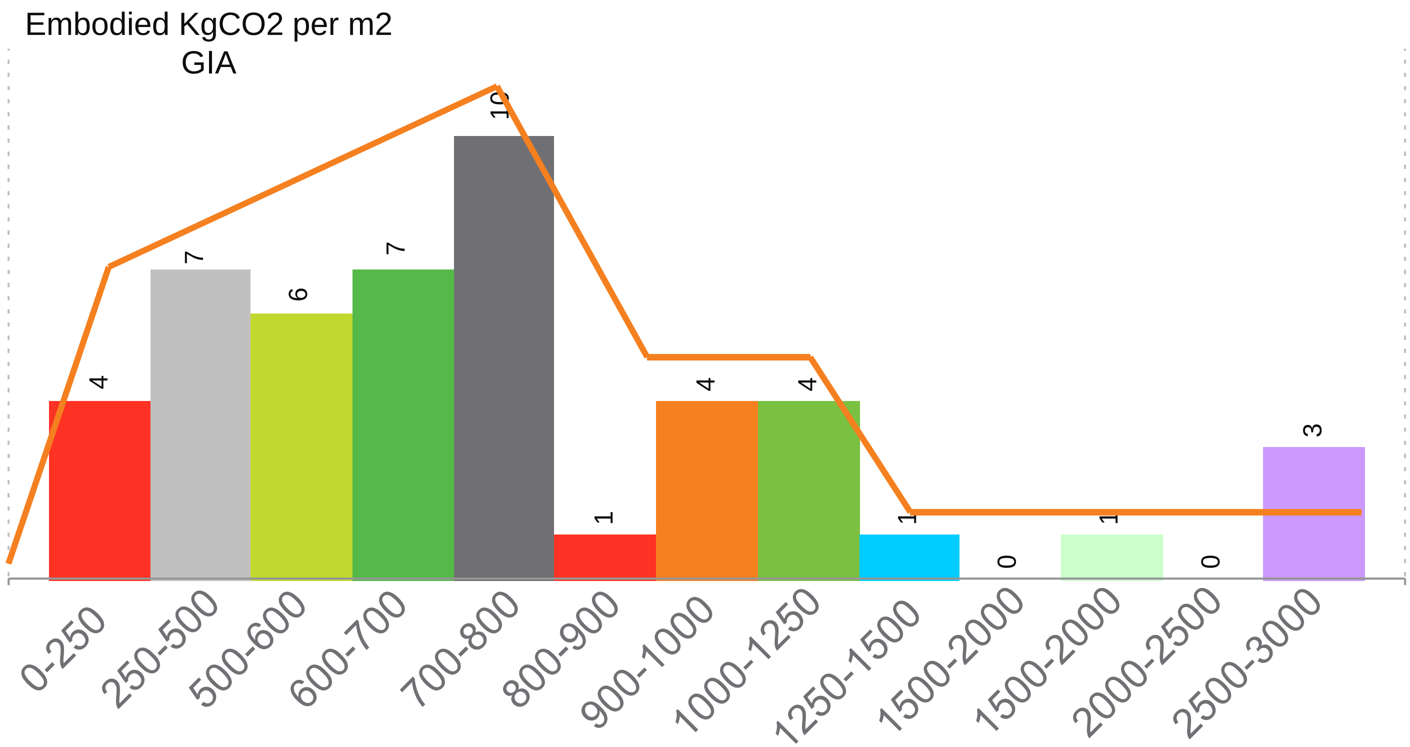
Embodied CO_2 benchmarking with CRR

CRR frequency distribution of all projects entered by Davis Langdon



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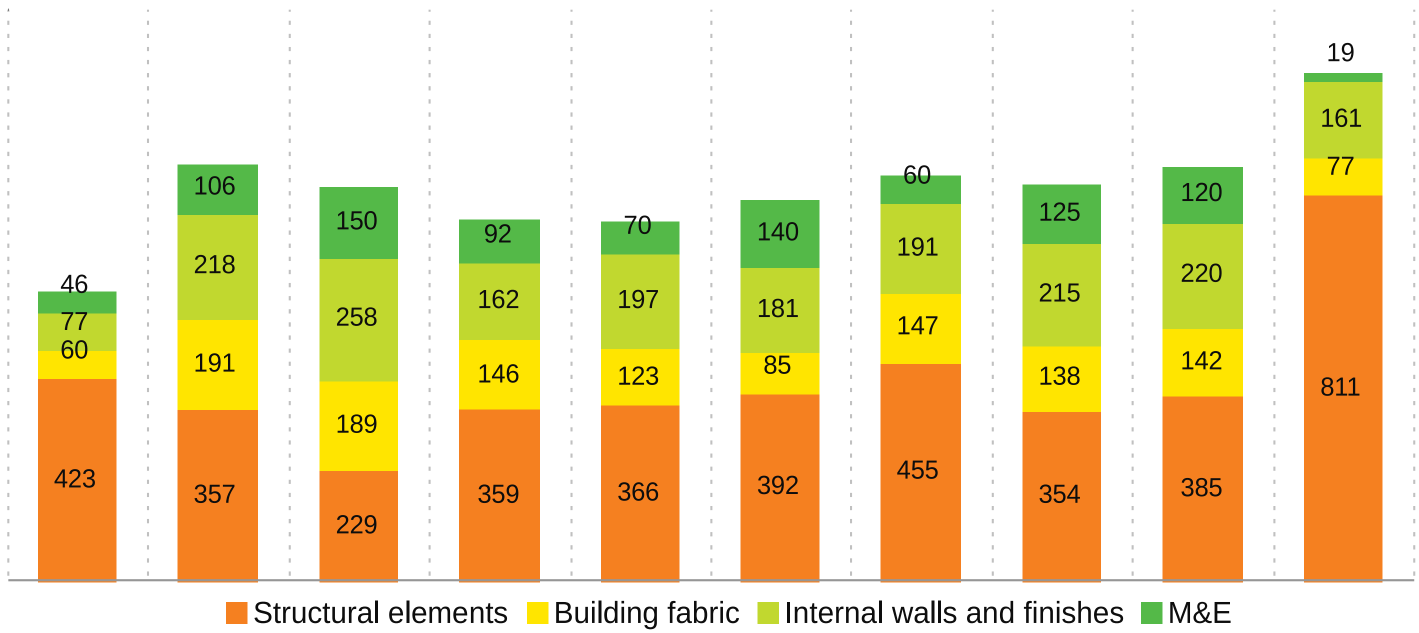
Offices CO_2 emissions study - Findings

- Embodied CO_2 of 10 different office projects from the same developer

Embodied $kgCO_2$ per m^2 GIA



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the move to CO_2e + recent development

- the carbon ready reckoner

an early design stage carbon calculator that can provide the design team with a detailed embodied CO_2e assessment of the building/civil engineering structure in sufficient time to inform the design process

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Carbon as a measure of sustainability

Building Carbon Footprint

Operational CO_2 | **Embodied CO_2**

- Traditionally, operational CO_2 dominated the whole-life carbon emissions of a building.
- With financial incentives and strict regulation, operational emissions are becoming insignificant.
- Many buildings today are designed to be carbon neutral.
- In the UK it costs £12 on average to offset one tonne of CO_2.
- The UK shadow price of carbon is currently £26.50

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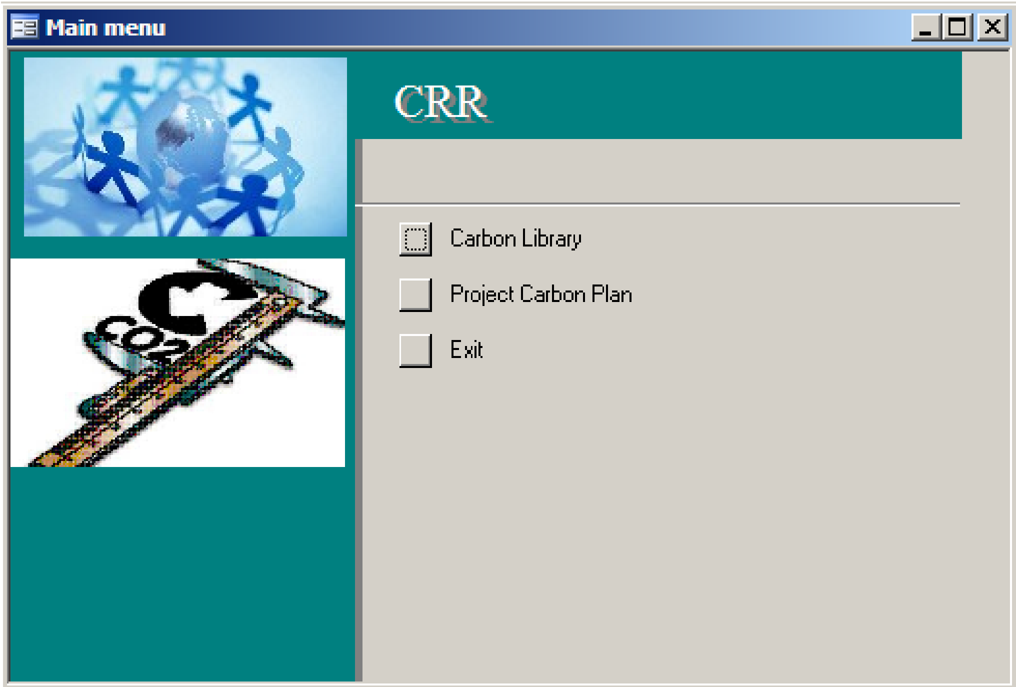
Carbon ready reckoner

Carbon Ready Reckoner

Davis Langdon developed a tool that can answer these questions.



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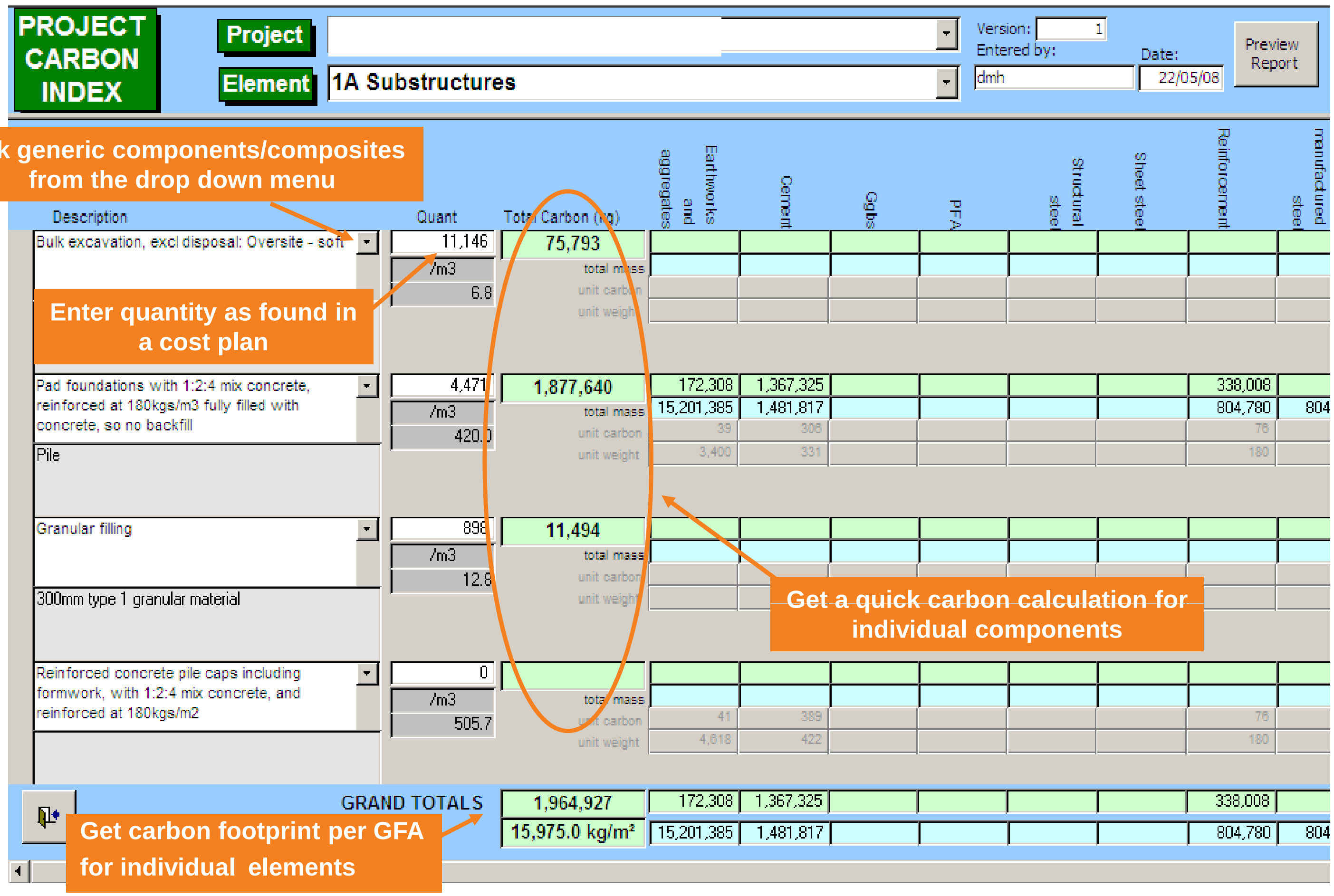
Carbon Ready Reckoner



Carbon Ready Reckoner

- A number of office buildings were entered into CRR during a benchmarking exercise.
- Davis Langdon is due to deliver embodied CO_2 estimates along with its cost plans using CRR in the near future.

Carbon Index

Project: XXXX Borough Council

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	Quantity	Total Carbon (kg)	kg/m² GIA
5K Protective installation			
Sprinkler system	12470 m2	141,609	11.4 kg/m²
5K Protective installation total carbon (kg)		141,609	11.4 kg/m²
6A Site works			
Hard landscaping	3811 m2	265,722	21.3 kg/m²
Tarmac with limestone chippings grade suited to car park areas	132 m2	1,315	0.1 kg/m²
6A Site works total carbon (kg)		267,037	21.4 kg/m²
6B Drainage			
Manholes	20 nr	47,369	3.8 kg/m²
Drainage	500 m	36,667	2.9 kg/m²
6B Drainage total carbon (kg)		84,037	6.7 kg/m²
Project XXXX Borough Council		10,229,891	820.4 kg/m²

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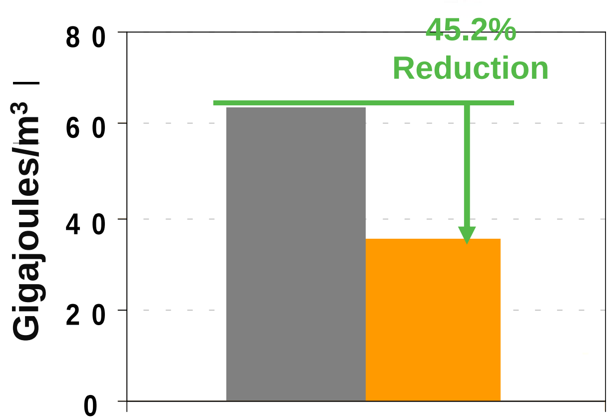
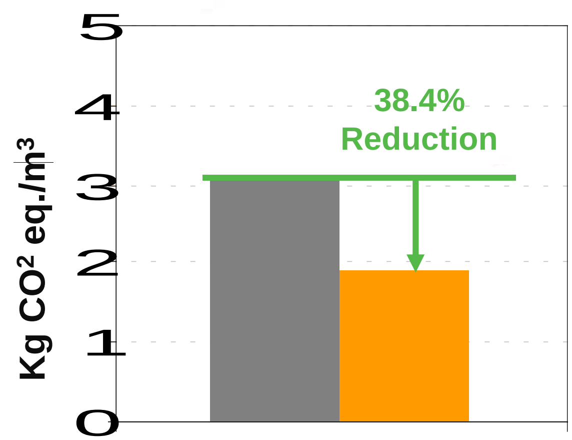
Alternative Structural Frames

Embodied Energy Mitigation by Alternative Glulam&Precast Concrete Frame



Global Warming Impact Mitigation by Alternative Glulam&Precast Concrete Frame



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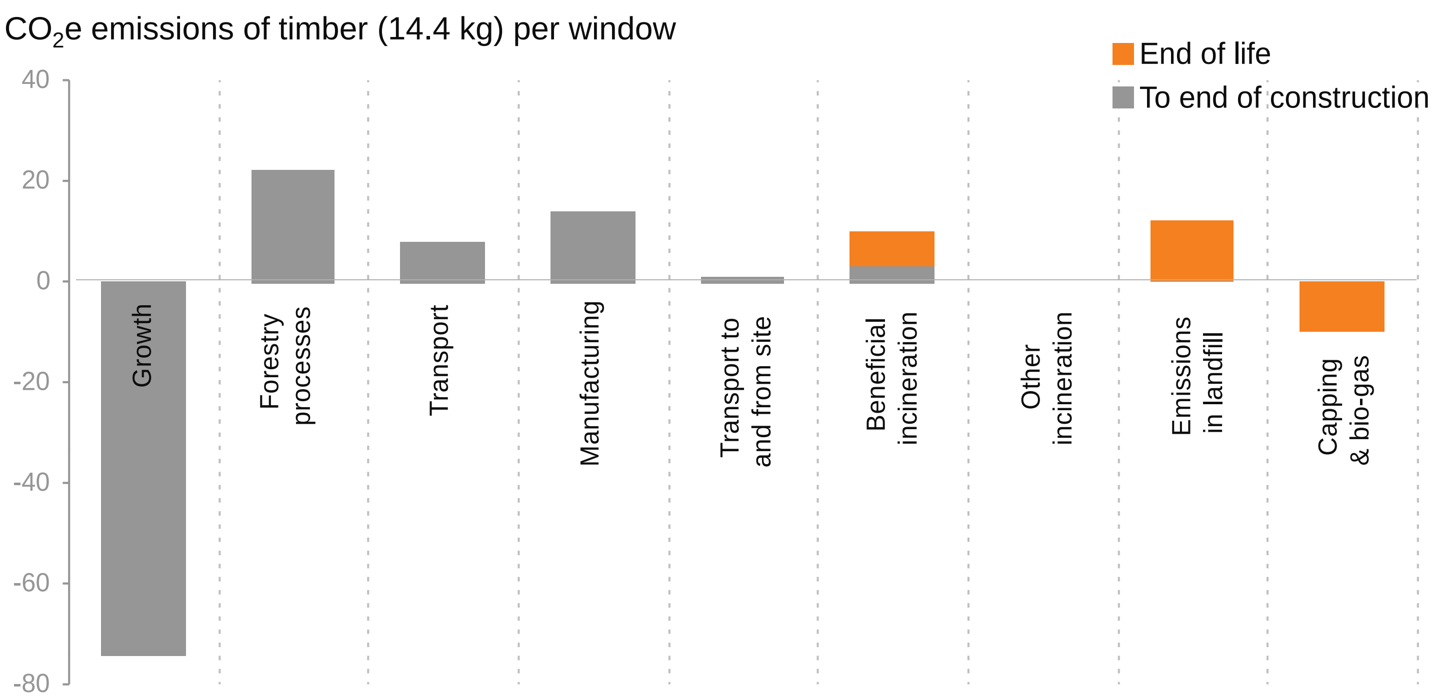
Comparison of Life Cycle Assessment of CO_2e for windows

CO_2e emissions for the timber part of a wood window



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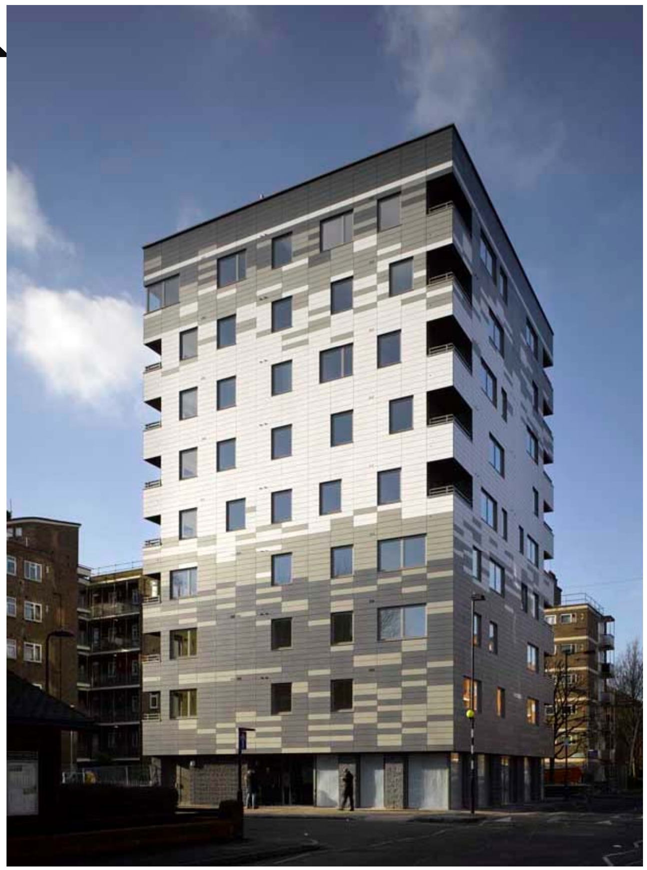
STADTHAUS, 24 MURRAY GROVE ARCHITECTS: WAUGH THISTLETON & STRUCTURAL ENGINEERS: TECHNIKER

Global construction consultants

the move to CO_2e + recent development

timber and other 'natural products' are the future eco materials



bamboo the most rapidly CO_2 sequestering material together with cork and other rapid renewable materials potentially have very low or negative CO_2e values

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THANK YOU

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