



# Embodied energy LCA assessment of replacement options for windows and traditional buildings

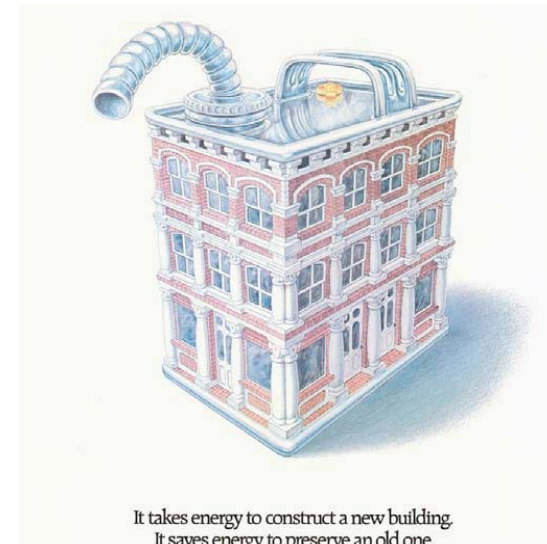
Crichton Carbon Centre and  
Small World Consulting for Historic Scotland





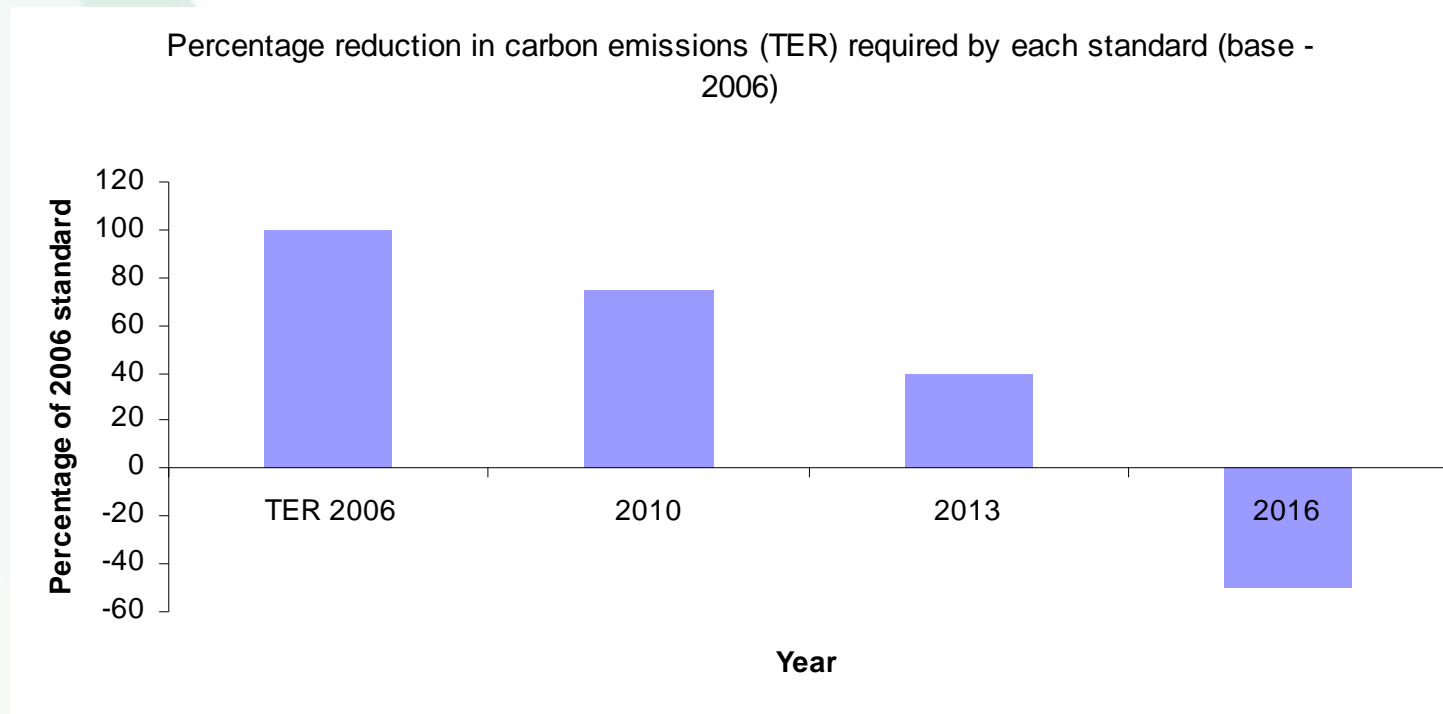
## Outline

- Sustainable Construction
- Embodied Energy and Existing Buildings
- Process Based Vs Input Output LCA
- Scope of Work
- Results and Discussion





## Drivers for Sustainability





## Sustainability in terms of housing needs to address five key areas:

Conservation of natural resources (land energy and water)

Sensible use of man-made materials

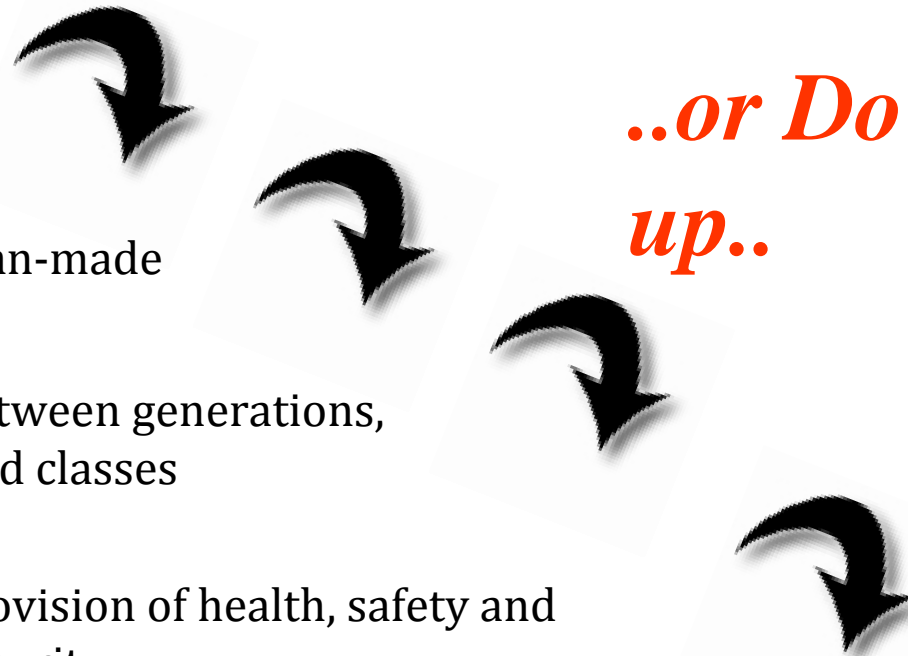
Equity between generations, people and classes

Provision of health, safety and security.

Maintenance of ecosystems and their regenerative potential

*Knock it down..*

*..or Do it up..*

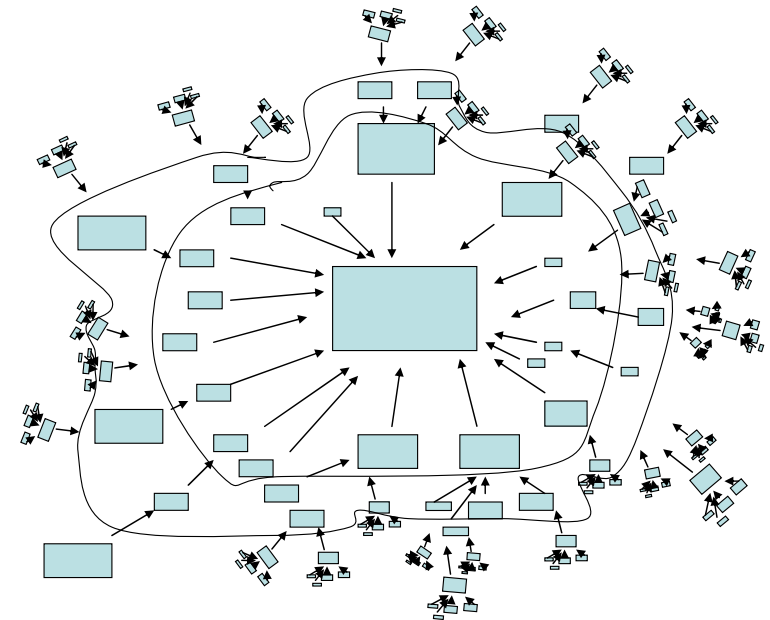




# Life Cycle Assessment Methodologies

Process based Life Cycle Analysis (LCA)

Input Output Based Life Cycle Analysis (LCA)





## Embodied Energy



The energy required to extract, process, manufacture, transport and install building materials.





## Embodied Energy

- ***Feedstock Energy:*** energy that is used as a material rather than a fuel (e.g. oil and gas can be used as a material to manufacture products such as plastic and rubber)
- ***Fuel Energy:*** energy used as a fuel (e.g. burning fuel oil or gas and therefore releasing CO<sub>2</sub> to the atmosphere).



## Embodied Energy Types

- Initial embodied energy
- Direct energy: Transportation and construction processes
- Indirect energy: Acquire, process and manufacture
- Recurring embodied energy
- Energy of building maintenance and renovation



## Dealing with Uncertainty

- An inexact science for whole buildings
- Uses estimating factors
- Should include emissions associated with fuel use **and** other process emissions
- Calculating equivalent embodied energy
- Defining Boundaries
  - Cradle to Grave
  - Cradle to Gate
  - Cradle to Site





## Aims and Objectives

- The objective of this research was to undertake a comparative assessment of various refurbishment or replacement options within a traditional rural dwelling.
- The case study chosen was a two bedroom cottage situated in the border region of Scotland.



Easter Weens Cottage



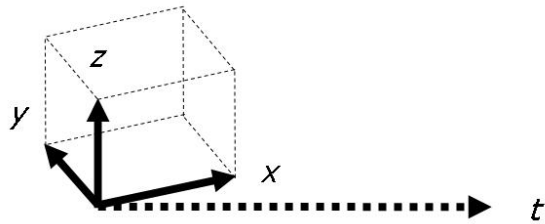
## Building Options

Option 1	Baseline	Retaining current building fabric in its current state with no intervention or improvements
Option 2	Upgrade	Undertake a comprehensive upgrade of the building form and fabric but using existing heating and lighting
Option 3	Scottish Building Standards (SBS) 2008 Compliant	Demolish and replace existing building form and fabric to SBS 2008 compliance building of comparable build type
Option 4	Code for Sustainable Homes (CSH) Level 3	Refurbishing building Code for Sustainable Homes Level 3 compliance (form and fabric only)
Option 5	Code for Sustainable Homes (CSH) Level 5	Refurbishing building Code for Sustainable Homes Level 5 compliance (all the above and renewable energy)



## 4 Dimensional Cost Modelling

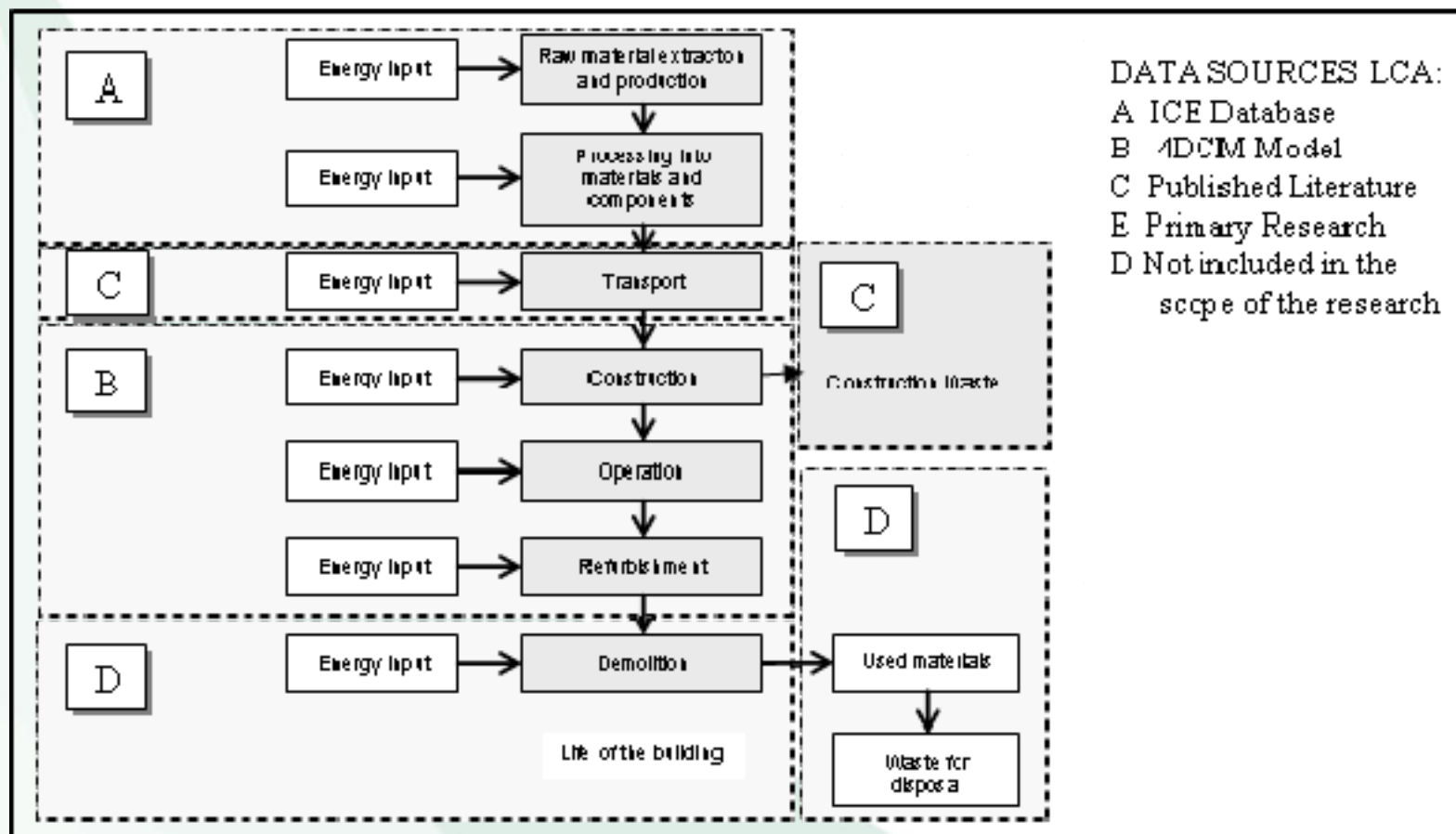
RLB | Rider Levett Bucknall



**4DCM Model**  
The  $x$  variable (length) times  $y$  (width) gives area. The area times  $z$  (height) gives volume. The fourth dimension is  $t$  (time).

The model was adapted to incorporate the input-output embodied energy methodology developed by Small World Consulting.

The model was then updated with the latest research on embodied energy analysis, including Bath University's ICE database and DEFRA.





## Building Intervention Options

Case	Summary	Description
<b>Option 1</b>	Existing building Baseline	<p>External walls: Sandstone block with plasterboard (internal) no insulation</p> <p>Internal partitions: timber frame lath and plaster finish</p> <p>Roof: Timber/slate (&lt; 50mm insulation)</p> <p>Ceilings: Timber lath and plaster finish, T&amp;G floorboards</p> <p>Floor: Suspended T&amp;G floorboards carpet throughout</p> <p>Heating: oil</p> <p>Windows: Mix upvc/timber</p>



## Building Intervention Options

Case	Summary	Description
<b>Option 2</b>	Existing building Upgrade	As with Option1 but with; Inner walls: timber frame plasterboard +100mm GF insulation Floor: 150mm XP foam Roof: 250mm GF insulation Windows: Timber DG S/C SBS 2008 compliant



## Building Intervention Options

Case	Summary	Description
<b>Option 3</b>	Demolition and replacement SBS building standards compliant	As with Option 2 but with; External walls: sandstone block low uvalue XP foam insulation low air permeability Internal walls: timber frame plasterboard Ground floor: sold concrete / screed insulated Roof: 300mm GF insulation Heating: TRV heating controls and thermostats



## Building Intervention Options

Case	Summary	Description
<b>Option 4</b>	Code for Sustainable Homes Level 3	<p>External walls: Timber frame with plasterboard finish, insulation, ventilated cavity, brickwork cladding low ventilation rate</p> <p>Internal partitions: timber stud with plasterboard</p> <p>Ceilings: Timber with plasterboard T&amp;G flooring</p> <p>Roof: timber / slate</p> <p>Ground floor: sold concrete / screed insulated</p> <p>Flooring: carpet throughout</p> <p>Windows: timber DG S/C argon low e</p>

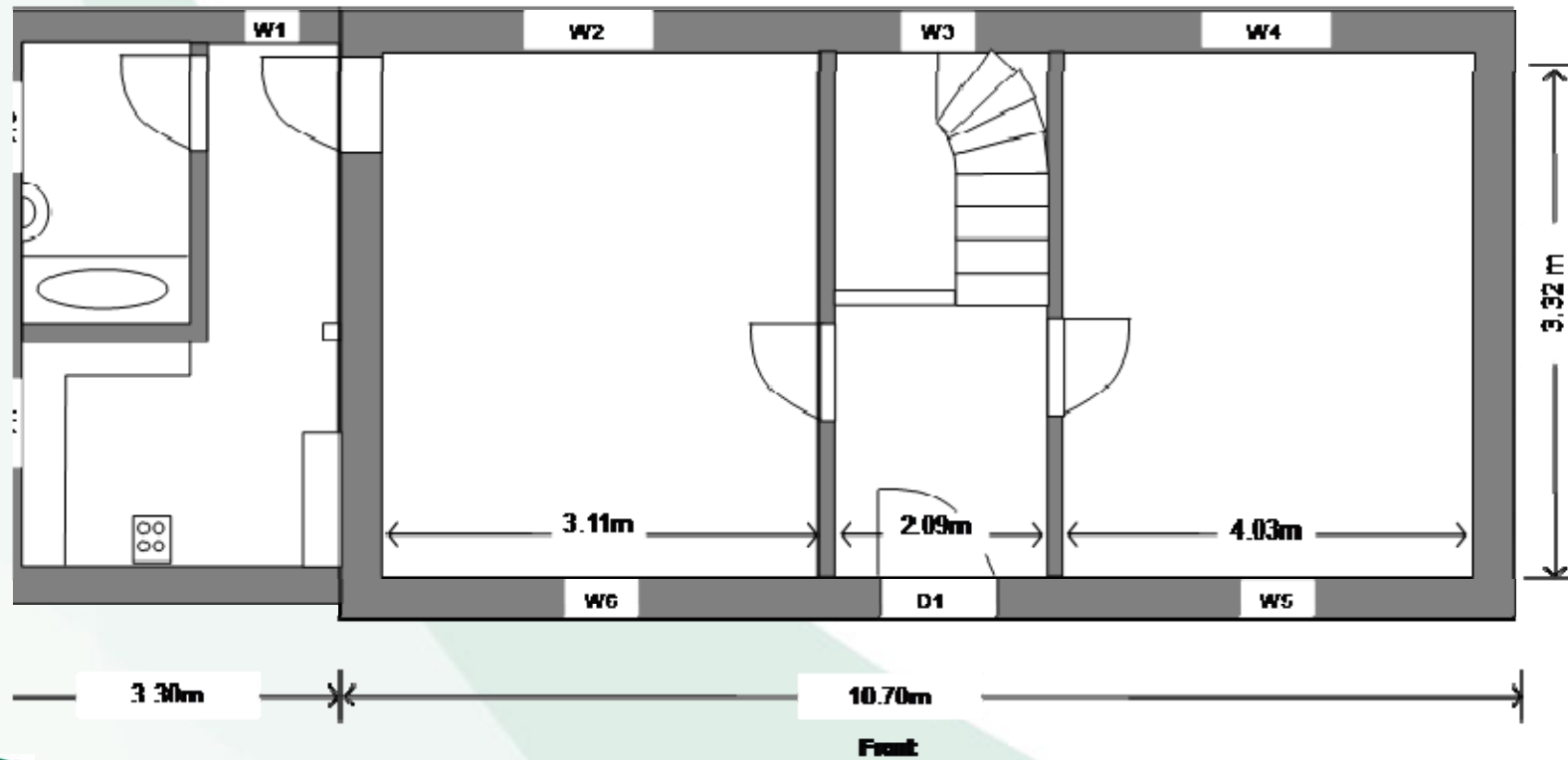


## Building Intervention Options

Case	Summary	Description
<b>Option 5</b>	Code for Sustainable Homes Level 5	As Option 4 but with: Windows: timber DG T/C argon low e 2kw Solar Photovoltaic

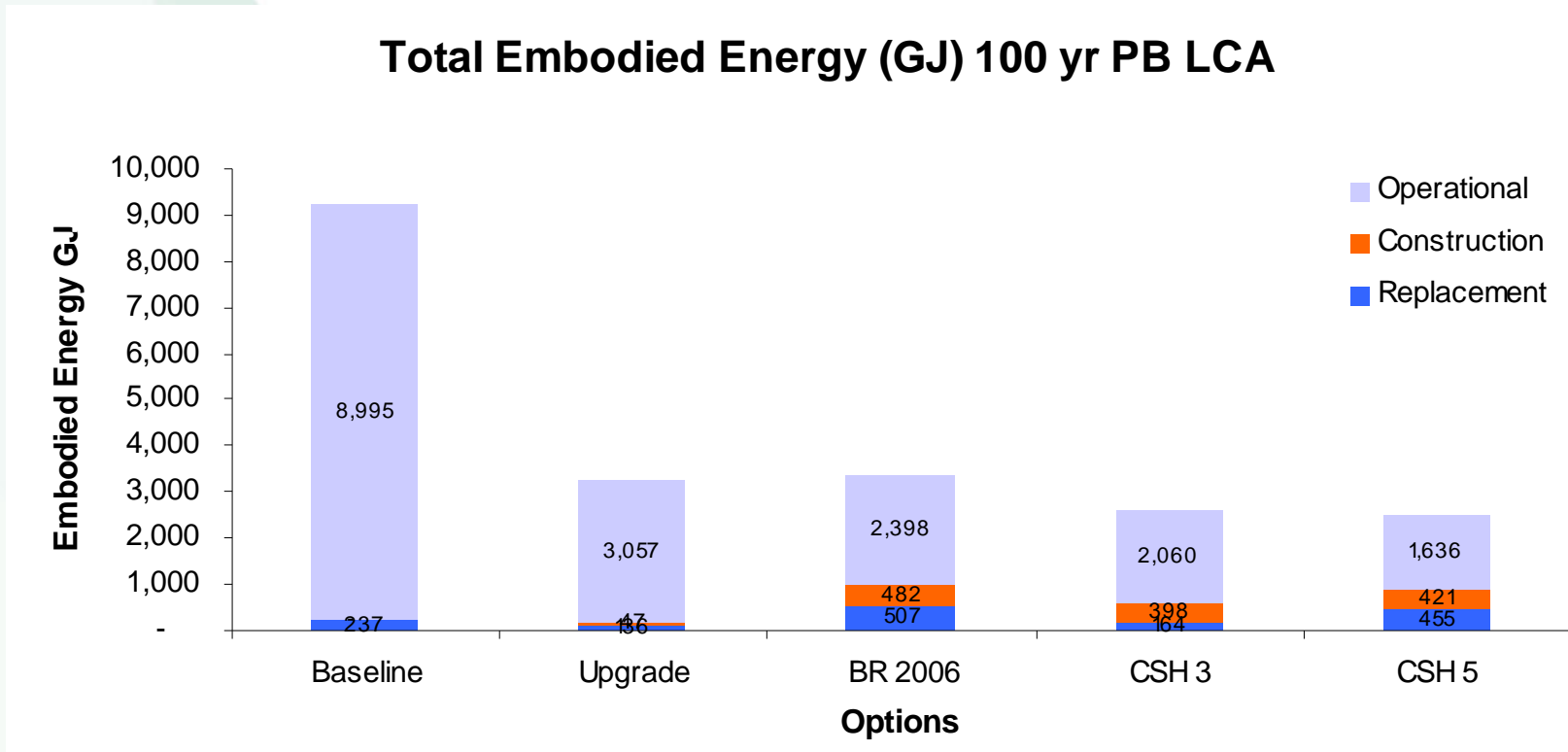


# Ground Floor Plan





## Results - Summary Embodied Energy for Options 1 – 5 (GJ) (PB LCA Methodology)



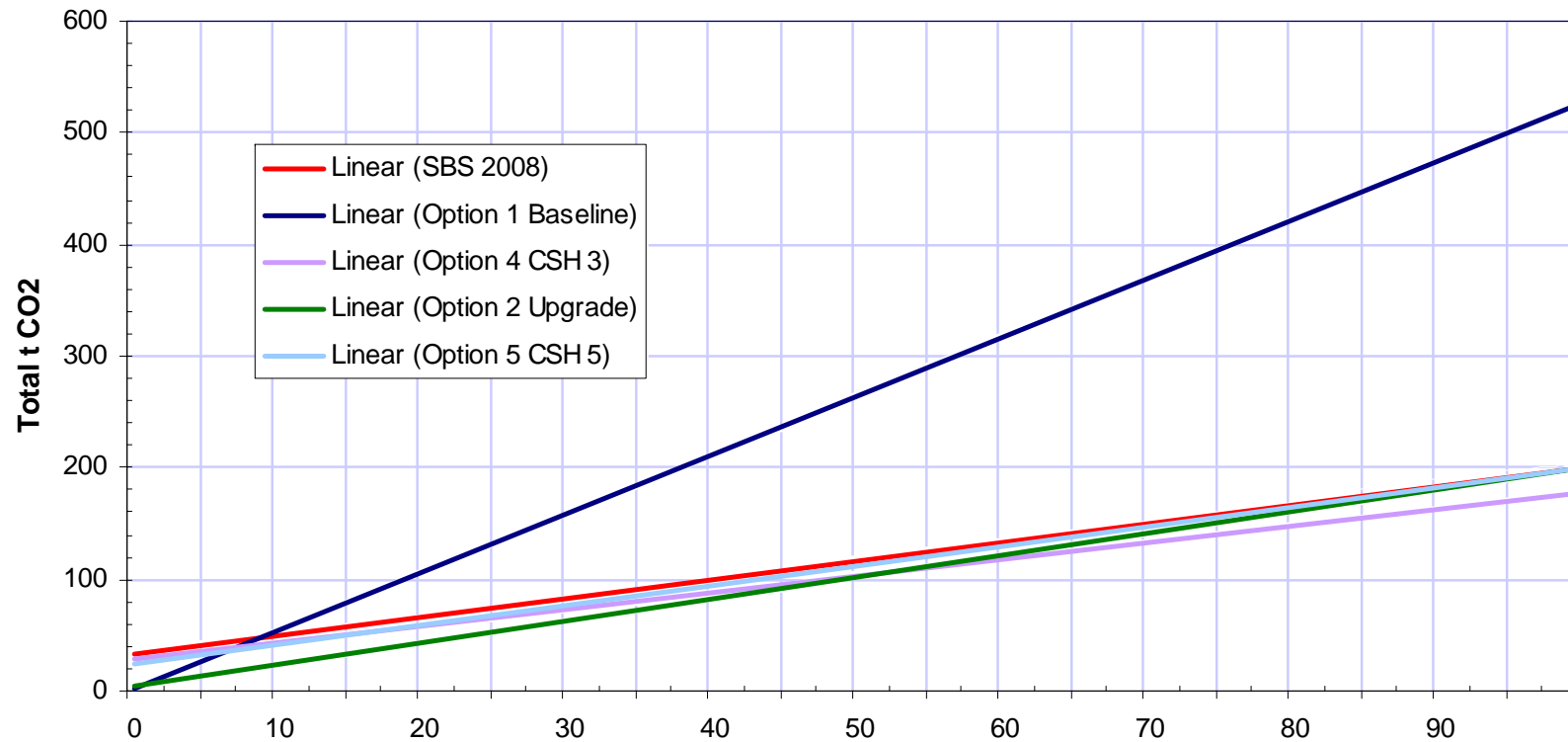


# Embodied and Operation Energy as a % of Total

Option	Description	Operational Energy (%) of total energy	Embodied energy (%) of total energy
Option 1	Baseline	97.4	2.6
Option 2	Upgrade	94.3	5.7
Option 3	SBS 2008	70.8	29.2
Option 4	CSH 3	78.6	21.4
Option 5	CSH 5	65.1	34.9

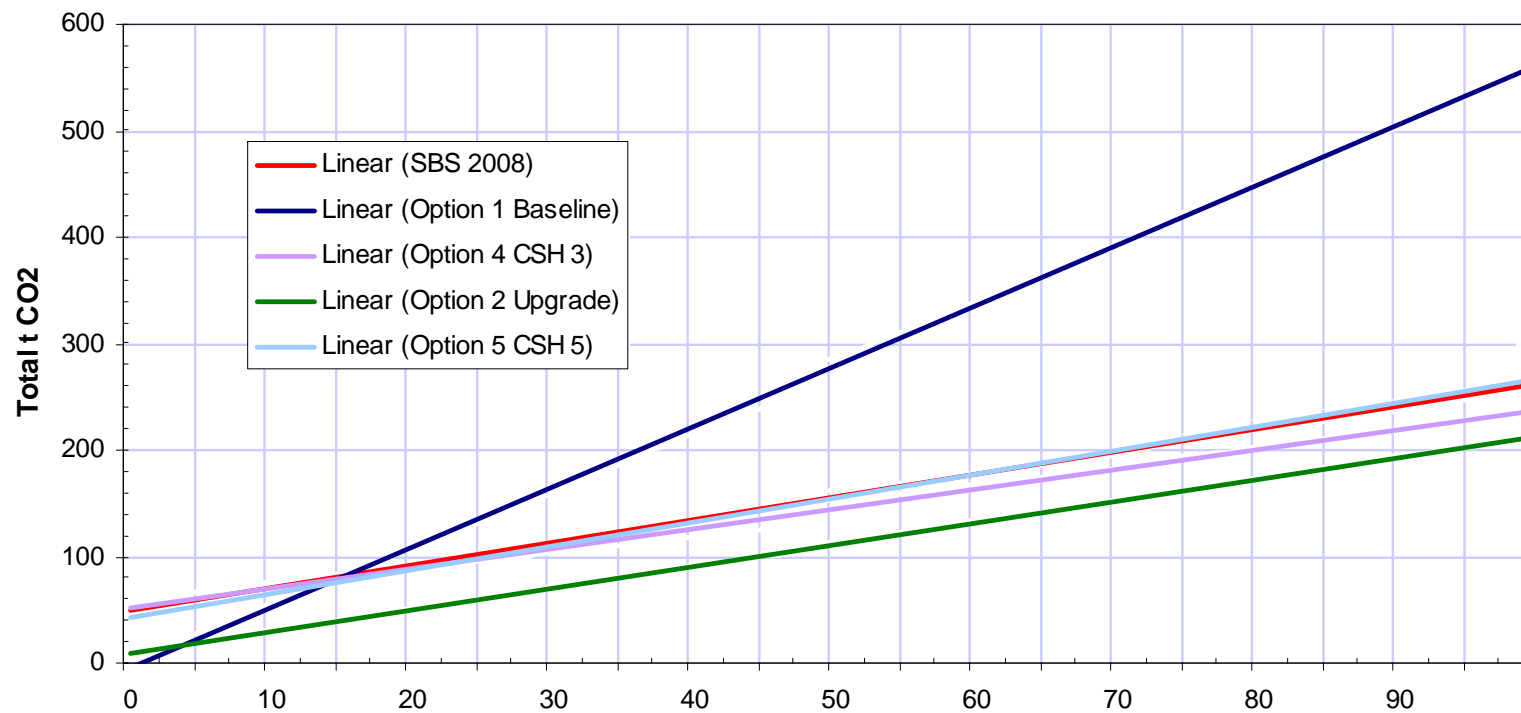


## Total energy consumption (Embodied and Operational) GJ



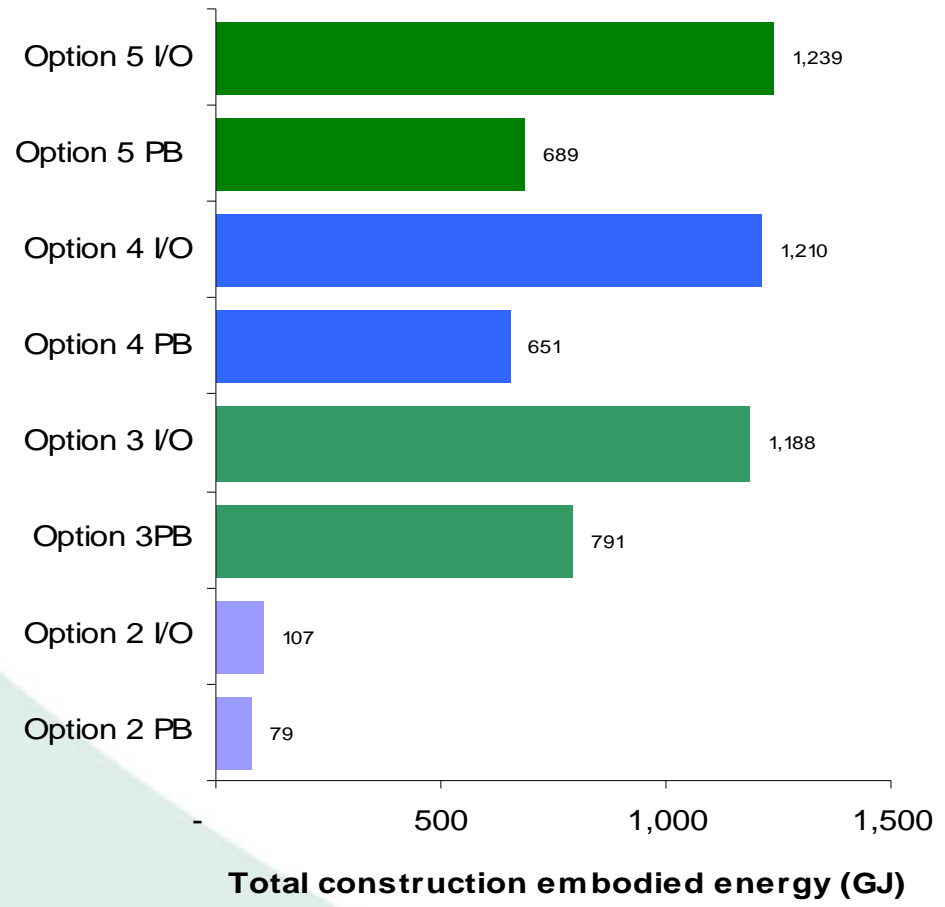


## Total embodied carbon over 100 yrs using Input Output LCA methodology (linear) tCO2





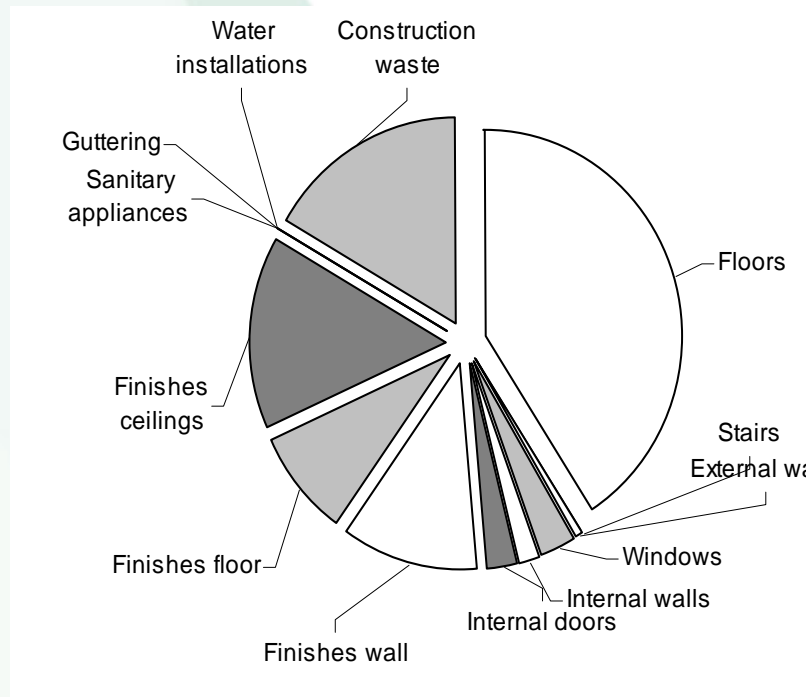
Comparison between total construction embodied energy using Process Based and Input Output LCA methodology.



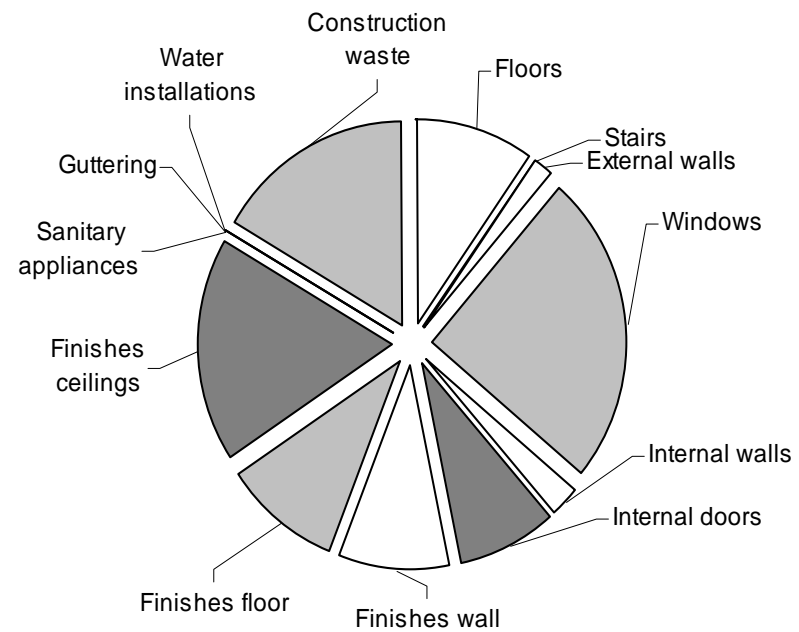


# Distribution of embodied energy in building components for Option 2 (Building Upgrade)

Process Based LCA



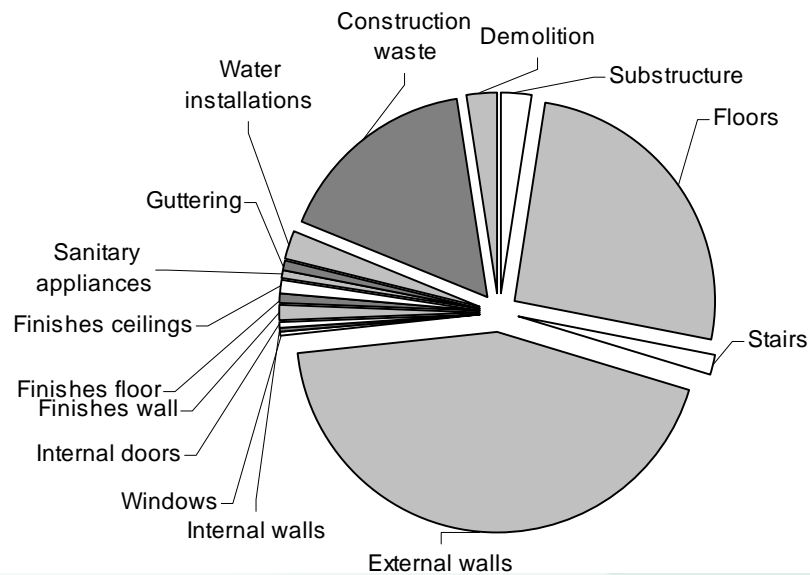
Input Output LCA



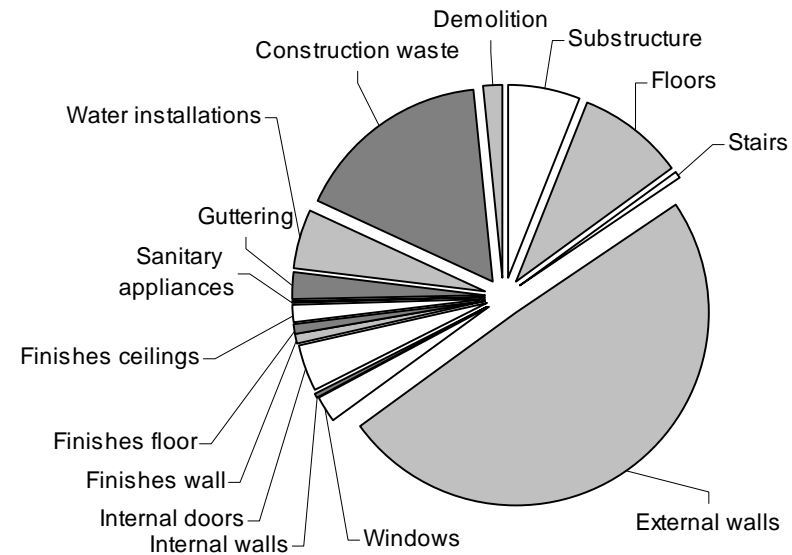


# Distribution of embodied energy in building components for Option 3 (SBS 2008 Compliant)

**Process Based LCA**

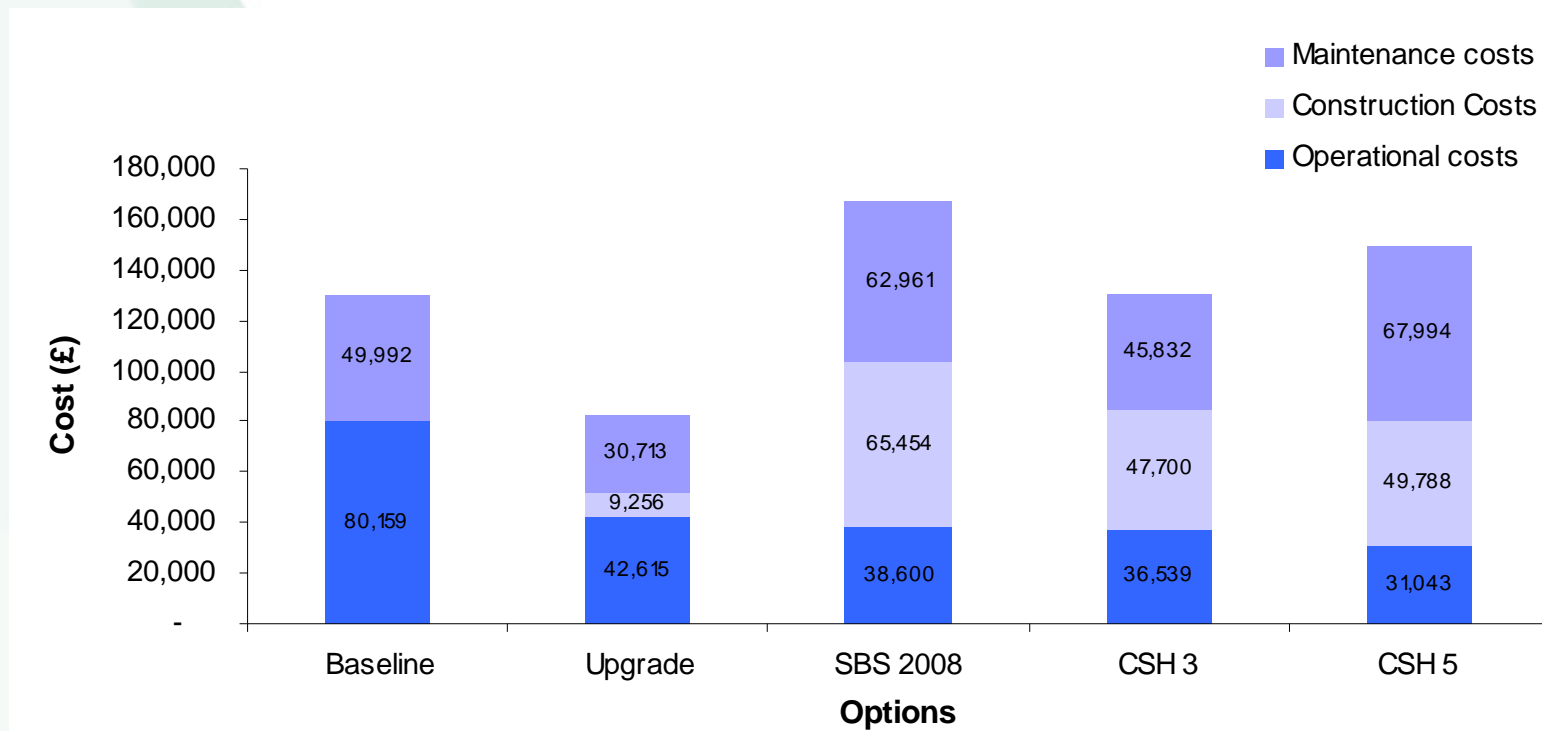


**Input Output LCA**



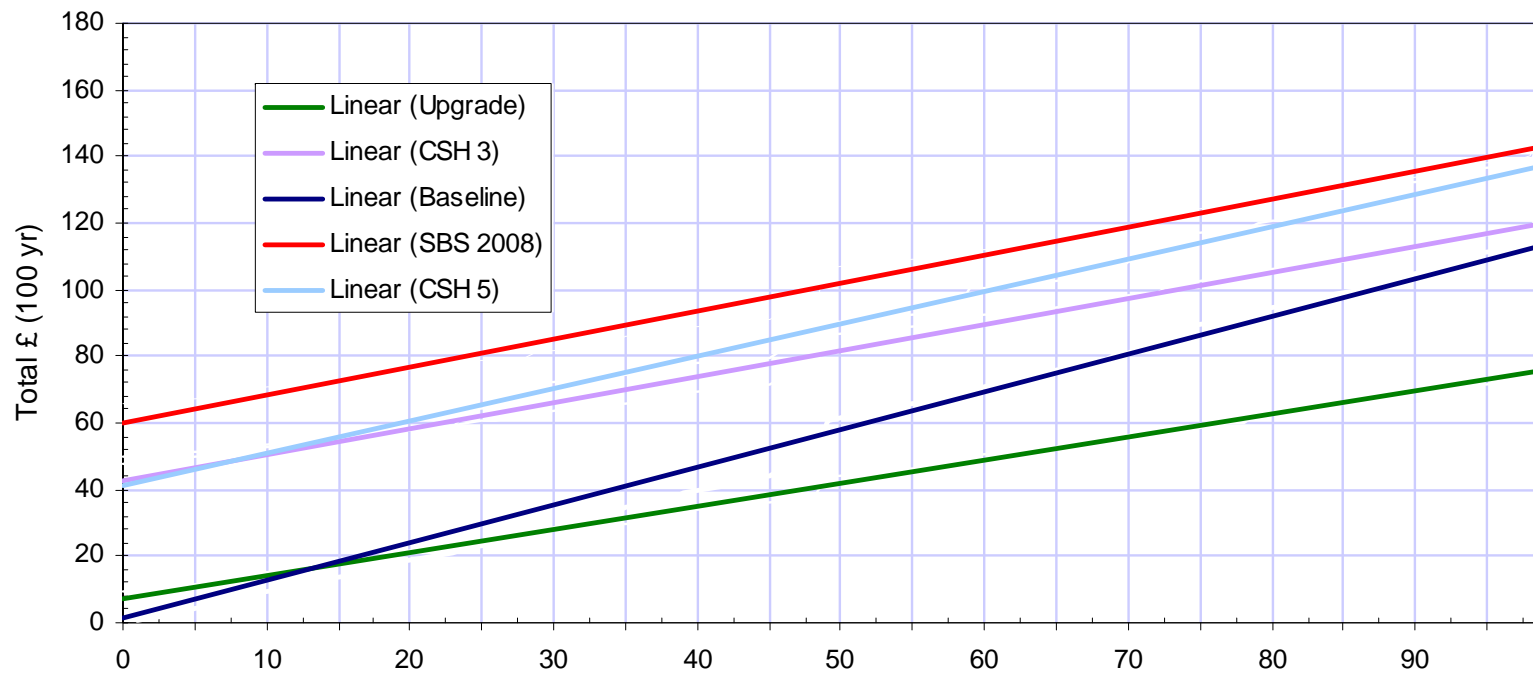


## Total estimated construction, operational and maintenance costs using the 4DCM model for each option over 100 yrs



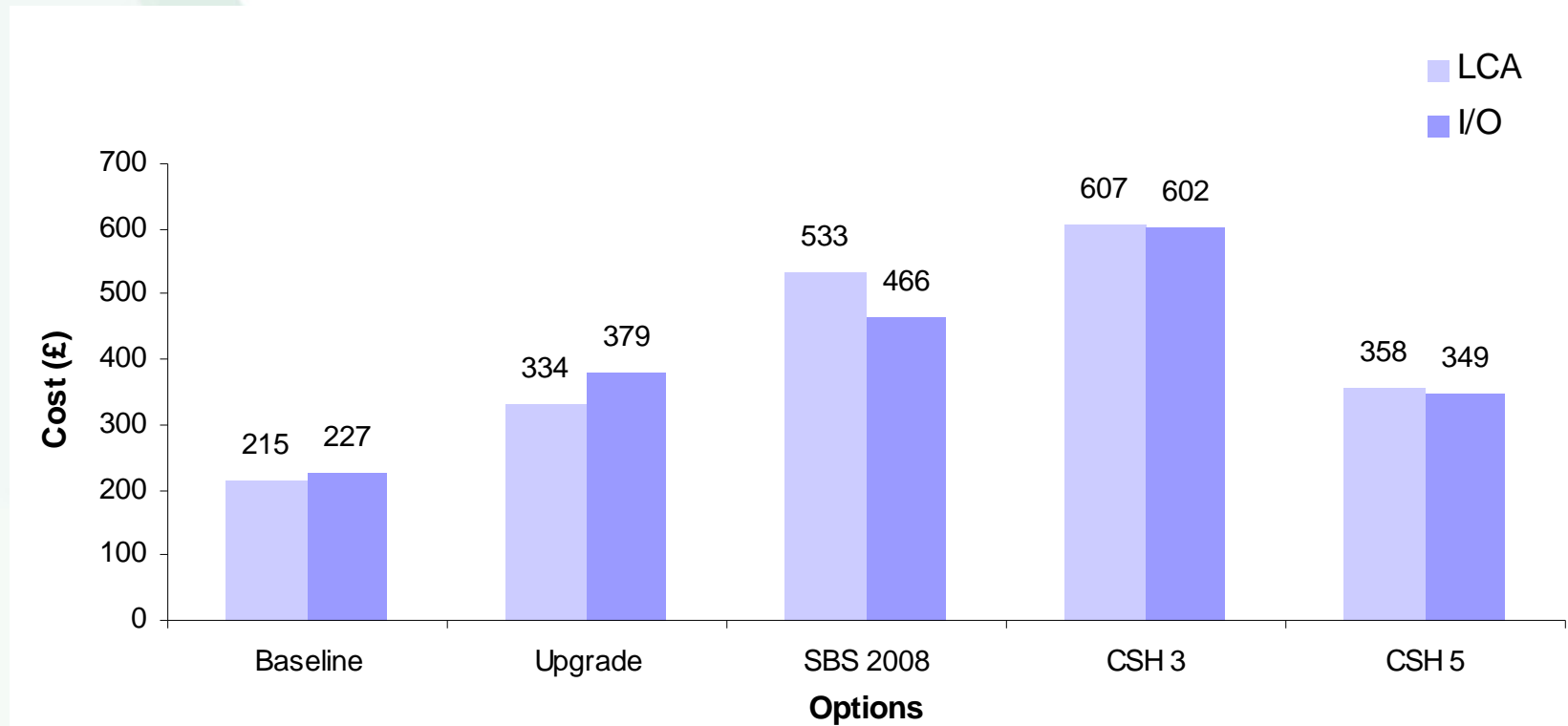


## Total estimated construction, operational and maintenance costs (£) over the lifetime of the building (100 years)



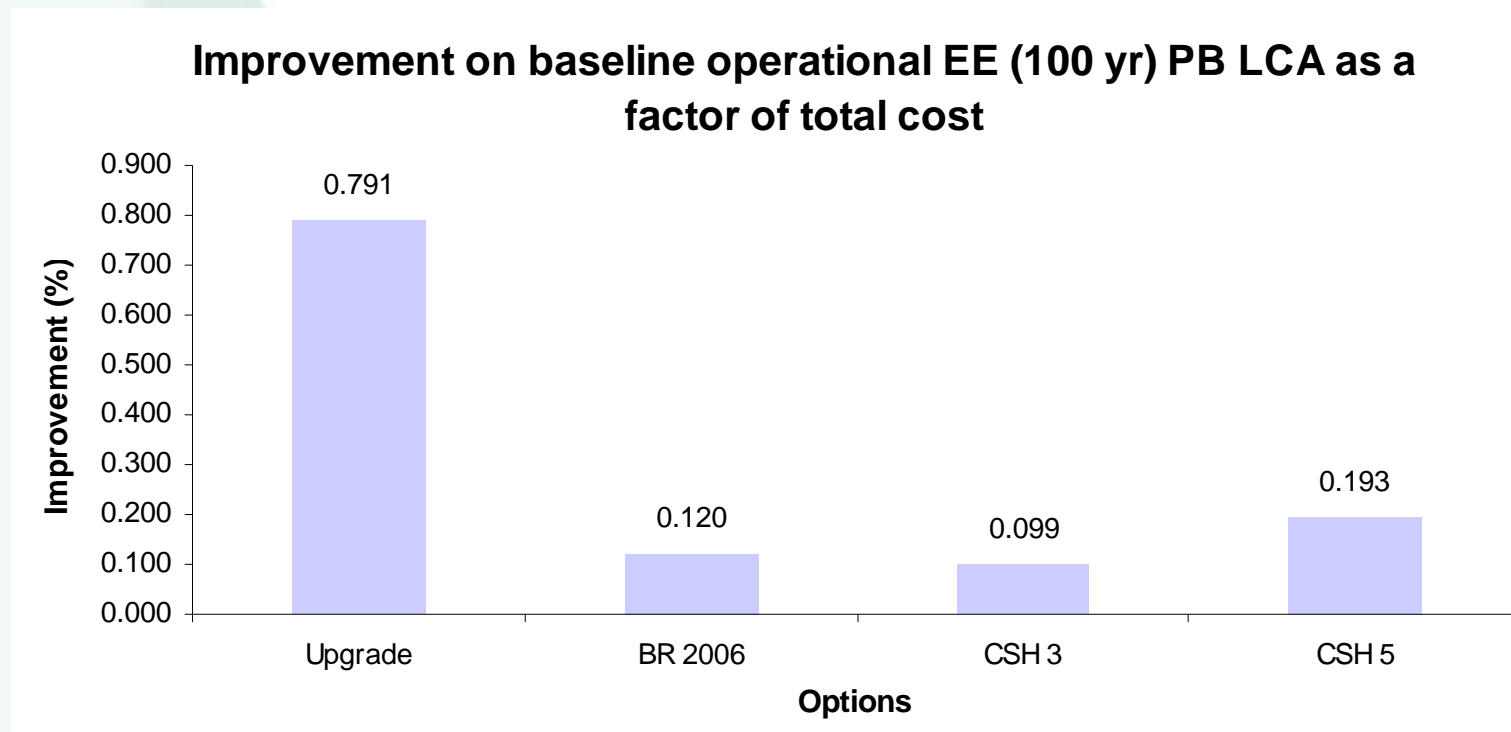


## Cost (£) per tonne of CO2 produced over the building lifetime comparing Process-Based and Input Output LCA results





## Total cost (£) per GJ of energy consumed





## Conclusions

- LCA process-based assessments of materials and products produce variable results and depend highly on the system boundaries chosen. It is not always clear what is included within the system boundaries making it difficult to achieve consistency within the method.
- It is highly likely that the results obtained on the embodied energy of the window replacement options underestimate the full significance of this life cycle phase.



## Conclusions

- Traditional buildings that are well insulated and with efficient heating and lighting systems have the potential to out perform new buildings over the life of the building (100 yrs) when total embodied energy is included in the equation
- The simplest energy improvements are where the most cost/benefits arise.



## Conclusions

- In terms of building replacement, even when compared to traditional buildings with very poor thermal performance, investing in a replacement building, even a very highly efficient building, is unlikely to recoup the investment over the life (100 yrs) of the building.
- In terms of cost returns on investment, the traditional building refurbishment option has significant cost benefits over the life of the new build, regardless of the energy performance level.



# The Crichton Carbon Centre

An international centre of excellence on climate change

Linking **business needs** with **academic expertise** to address **climate change** and encourage **behavioural change** in industry and society