The Application of Elemental Embodied Carbon Prediction Model for Buildings

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Outline

- Background
- Carbon hotspots
- Research method
- Findings
- Proposed EC Model
- Conclusions

Embodied Carbon vs. Operational Carbon

Operational Carbon

Emissions from the energy consumption during the operation of the building – Regulated and Unregulated

E.g. HVAC, Lighting

Control measures

Zero OC – Zero regulated emissions

Embodied Carbon

Emissions from energy consumption and chemical processes

E.g. material extraction, manufacturing, transport, etc.

EC (not controlled)

EC vs. OC

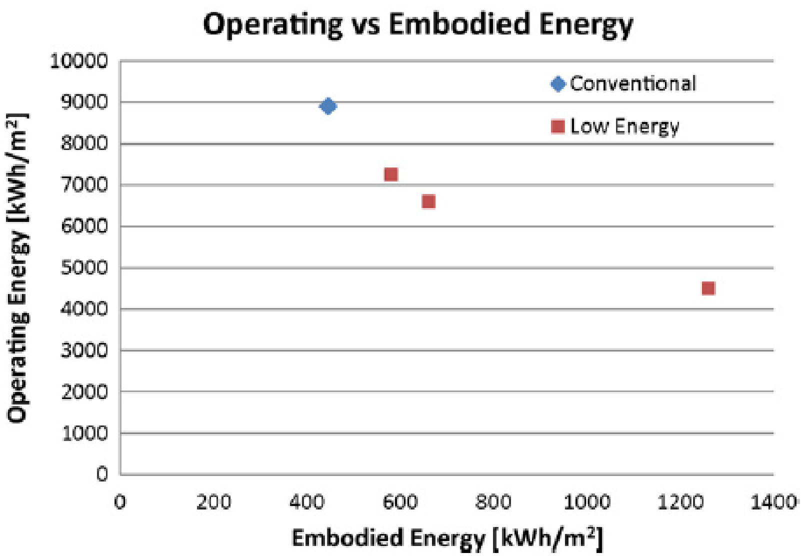


Figure: Operational and embodied energy for case studies (Source: Ramesh et al., 2010)

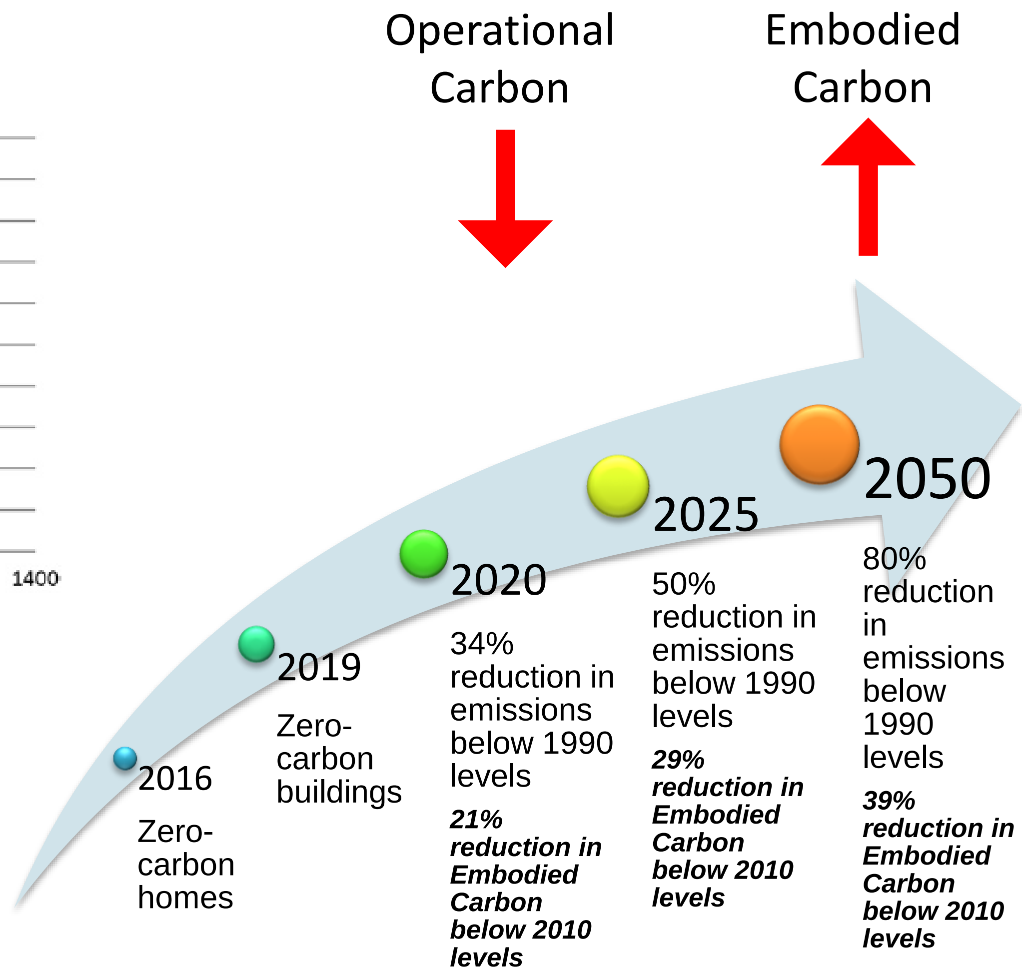
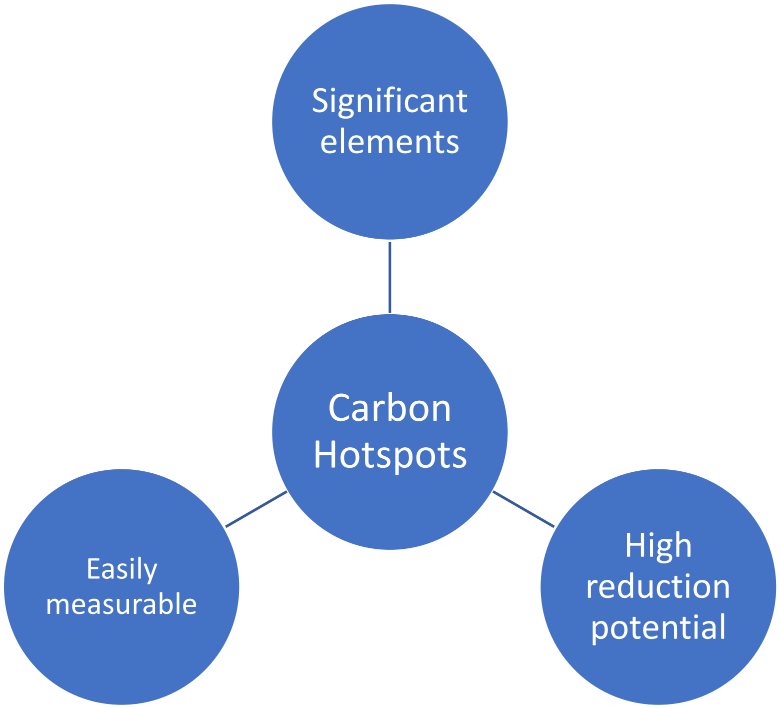


Figure : 2050 low carbon trajectory – UK (From: The Green Construction Board, 2013)

BACKGROUND

- Embodied Carbon (EC) in buildings is well acknowledged.
- There are numerous tools and methods to estimate EC right from the beginning of a construction project. However, each tool has its own pros and cons.
- Using Element Unit Rates (EC-EUR) and Element Unit Quantity (EUQ) can be a good approach to estimate EC during early stages of design.
- This is made possible by identifying carbon hotspots in buildings and developing EC-EURs for different specifications of the carbon hotspots.

CARBON HOTSPOTS



Carbon Critical Element

80:20 Pareto Rule

Case studies

- Monahan and Powell (2011) modelled a two storied residential building (in the UK) in three different scenarios – timber frame and larch cladding, timber frame and brick cladding, conventional masonry cavity wall.
- Substructure, external walls and roof were identified as the carbon hotspots in the building – timber frame and larch cladding (elements contributing 81% of EC)

Timber frame and larch cladding	Timber frame and brick cladding	Conventional masonry cavity wall
Baseline	+32% of EC	+51% of EC

- The difference in EC was attributable to the difference in foundations and external walls

Case studies

- Shafiq et al. (2015) studied a two storied office building in Malaysia by modelling six different scenarios for structural composition using Building Information Model (BIM)
- Only few elements were studied including foundation, beams, slabs, columns and staircases
- Different grades or classes of concrete and steel were combined to generated different composition which resulted in different material quantities producing varying EC
- EC reduction of up to 31% was achievable by using different grades or classes of concrete and steel

Research method

1. Obtain EC analyses of office buildings (28 buildings)
2. Group elements in accordance with NRM element classification
3. Calculate the % contribution of each element total
4. Arrange elements in descending order as per the group elemental total of EC
5. Identify the elements responsible for 80% of EC emissions for each individual building

Research method

Identifying carbon hotspots of a building – an example

Building Elements (NRM compliant)	Embodied Carbon % (in descending order)	Cumulative Embodied Carbon%
2A Frame	38.54	38.5
2E External walls	20.30	58.8
5 Services	13.82	72.7
1A Substructures	9.90	82.6
2B Upper floors	6.71	89.3
2C Roof	3.94	93.2
2D Stairs	2.44	95.7
2G Internal walls and partitions	1.66	97.3
3B Floor finishes	1.50	98.8
4A Fittings and furnishings	0.43	99.2
3A Wall finishes	0.34	99.6
2H Internal doors	0.32	99.9
3C Ceiling finishes	0.09	100.0
2F Windows and external doors	0.01	100.0

Research method

Building ID	1A Substructures	2A Frame	2B Upper floors	2C Roof	2D Stairs	2E External walls	2F Windows and external doors	2G Internal walls and partitions	2H Internal doors	3A Wall finishes	3B Floor finishes	3C Ceiling finishes	4A Fittings and furnishings	5 Services
#D1001	x	x				x								x
#D1002	x	x				x								x
#D1003	x	x	x			x								
#D1004	x	x				x								x
#D1005	x	x				x								x
.														
.														
.														
.														
#D1028	x	x	x			x								x
Probability of occurrence	0.9	1	0.6	0.1	0	0.8	0.11	0	0	0	0.2	0	0	0.9

Key Findings

- Frame was found to be a hotspot in all the buildings.
- Substructure and Services were found to be hotspots in 90% of the buildings.
- External Walls were found to be a hotspot in 80% of the buildings in the sample.
- Stairs, Internal Doors, Wall Finishes, Ceiling Finishes and Fittings and Furnishings were not found as hotspots in any of the buildings.
- Rest of the elements were found to be hotspots in some of the buildings.

Key Findings

Descriptive statistics of the sample (28 buildings)

36% of elements responsible for 80% of EC

Element	Average EC per GIFA ($kgCO_2$ per m^2)	Minimum	Maximum	Standard Deviation	Cumulative EC %
2A Frame	236.72	98.00	486.41	101.13	30.1
1A Substructures	137.20	33.21	320.72	65.31	47.5
2E External Walls	111.24	8.37	265.80	63.35	61.6
5 Services	106.81	6.63	192.88	50.16	75.2
2B Upper Floors	75.99	1.72	191.08	38.68	84.8
3B Floor Finishes	37.69	0.39	97.77	28.82	89.6
2C Roof	25.05	2.88	103.25	19.69	92.8
2G Internal Walls and Partitions	20.14	1.19	64.37	15.97	95.3
2F Windows and External Doors	15.20	0.02	157.64	35.20	97.3
3C Ceiling Finishes	8.55	0.65	24.62	6.05	98.3
2D Stairs	7.00	2.47	21.46	5.01	99.2
3A Wall Finishes	3.65	0.22	18.47	4.23	99.7
2H Internal Doors	1.50	0.12	7.32	1.79	99.9
4A Fittings and Furnishings	0.86	0.02	3.39	1.15	100.0
EC of the building	785.31	431.61	1,368.17	215.92	

Organisers:

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Proposed EC model

- $EC = EUQ_{Fr}.EUR_{Fr} + EUQ_{Sub}.EUR_{Sub} + EUQ_{EW}.EUR_{EW} + EUQ_{Ser}.EUR_{Ser} + EUQ_{UF}.EUR_{UF} + k$

Frame

Substruct
ure

External
Walls

Service
s

Upper
Floors

k – Minor EC components of the rest of the elements (20% of EC emissions)

EUQ definitions of the hotspots

Elements	EUQ Definition
Frame	GIFA - area of a building measured to the internal face of the perimeter walls at each floor level (m^2).
Substructure	Area of lowest floor measured to the internal face of the external wall (as for GIFA) (m^2).
External Walls	Area of external walls measured on the inner face (excluding openings) (m^2).
Services	GIFA – same as for Frame (m^2).
Upper Floors	Area of upper floor measured to the internal face of the external wall (as for GIFA) (m^2).

Developing EC-EUR

Elements	Design options
Frame	Concrete, steel and hybrid
Substructure	Pile, raft, pad and strip
External Walls	Cavity and curtain walls
Services	Non-air-conditioned, air-conditioned – with and without BMS or lift installations
Upper Floors	In-situ concrete floors, pre-cast concrete floors, metal decking and timber floors

Developing EC-EUR

Frame	Average EC per GIFA	Minimum EC per GIFA	Maximum EC per GIFA	Standard Deviation
	$kgCO_2/m^2$			
Concrete (1)	108.51	-	-	-
Steel (14)	242.86	98.00	486.41	104.87
Hybrid (3)	230.36	191.49	291.38	53.50

Conclusions

- Carbon hotspots was identified as a good approach to predict EC during the early stages of projects; 80:20 Pareto Principle was used to identify hotspots.
- Frame, Substructure, External Walls, Services and Upper Floors were identified as carbon hotspots of the selected sample of 28 offices.
- 80:20 Pareto Rule was not supported in the research context instead the findings propose an 80:36 ratio - 80% of EC emissions in office buildings are attributable to 36% of building elements.
- There is a need for the development of benchmarks for EC-EURs of alternative design options of the identified carbon hotspots.
- Developing such EC-EURs will facilitate EC estimating during early stages of design which has the potential for huge emission reductions.

Thank you

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