INVENTORY OF CARBON & ENERGY (ICE)

Version 1.6a

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This project was joint funded under the Carbon Vision Buildings program by:

Available from: www.bath.ac.uk/mech-eng/sert/embodied/

Inventory of Carbon & Energy (ICE)

Welcome to the Inventory of Carbon & Energy (ICE) Version 1.6a. ICE is the University of Bath’s embodied energy & embodied carbon database, and is the freely available summary of the larger ICE-Database. The aim of this work was to create an inventory of embodied energy and carbon coefficients for building materials. The data has been collected from secondary resources in the public domain, including journal articles, Life Cycle Assessments (LCA’s), books, conference papers...etc. There has been no use of subscription based resources due to potential copyright issues. To aid in the selection of 'best' coefficients it was required to create a database (called the ICE-Database). This database stores relevant information from the literature (i.e. Country of data, year, boundaries, report specifics (Data source), notes...etc). At the time of writing the ICE-Database contained over 1,700 records on embodied energy. The work presented here is a summary of the information contained within the larger ICE-Database. This report has been structured into 34 main material groups (i.e. Aggregates, Aluminium...etc), a material profile was created for each main material. For an introduction to these profiles please see the 'Material Profiles Guide'.

EMBODIED ENERGY (CARBON)

“The embodied energy (carbon) of a building material can be taken as the total primary energy consumed (carbon released) over its life cycle. This would normally include (at least) extraction, manufacturing and transportation. Ideally the boundaries would be set from the extraction of raw materials (inc fuels) until the end of the products lifetime (including energy from manufacturing, transport, energy to manufacture capital equipment, heating & lighting of factory, maintenance, disposal...etc), known as ‘Cradle-to-Grave’. It has become common practice to specify the embodied energy as ‘Cradle-to-Gate’, which includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is ‘Cradle-to-Site’, which includes all of the energy consumed until the product has reached the point of use (i.e. building site).”

Data on embodied energy & carbon data was not always determined to have complete boundary conditions (e.g. the energy not traced back to the earth, electricity not traced upstream...etc). However, incomplete data often contained enough substance to have a useful role when estimating embodied energy coefficients. Cradle-to-Gate was the most
commonly specified boundary condition and was selected as the ideal scope of this study. This has been revised from the previous ideal of cradle to site. It is now encouraged for the user to consider the impacts of transportation for their specific case. It should be noted that the boundary conditions for each material are specified within the material profiles. Data intricacies and inconsistencies made it very difficult to maintain the same boundary conditions for the entire inventory. In a few cases Cradle-to-Grave has been specified due to the original data resources. In many cases, and certainly for materials with high embodied energy and high density, the difference between Cradle-to-Gate and Cradle-to-Site could be considered negligible. Although this will certainly not be true for materials with a very low embodied energy per kilogram, such as aggregates, sand...etc.

ICE contains both embodied energy and carbon data, but the embodied energy coefficients carry a higher accuracy. One of the reasons for this was that the majority of the collected data was for embodied energy, and not embodied carbon. It was therefore necessary to estimate the embodied carbon for many materials. Ideally the embodied carbon would be derived from an accurate Life Cycle Assessment; however this was not normally the case. Many of the embodied carbon coefficients within ICE were estimated by the authors of this report. In these cases the embodied carbon was estimated from the typical fuel mix in the relevant UK industries. This method is not perfect, but it must be remembered that neither are the results from Life Cycle Assessments (the preferred source). It remains vastly superior to applying a common conversion factor from embodied energy to embodied carbon across the whole dataset.

From analysing the ICE-Database it was estimated that approximately 40% of the collected data either specified the embodied carbon, a global warming potential (or similar method of greenhouse gas measurement) or a fuel mix (from which the carbon emissions could be estimated). Of this 40% around half were the less useful (to estimating embodied carbon (dioxide)) GWP or fuel mix, therefore only 20% of authors were specifying a useful embodied carbon. Consequently the author had less data to verify embodied carbon coefficients. Another reason for greater uncertainty in embodied carbon was a result of different fuel mixes and technologies (i.e. electricity generation). For example, two factories could manufacture the same product, resulting in the same embodied energy per kilogram of product produced, but the total carbon emitted by both could vary widely dependent upon the mix of fuels consumed by the factory.

The nature of this work and the problems outlined above made selection of a single value difficult and in fact a range of data would have been far simpler to select, but less useful to apply in calculations. There are several openly available inventories similar in nature to this one, and more subscription basis ones. Comparison of the selected values in these inventories would show many similarities but also many differences. It is rare that one single
value could be universally agreed upon by researchers within this field of work. Uncertainty is unfortunately a part of embodied energy and carbon analysis and even the most reliable data carries a natural level of uncertainty. That said results from ICE have proved to be robust when compared to those of other databases.

Caution must be exerted when analysing materials that have feedstock energy. Feedstock energy is the 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 plastics and rubber instead of direct combustion. When collecting data it was not always apparent if feedstock energy was included or excluded from the data. For this reason the values in the ICE-Database are stored as reported in the literature, hence the records in the database needed to be manually examined. The database statistics may prove misleading in some instances (some records include feedstock energy, some exclude it and others were unknown). The feedstock energy in this inventory was identified and is included in the total embodied energy coefficients in this report.

The next page explains the criteria for selection, which was used when estimating embodied energy & embodied carbon.

For the authors' contact details or to download further copies of this report please visit:

www.bath.ac.uk/mech-eng/sert/embodied/
Selection Criteria

The criteria used to estimate the embodied energy & carbon are displayed below. Due to the difficulties experienced when selecting these values the criteria needed to be flexible but maintain an ideal set of conditions. One of the main difficulties was inconsistent & poor specification of data in the literature, i.e. different and incomplete boundary conditions and authors not reporting enough detail on the scope of their study.

Five criteria were applied for the selection of embodied energy and carbon values for the individual materials incorporated into the ICE database. This ensured consistency of data within the inventory. The criteria were:

1-Compliance with Approved Methodologies/Standards: Preference was given to data sources that complied with accepted methodologies. In the case of modern data an ideal study would be ISO 14040/44 compliant (the International standard on environmental life cycle assessment). However, even studies that comply with the ISO standards can have wide ranging and significant differences in methodology, as such further selection criteria were necessary, thus ensuring data consistency. A recycled content, or cut-off approach, was preferred for the handling of (metals) recycling.

2-System Boundaries: The system boundaries were adopted as appropriate for ‘cradle-to-gate’ embodiment. Feedstock energy was included only if it represented a permanent loss of valuable resources, such as fossil fuel use. For example, fossil fuels utilised as feedstocks, such as the petro-chemicals used in the production of plastics, were included (although identified separately). However, the calorific value of timber has been excluded. This approach is consistent with a number of published studies and methodologies. The effects of carbon sequestration (for example carbon that was sequestered during the growing of organic materials, i.e. timber) were considered but not integrated into the data. For justification of this decision please see the timber material profile. Non-fuel related carbon emissions have been accounted for (Process related emissions).

3-Origin (Country) of Data: Ideally the data incorporated into the ICE inventory would have been restricted to that emanating from the British Isles. But in the case of most materials this was not feasible, and the best available embodied energy data from foreign sources had to be adopted (using, for example, European and world-wide averages). A much stronger preference was given to embodied carbon data from UK sources, due to national differences in fuel mixes and electricity generation.
4-Age of the Data Sources: Preference was given to modern sources of data, this was especially the case with embodied carbon; historical changes in fuel mix and carbon coefficients associated with electricity generation give rise to greater uncertainty in the embodied carbon values.

5-Embodied Carbon: Ideally data would be obtained from a study that has considered the life cycle carbon emissions, for example via a detailed LCA, but there is often an absence of such data. In many cases substitute values therefore had to be estimated using the typical fuel split for the particular UK industrial sector. British emission factors were applied to estimate the fuel-related carbon. Additional carbon (non-energy related, i.e. process related carbon) carbon was included.

In addition to these selection criteria the data primarily focused on construction materials. The embodied energy and carbon coefficients selected for the ICE database were representative of typical materials employed in the British market. In the case of metals, the values for virgin and recycled materials were first estimated, and then a recycling rate (and recycled content) was assumed for the metals typically used in the marketplace. This enabled an approximate value for embodied energy in industrial components to be determined. In order to ensure that this data was representative of typical products (taking timber as an example), the UK consumption of various types of timber was applied to estimate a single ‘representative’ value that can be used in the absence of more detailed knowledge of the specific type of timber (i.e., plywood, chipboard, softwood, ...etc.). Finally it was aimed to select data that represented readily usable construction products, i.e., semi-fabricated components (sections, sheets, rods...etc. which are usable without further processing), rather than (immediately) unusable products such as steel billet or aluminium ingot.
Notes

Transport

In the previous versions of ICE the boundary conditions were ideally selected as cradle to site. This was based on the assumption that in many cases transport from factory gate to construction site would be negligible. Whilst this may be true for many materials, and normally true for high embodied energy and carbon materials, this is not exclusively the case. In the case of very low embodied energy and carbon materials, such as sand and aggregates, transport is likely to be significant. For these reasons the ideal boundaries have been modified to cradle to gate (from the previous cradle to site). This decision will also encourage the data users to estimate transport specific to their case in hand. This should act as a further check to ensure transporting the selected material many thousands of miles around the world does not create more energy and carbon than a local alternative.

To estimate the embodied energy and carbon of transport it is recommended that users start with the following resources (in no particular order):

- DEFRA, 2007. “Guidelines to Defra’s GHG conversion factors for company reporting” [link]
- European Commission’s information hub on life cycle thinking based data, tools and services. [link]
- Data in LCA software and databases such as SimaPro, GaBi or Ecoinvent.

Recycling Methodology (Particularly Metals)

When applying the ICE data it is important to ensure that the ICE recycling methodology is consistent with the scope and boundaries of your study, especially for metals. It is particularly important that recycling methodologies are not mixed. This could occur with the use of data from different resources. If this is the case then care must be exerted to ensure that all of the data is applied in a consistent manner. Some of the ICE data (especially if classified as a ‘Typical’ or ‘General’ metal) has a pre-selected recycled content and this conforms to the default ICE recycling methodology.

The default ICE recycling methodology is known as the recycled content approach. However, the metal industries endorse a methodology that is often known as the substitution method. Each method is fundamentally different. The recycled content approach is a method that credits recycling, whereas the substitution method credits
recyclability. This may be considered in the context of a building. Using the recycled content approach the incoming metals to the building could be split between recycled and primary materials. If this gives 40% recycled metals then the recycled content is set at 40%. This is a start of life method (i.e. start of life of the building) for crediting recycling. Using this method the materials entering a building takes the recycling credit (thus upstream of the building/application).

The substitution method has the opposite school of thought. In this method it is the act of recyclability that is credited and therefore it is an end of life methodology. Using this methodology the recycled content of the materials entering the building is not considered in the analysis. Instead the ability for the materials to be recycled at the end of the products lifetime is considered. For example, in the case of metals this could feasibly be taken as, say, 85% recyclability. This implies that at the end of the buildings lifetime it is expected that 85% of the metals in the building will be recycled into new products. Therefore the building will be credited to the extent that 85% of the materials (metals) will be treated as recycled (and therefore it is a substitution of primary and recycled materials, hence the name). Such a methodology may be approximated by applying a recycled content of 85%.

It is clear that the application of each methodology will yield very different results; this is particularly true for aluminium. Recycled aluminium can have a saving of 85-90% in its embodied impacts over primary aluminium. It is therefore important that an appropriate methodology for the study in hand must be selected. The methodology must be consistent with the goal and scope of the study. The authors of this work remain convinced that for construction, where lifetimes are large (60-100 years in the residential sector), the recycled content approach is the most suitable method. The present authors consider that it reflects a truer picture of our current impacts and that the substitution method may run the risk of under accounting for the full impacts of primary metal production. They believe that the advantages of the recycled content methodology fit in more appropriately with the (normal) primary motivation for undertaking an embodied energy and carbon assessment. This is normally to estimate the current impacts of its production. However if the purpose of the study is different then it may be desirable to apply a different recycling methodology.

Essentially, each method suffers from its own pitfalls and neither may be applicable under all circumstances. The ICE data is structured to identify the difference between recycled and primary metals. The user is therefore free to apply any recycling methodology.
Things to Consider...

- **Functional units**: It is inappropriate to compare materials solely on a kilogram basis. Products must be compared on a functional unit basis, a comparative study should consider the quantity of materials required to provide a set function. It is only then that two materials can be compared for a set purpose. For example, what if the quantity of aluminium that is required to provide a square meter of façade versus the quantity of timber?

- **Lifetime**: Ideally the functional unit should consider the lifetime of the product. For example, what if product A lasts 40 years and product B only lasts 20 years? This may change the conclusion of the study.

- **Waste**: The manufacture of 1 kg of product requires more than this quantity of material. The quantity of waste must be considered. Additionally what happens to the wasted materials? Is it re-used, recycled, or disposed?

- **Maintenance**: What are the maintenance requirements and how does this impact on the energy and material consumption? Does the product require periodical attention, e.g. re-painting?

- **Further processing energy**: Highly fabricated and intricate items require manufacturing operations that are beyond the boundaries of this report. In the case of a whole building such a contribution could be assumed to be minimal, however the study of an individual product may require this energy to be investigated.

The following pages contain the main ICE data...
The Inventory of Carbon & Energy (ICE) – Main Data Tables
<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy &amp; Carbon Data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EE - MJ/kg</td>
<td>EC - kgCO2/Kg</td>
</tr>
<tr>
<td><strong>Aggregate</strong></td>
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</tr>
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<td>Virgin</td>
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<td>General</td>
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<td><strong>Rolled</strong></td>
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<td>Virgin</td>
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<td>Road &amp; Pavement</td>
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<td><strong>Example</strong>: Road</td>
<td>2.672 MJ/Sqm</td>
<td>134 KgCO2/Sqm</td>
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<td><strong>Bitumen</strong></td>
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<td>44.00</td>
<td>2.42 (?)</td>
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<tr>
<td>Virgin</td>
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<td>1.79 (?)</td>
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<tr>
<td>Recycled</td>
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<td>1.17 (?)</td>
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<td><strong>Bricks</strong></td>
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<tr>
<td>General (Common Brick)</td>
<td>3.00</td>
<td>0.22</td>
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<tr>
<td><strong>Example</strong>: Single Brick</td>
<td>6.4 MJ per brick</td>
<td>0.82 kgCO2 per brick</td>
</tr>
<tr>
<td><strong>Facing Bricks</strong></td>
<td>8.29</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Example</strong>: Single Facing Brick</td>
<td>23 MJ per brick</td>
<td>1.46 kgCO2 per brick</td>
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<tr>
<td><strong>Limestone</strong></td>
<td>0.85</td>
<td></td>
</tr>
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<td><strong>Stone</strong></td>
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<td></td>
</tr>
<tr>
<td>General</td>
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<td>4.1 (?)</td>
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<td><strong>Cement</strong></td>
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<td>General (Typical)</td>
<td>4.6</td>
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<td>Fibre Cement</td>
<td>10.90</td>
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<td>Mortar (1:3 cement:sand mix)</td>
<td>1.40</td>
<td>0.23</td>
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<td>Mortar (1:4)</td>
<td>1.24</td>
<td>0.27</td>
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<td>Mortar (1:5)</td>
<td>0.99</td>
<td>0.33</td>
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<tr>
<td>Mortar (1:4:4 Cement:Lime:Sand mix)</td>
<td>1.37</td>
<td>0.196</td>
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<tr>
<td>Mortar (1:6 Cement:Lime:Sand mix)</td>
<td>1.18</td>
<td>0.163</td>
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<td>Mortar (1:2:9 Cement:Lime:Sand mix)</td>
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<tr>
<td>Soil-Cement</td>
<td>0.95</td>
<td>0.14</td>
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<tr>
<td><strong>% Cementitious Replacement</strong></td>
<td>0%</td>
<td>25% 50%</td>
</tr>
<tr>
<td><strong>General (with Fly Ash Replacement)</strong></td>
<td>4.6</td>
<td>3.52 2.43</td>
</tr>
<tr>
<td><strong>General (with Blast Furnace Slag Replacement)</strong></td>
<td>4.6</td>
<td>3.81 3.01</td>
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### INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy &amp; Carbon Data</th>
<th>Comments</th>
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<tbody>
<tr>
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<td>EE - MJ/kg</td>
<td>EC - kgCO2/Kg</td>
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<td><strong>Ceramics</strong></td>
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<td>General</td>
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<tr>
<td>Fittings</td>
<td>29.00</td>
<td>1.08</td>
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<tr>
<td>Refractory products</td>
<td>9.50</td>
<td>0.88</td>
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<tr>
<td>Sanitary Products</td>
<td>29.00</td>
<td>1.08</td>
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<td>Tile</td>
<td>8.60</td>
<td>0.89</td>
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<tr>
<td><strong>Clay</strong></td>
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<tr>
<td>General (Simple Baked Products)</td>
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<td>Tile</td>
<td>6.50</td>
<td>0.64</td>
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<td>Vitrified clay pipe DN 100 &amp; DN 150</td>
<td>6.19</td>
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<td>Vitrified clay pipe DN 200 &amp; DN 300</td>
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<td>Vitrified clay pipe DN 500</td>
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<td>General</td>
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<td>0.130</td>
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<td><strong>REINFORCED CONCRETE</strong></td>
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<td>Block - 8 MPa</td>
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<td>0.061</td>
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<td>Block - 10 MPa</td>
<td>2.07</td>
<td>0.074</td>
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<td>Block - 12 MPa</td>
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<td>Block - 13 MPa</td>
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<td>0.089</td>
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<tr>
<td>Autoclaved Aerated Blocks (AAC’s)</td>
<td>3.50</td>
<td>0.28 to 0.375</td>
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#### MISCELLANEOUS VALUES

<p>| | | | |</p>
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<tbody>
<tr>
<td>Prefabricated Concrete</td>
<td>2.00</td>
<td>0.216</td>
<td>Literature resources suggest this value, unknown why so high</td>
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<td>Fibre-Reinforced</td>
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<td>Concrete Road &amp; Pavement</td>
<td>1.26</td>
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<tr>
<td>EXAMPLE Road</td>
<td>2.085 MJ/m³</td>
<td>187.7 KgCO2/m³</td>
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<tr>
<td>Wood-Wool Reinforced</td>
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#### NOMINAL PROPORTIONS METHOD (Volume), Proportions from BS 8500:2006 (ICE Cement, Mortar & Concrete Model Calculations)

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<thead>
<tr>
<th>% Cement Replacement - Fly Ash</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>Note</th>
<th>0% is a standard concrete</th>
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<tbody>
<tr>
<td>GEN 6</td>
<td>0.64</td>
<td>0.57</td>
<td>0.50</td>
<td>0.071</td>
<td>0.059</td>
<td>0.046</td>
<td>Compressive Strength C6/8 MPa</td>
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<tr>
<td>GEN 1</td>
<td>0.77</td>
<td>0.66</td>
<td>0.60</td>
<td>0.126</td>
<td>0.102</td>
<td>0.087</td>
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<tr>
<td>GEN 2</td>
<td>0.81</td>
<td>0.70</td>
<td>0.58</td>
<td>0.103</td>
<td>0.083</td>
<td>0.062</td>
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<td>GEN 3</td>
<td>0.85</td>
<td>0.73</td>
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<td>RC20</td>
<td>0.95</td>
<td>0.90</td>
<td>0.62</td>
<td>0.128</td>
<td>0.102</td>
<td>0.075</td>
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<td>0.99</td>
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<td>0.64</td>
<td>0.134</td>
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<td>0.081</td>
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<td>RC30</td>
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<td>0.96</td>
<td>0.72</td>
<td>0.153</td>
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#### COMMENTS

The first column represents standard concrete, created with 100% Portland cement. The other columns are estimates based on a direct substitution of fly ash or blast furnace slag in place of the cement content. The ICE Cement, Mortar & Concrete Model was applied. It was assumed that there will be no changes in the quantities of water, aggregates or plasticiser/additives due to the use of cementitious replacement materials.
### INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

<table>
<thead>
<tr>
<th>Materials</th>
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<td>3.83 (?)</td>
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<tr>
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<tr>
<td>Virgin if produced with zinc</td>
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<td>Mercury</td>
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<td>Quartz powder</td>
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<td>Slag (GBGS)</td>
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<td>Vicuclad</td>
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# INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy &amp; Carbon Data</th>
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<tbody>
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<td>EE - MJ/kg</td>
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<td>Water</td>
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<td>Yttrium</td>
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<td>Zirconium</td>
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**Paint**

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<tr>
<th>General</th>
<th>68.00</th>
<th>3.56</th>
<th>Large variations in data, especially for carbon emissions.</th>
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<tbody>
<tr>
<td>EXAMPLE: Single Coat</td>
<td>10.2 MJ/Sqm</td>
<td>0.53 kgCO2/Sqm</td>
<td>Assuming 6.66 Sqm Coverage per kg</td>
</tr>
<tr>
<td>EXAMPLE: Double Coat</td>
<td>20.4 MJ/Sqm</td>
<td>1.06 kgCO2/Sqm</td>
<td>Assuming 3.33 Sqm Coverage per kg</td>
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<tr>
<td>EXAMPLE: Triple Coat</td>
<td>36.5 MJ/Sqm</td>
<td>1.60 kgCO2/Sqm</td>
<td>Assuming 2.22 Sqm Coverage per kg</td>
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</table>

**Paper**

| Paperboard (General for construction use) | 24.80 | 1.32 | Excluding CV of wood, excludes carbon sequestration |
| Fine Paper                              | 29.20 | 1.56 | Excluding CV of wood, excludes carbon sequestration |
| Wallpaper                                | 36.40 | 1.93 | |

**Plaster**

| General (Gypsum) | 1.80 | 0.12 | Problems selecting good value, inconsistent figures, West et al believe this is because of past aggregation of EE with cement |
| Plasterboard     | 6.75 | 0.38 | |

**Plastics**

| General | 80.50 | 2.53 | 35.6 MJ/kg Feedstock Energy (Included). Determined by the average use of each type of plastic used in the European construction industry |
| ABS     | 95.30 | 3.10 | 48.6 MJ/kg Feedstock Energy (Included) |
| General Polyethylene | 83.10 | 1.94 | 54.4 MJ/kg Feedstock Energy (Included). Based on the average use of types of PE in European construction |
| High Density Polyethylene (HDPE) | 76.70 | 1.60 | 54.3 MJ/kg Feedstock Energy (Included) |
| HDPE Pipe | 84.40 | 2.00 | 55.1 MJ/kg Feedstock Energy (Included) |
| Low Density Polyethylene (LDPE) | 78.10 | 1.70 | 51.8 MJ/kg Feedstock Energy (Included) |
| LDPE Film | 89.30 | 1.98 | 55.8 MJ/kg Feedstock Energy (Included) |
| Nylon 6 | 120.50 | 5.30 | 36.6 MJ/kg Feedstock Energy (Included) |
| Nylon 6,6 | 138.60 | 6.50 | 50.7 MJ/kg Feedstock Energy (Included) |
| Polycarbonate | 112.90 | 3.06 | 36.7 MJ/kg Feedstock Energy (Included) |
| Polypropylene, Oriented Film | 99.20 | 2.70 | 52.7 MJ/kg Feedstock Energy (Included) |
| Polypropylene, Injection Moulding | 115.10 | 3.90 | 54 MJ/kg Feedstock Energy (Included) |
| Expanded Polystyrene | 88.60 | 2.50 | 46.2 MJ/kg Feedstock Energy (Included) |
| General Purpose Polystyrene | 86.40 | 2.70 | 46.3 MJ/kg Feedstock Energy (Included) |
| High Impact Polystyrene | 87.40 | 2.85 | 46.4 MJ/kg Feedstock Energy (Included) |
| Thermoformed Expanded Polystyrene | 109.20 | 3.40 | 49.7 MJ/kg Feedstock Energy (Included) |
| Polyurethane | 72.10 | 3.00 | 34.6 MJ/kg Feedstock Energy (Included). Poor data availability of feedstock energy |
| PVC General | 77.20 | 2.41 | 28.1 MJ/kg Feedstock Energy (Included). Assumed market average use of types of PVC in the European construction industry |
| PVC Pipe | 87.50 | 2.56 | 24.4 MJ/kg Feedstock Energy (Included) |
| Calendered Sheet PVC | 68.60 | 2.66 | 24.4 MJ/kg Feedstock Energy (Included) |
| PVC Injection Moulding | 95.10 | 2.20 | 35.1 MJ/kg Feedstock Energy (Included) |
| UPVC Film | 69.40 | 2.50 | 25.3 MJ/kg Feedstock Energy (Included) |

**Rubber**

| General | 101.70 | 3.18 | 41.1 MJ/kg Feedstock Energy (Included). Assumes that natural rubber accounts for 35% of market. Difficult to estimate carbon emissions |
| Synthetic rubber | 110.90 | 4.00 | 42 MJ/kg Feedstock Energy (Included). Difficult to estimate carbon emissions |
| Natural latex rubber | 67.60 | 1.63 | 39.43 MJ/kg Feedstock Energy (Included). Feedstock from the production of carbon black. Difficult to estimate carbon emissions |

**Sand**

| General | 0.10 | 0.005 |

**Sealants and adhesives**

| Epoxide Resin | 139.30 | 5.91 | 42.6 MJ/kg Feedstock Energy (Included) |
| Mastic Sealant | 62.3 to 200 | - | |
| Melamine Resin | 113.00 | - | Reference 77 |
| Phenol Formaldehyde | 87 to 90.3 | 3.40 | |
| Urea Formaldehyde | 40 to 78.2 | 1.3 to 2.28 | |

**Soil**

| General (Rammed Soil) | 0.45 | 0.023 |
# INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy &amp; Carbon Data</th>
<th>Comments</th>
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<td>EC - kgCO2/Kg</td>
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Data on stone was difficult to select, with high standard deviations and data ranges.
All timber values exclude the Calorific Value (CV) of wood. Timber values were particularly difficult to select!

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## INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

**Materials** | **Embodied Energy & Carbon Data** | **Comments**
--- | --- | ---
 | **EE** - MJ/kg | **EC** - kgCO2/Kg | **EE = Embodied Energy, EC = Embodied Carbon**

### Miscellaneous:

<table>
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<tr>
<th>PV Modules</th>
<th>Embodied Energy - MJ</th>
<th>Embodied Carbon - Kg CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocrystalline</td>
<td>4750 (2590 to 8640)</td>
<td>242 (132 to 440)</td>
</tr>
<tr>
<td>Polycrystalline</td>
<td>4070 (1945 to 5660)</td>
<td>268 (99 to 289)</td>
</tr>
<tr>
<td>ThinFilm</td>
<td>1305 (775 to 1800)</td>
<td>97 (60 to 92)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Windows</th>
<th>Embodied Energy - MJ</th>
<th>Embodied Carbon - Kg CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2mx1.2m Single Glazed Timber Framed Unit</td>
<td>286 ?</td>
<td>14.60</td>
</tr>
<tr>
<td>1.2mx1.2m Double Glazed (Air or Argon Filled):</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Aluminium Framed</td>
<td>3470</td>
<td>270</td>
</tr>
<tr>
<td>PVC Framed</td>
<td>2150 to 2470</td>
<td>110 to 126</td>
</tr>
<tr>
<td>Aluminium-Clad Timber Framed</td>
<td>950 to 1460</td>
<td>48 to 74</td>
</tr>
<tr>
<td>Timber Framed</td>
<td>230 to 490</td>
<td>12 to 25</td>
</tr>
<tr>
<td>Krypton Filled Add:</td>
<td>510</td>
<td>36</td>
</tr>
<tr>
<td>Xenon Filled Add:</td>
<td>4500</td>
<td>229</td>
</tr>
</tbody>
</table>
Guide to the Material Profiles

The following worksheets contain profiles of the main materials within this inventory. The inventory was created through manually analysing the separate ICE-Database, which stored data on each value of embodied energy/carbon (i.e. Data source and where possible a hyperlink to the report, year of data, boundary conditions, fuel mix, specific comments...etc). The full ICE database contains far more detail than available in this inventory. These profiles have been created to present a summary of the database and to present the embodied energy & carbon values. Below you will find an example of a profile (largely blank) which has been separated into smaller segments to allow a clearer annotation of each section.

Section 1: Database statistics

The materials were broken down into sub-categories, which reflected how the data is stored within the database. Most materials have a general category, and are possibly broken down into more specific forms i.e. Aluminium general, Aluminium extruded..., etc. Each of the sub-categories are then broken down into further classifications according to the recycled/virgin content of the material. In many cases the authors of the data sources have not specified this data, hence it was required to create an unspecified classification.

Here are simple statistics from the main ICE-Database. They include the number of records within the database, which represents the sample size that was used to select this data. This may be used as a (simple) indicator of the quality and reliability of the selected values. Additional statistics include the average embodied energy (EE) from the literature; this should not be used in place of the selected values. The ICE database stored the data as published by the original author, hence each record had different boundary conditions or were for a very specific/rare form of the material. These facts can not be represented by statistics but only with manual examination of the ICE-Database records. However, in many cases these statistics are similar to the selected ‘best’ values. Finally, the standard deviation and a full data range are presented to maintain an openness to this inventory.

Material Profile: Example

The values of embodied energy are presented here; the example below is only for materials that can be recycled, i.e. metals. The format of presentation has minor variations according to the needs of the data being presented. The ‘general’ material classification is the value that should be used if unsure of which value to select. The primary material is for predominantly virgin materials and secondary for predominantly recycled materials i.e. many authors allow a slight fraction of recycled material under a primary classification, but these are not always stated. Alternatively a recycled content could be assumed and these values can be used to estimate the embodied energy for any given recycled content.

The embodied carbon has been presented separately. Again the values distinguish between primary (virgin) materials, secondary (recycled) materials and the average value typical of the UK market place. The best range is what the author of this work believes to be a more appropriate range than the full range given in the database statistics (presented in section 1, above). The selection of the range and the ‘best’ values of embodied energy was not an easy task, especially with so many holes in data provided by authors, but they provide a useful insight into the potential variations of embodied energy within this material. The selected coefficient of embodied energy may not fall within the centre of the range for a number of reasons. The selected value of embodied energy tries to represent the average on the marketplace. However, variations in manufacturing methods or factory efficiency are inevitable.

Section 2: Selected (or ‘Best’) values of embodied energy & carbon

The best range is what the author of this work believes to be a more appropriate range than the full range given in the database statistics (presented in section 1, above). The selection of the range and the ‘best’ values of embodied energy was not an easy task, especially with so many holes in data provided by authors, but they provide a useful insight into the potential variations of embodied energy within this material. The selected coefficient of embodied energy may not fall within the centre of the range for a number of reasons. The selected value of embodied energy tries to represent the average on the marketplace. However, variations in manufacturing methods or factory efficiency are inevitable.
Guide to the Material Profiles

Section 3: Scatter Graph and Fuel split & embodied carbon split

There is a scatter graph for each material (sometimes more than one scatter graph where it is beneficial). The scatter graph plots the year of data versus the value of embodied energy for each data point in the database. This maintains the transparency of this inventory and highlights any historical variations in data values, which may be a result of technological shifts. It could also be determined whether a small number of data points distort the above database statistics.

The fuel split is presented here along with the fraction of embodied carbon resulting from the energy source (or additional carbon released from non-energy sources). Ideally this data will be specified by authors completing a detailed study, but this was seldom the case and in many cases this data was estimated from the typical fuel mix within the relevant UK industry which was obtained from the Department of Trade and Industry (DTI). In several cases it was not possible to provide a fuel mix or carbon breakdown. Here the typical embodied carbon was estimated based on values specified by authors in the literature.

Where possible the historical embodied carbon per unit fuel (energy) use was calculated as an index of 1990 data. This data is general and was estimated from the typical fuel split in the most appropriate industry. It was not a detailed analysis, in that it is generalised for the entire industry and not for specific products. It illustrates any improvement in carbon emissions since 1990 and the variation in carbon contributions by (fuel) source. This section does not appear on all profiles.

Data extracted from the most recent CIBSE guide (Volume A) is presented here for each material. The list of materials here was in many cases more specific than there is data available on embodied energy. But it may be possible to estimate the appropriate embodied energy from the most similar material in the inventory or to use the general category.

Data extracted from the most recent CIBSE guide (Volume A) is presented here for each material. The list of materials here was in many cases more specific than there is data available on embodied energy. But it may be possible to estimate the appropriate embodied energy from the most similar material in the inventory or to use the general category.

Section 4: Material Properties (CIBSE Data)

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>230</td>
<td>2700</td>
<td>888</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Galvanised</td>
<td>45</td>
<td>7080</td>
<td>425</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Material Profile: Aggregate

Embodied Energy (EE) Database Statistics - MJ/Kg

| Material         | No. Records | Average EE (MJ/Kg) | Standard Deviation | Minimum EE (MJ/Kg) | Maximum EE (MJ/Kg) | Comments on the Database Statistics:
|------------------|-------------|--------------------|--------------------|-------------------|--------------------|-----------------------------------------------
| Aggregate        | 36          | 0.11               | 0.12               | 0.01              | 0.50               | None                                          
| Aggregate, General| 36          | 0.11               | 0.12               | 0.01              | 0.50               | None                                          
| Predominantly Recycled | 3   | 0.25               | 0.01               | 0.10              | 0.40               | None                                          
| Unspecified      | 17          | 0.11               | 0.07               | 0.02              | 0.28               | None                                          
| Virgin           | 16          | 0.11               | 0.15               | 0.01              | 0.50               | None                                          

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy (MJ/Kg)</th>
<th>Embodied Carbon (Kg CO2/Kg)</th>
<th>Boundaries</th>
<th>Best EE Range (MJ/Kg)</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Aggregate</td>
<td>0.1</td>
<td>0.005</td>
<td>Cradle to Gate</td>
<td>0.05</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Comments

It should be noted that the scatter graph does not display all of the data that needs to be considered when selecting a best value, e.g., the boundary conditions (cradle to site, cradle to gate...etc), these are stored in the database but they are not represented in the scatter graph. Transport will likely be significant for aggregates.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m⁻¹K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aggregate</td>
<td>Undried</td>
<td>1.8</td>
<td>2240</td>
<td>840</td>
<td>9.56E⁻⁰⁷</td>
</tr>
<tr>
<td>aggregate (sand, gravel or stone)</td>
<td>Oven dried</td>
<td>1.3</td>
<td>2240</td>
<td>920</td>
<td>6.30E⁻⁰⁷</td>
</tr>
</tbody>
</table>
**Material Profile: Aluminium**

**Embodied Energy (EE) Database Statistics - MJ/Kg**

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>111</td>
<td>157.1</td>
<td>104.7</td>
<td>8.0</td>
<td>252.7</td>
<td></td>
</tr>
<tr>
<td>50% Recycled</td>
<td>4</td>
<td>105.6</td>
<td>53.4</td>
<td>56.9</td>
<td>184.0</td>
<td></td>
</tr>
<tr>
<td>Other Specification</td>
<td>2</td>
<td>149.5</td>
<td>76.5</td>
<td>55.0</td>
<td>183.2</td>
<td></td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>28</td>
<td>17.9</td>
<td>6.9</td>
<td>3.0</td>
<td>42.3</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>14</td>
<td>199.1</td>
<td>67.9</td>
<td>66.1</td>
<td>249.9</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>62</td>
<td>224.4</td>
<td>68.9</td>
<td>53.2</td>
<td>332.5</td>
<td></td>
</tr>
</tbody>
</table>

**Selected Embodied Energy & Carbon Values and Associated Data**

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical Primary Secondary</td>
<td>UK Typical Primary Secondary</td>
<td>Cradle to Gate</td>
<td>Low EE High EE</td>
<td></td>
</tr>
<tr>
<td>General Aluminium</td>
<td>155.00</td>
<td>218</td>
<td>28.8</td>
<td>8.24</td>
<td>11.5</td>
</tr>
<tr>
<td>Cast Products</td>
<td>159.00</td>
<td>225.5</td>
<td>24.5</td>
<td>8.28</td>
<td>11.7</td>
</tr>
<tr>
<td>Extruded</td>
<td>154.00</td>
<td>213.5</td>
<td>34.1</td>
<td>8.16</td>
<td>11.2</td>
</tr>
<tr>
<td>Rolled</td>
<td>155.00</td>
<td>217</td>
<td>27.8</td>
<td>8.26</td>
<td>11.5</td>
</tr>
</tbody>
</table>

**Comments**

Worldwide average data was selected and obtained from the International Aluminium Institute (IAI). The data is freely available from the IAI. The averages from the database statistics are in good agreement with the final selected values. The value for general aluminium was calculated assuming the UK split between the different forms of aluminium. The selected value for secondary aluminium is towards the top of the full data range in the database. This is because the value depends upon the level of material processing (i.e., ingot or (semi-) fabricated product). A 33% recycled content (worldwide average) was assumed for the typical market values statistic from the IAI, International Aluminium Institute). Primary aluminium production does have feedstock energy; this is because primary aluminium uses coke as a raw material in the production of carbon anodes. Please see note on recycling methodology at the front of the document.

**Material Scatter Graph**

EE Scatter Graph - Aluminium

**Fuel Split & Embodied Carbon Data**

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>63.6%</td>
<td>57.2%</td>
</tr>
<tr>
<td>Other</td>
<td>36.4%</td>
<td>42.8%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Fuel Split & Embodied Carbon Comments:**

The fraction of energy and carbon from electricity was extracted from an IAI (International Aluminium Institute) report.

**Material Properties (CIBSE Data)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m K-1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (M^2 S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td></td>
<td>230</td>
<td>2700</td>
<td>880</td>
<td>9.68013E-09</td>
</tr>
<tr>
<td>Aluminium cladding</td>
<td></td>
<td>45</td>
<td>7680</td>
<td>420</td>
<td>1.39509E-09</td>
</tr>
</tbody>
</table>
Material Profile: Asphalt

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>17</td>
<td>6.63</td>
<td>11.89</td>
<td>0.20</td>
<td>50.20</td>
<td></td>
</tr>
<tr>
<td>Asphalt, General</td>
<td>17</td>
<td>6.63</td>
<td>11.89</td>
<td>0.20</td>
<td>50.20</td>
<td></td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>2</td>
<td>7.32</td>
<td>0.28</td>
<td>7.12</td>
<td>7.52</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>13</td>
<td>7.46</td>
<td>13.47</td>
<td>0.23</td>
<td>50.20</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>2</td>
<td>0.49</td>
<td>0.40</td>
<td>0.20</td>
<td>0.77</td>
<td></td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embedded Energy (MJ/Kg)</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Low EE</th>
<th>High EE</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Asphalt</td>
<td>2.6</td>
<td>1.91</td>
<td>0.045</td>
<td>Cradle to Gate</td>
<td>0.23</td>
<td>4</td>
<td>See main comments</td>
</tr>
<tr>
<td>Roads &amp; Pavements</td>
<td>2.41</td>
<td>0.82</td>
<td>0.14</td>
<td>Not enough data sources</td>
<td>Very limited data, see reference 123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road Example</td>
<td>2.672 MJ/Sqm</td>
<td>908 MJ/Sqm</td>
<td>134 KgCO2/Sqm</td>
<td>40 year life time</td>
<td>Not enough data sources</td>
<td>limited data</td>
<td></td>
</tr>
</tbody>
</table>

Comments

Asphalt is a mixture of mineral aggregate with a bituminous binder, however in the US the term 'asphalt' is used as the term for 'bitumen' itself. This is obviously a cause of confusion, especially due to the large difference in embodied energy of these two distinct materials. Overall this data was difficult to select. The scatter graph below displays that the selected value is towards the lower end of the range. This is most likely because most of the resources did not specify if the data included feedstock energy (in fact most of them probably include them). There is a further problem from authors assuming that asphalt and bitumen have the same embodied energy (which is very inaccurate). Inappropriate use of the names asphalt and bitumen and international differences between the use of these names cause additional confusion. Consequently, the data was stored in its quoted form, as a result the data set (as seen in the scatter graph) has inconsistent boundaries and certain assumptions were required to be made when analysing the data.

Embodied Energy Scatter Graph - Asphalt

EE Scatter Graph - Asphalt

NO fuel split and embodied carbon breakdown data available. The values used were quoted in the main sources.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m K -1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg -1 K -1)</th>
<th>Thermal Diffusivity [*2 8 S -1]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt A</td>
<td></td>
<td>0.5</td>
<td>1700</td>
<td>1000</td>
<td>2.941E8E-07</td>
<td>The CIBSE guide provides two sets of values from different sources</td>
</tr>
<tr>
<td>Asphalt B</td>
<td></td>
<td>1.2</td>
<td>2300</td>
<td>1700</td>
<td>3.669E8E-07</td>
<td></td>
</tr>
<tr>
<td>Insured</td>
<td></td>
<td>1.2</td>
<td>2100</td>
<td>920</td>
<td>6.211E8E-07</td>
<td></td>
</tr>
<tr>
<td>Reflective coat</td>
<td></td>
<td>1.2</td>
<td>2300</td>
<td>1700</td>
<td>3.669E8E-07</td>
<td></td>
</tr>
<tr>
<td>Roofing, insulating</td>
<td></td>
<td>1.15</td>
<td>2330</td>
<td>840</td>
<td>5.874E8E-07</td>
<td></td>
</tr>
</tbody>
</table>
Material Profile: Bitumen

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>7</td>
<td>17.91</td>
<td>20.21</td>
<td>2.40</td>
<td>50.00</td>
<td>Very poor data availability and very large data range.</td>
</tr>
<tr>
<td>Bitumen, General</td>
<td>7</td>
<td>17.91</td>
<td>20.21</td>
<td>2.40</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>6</td>
<td>20.50</td>
<td>20.84</td>
<td>3.38</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>1</td>
<td>2.40</td>
<td>2.40</td>
<td>2.40</td>
<td>2.40</td>
<td></td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

Material Profile: Bitumen

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Bitumen</td>
<td>47</td>
<td>37.7 (?)</td>
<td>0.48</td>
<td>Cradle to Gate</td>
<td>(+/- 30%)</td>
<td>Unknown embodied carbon</td>
</tr>
</tbody>
</table>

Bitumen is a black/brown, sticky substance that is often used in paving roads or for waterproofing. Bitumen may be natural (crude bitumen) or synthetic (refined). Refined bitumen is the residual (bottom) fraction obtained by fractional distillation of crude oil. Naturally occurring crude bitumen is the prime feed stock for petroleum production from tar sands, of which the largest know reserves are in Canada. Bitumen must not be confused with asphalt, which is a mineral aggregate with a bituminous binder, however in the US the term 'asphalt' is used as the term for 'bitumen'. For selection of best values we experienced similar problems to asphalt (Bitumen is used to make asphalt), but with a smaller sample size. There was additional confusion as a result of the English speaking languages (British, American, Australian and Canadian) using the term 'Bitumen' in different ways. The author believes that the large data range can mainly be attributed to feedstocks. Bitumen is produced from oil, as such it has a high feedstock energy value. The inconsistencies among authors specifying embodied energy values made the data range appear larger than it should be.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m K-1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (M^2 S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen, composite, flooring</td>
<td></td>
<td>0.85</td>
<td>2400</td>
<td>1000</td>
<td>3.54167E-07</td>
</tr>
<tr>
<td>Bitumen, insulation, all types</td>
<td></td>
<td>0.2</td>
<td>1000</td>
<td>1700</td>
<td>1.17647E-07</td>
</tr>
</tbody>
</table>
## Material Profile: Brass

### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>9</td>
<td>80.70</td>
<td>71.87</td>
<td>16.81</td>
<td>239.00</td>
<td>Poor data quantity</td>
</tr>
<tr>
<td>Brass, General</td>
<td>9</td>
<td>80.70</td>
<td>71.87</td>
<td>16.81</td>
<td>239.00</td>
<td></td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>1</td>
<td>39.00</td>
<td>39.00</td>
<td>39.00</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>5</td>
<td>113.95</td>
<td>72.67</td>
<td>62.00</td>
<td>239.00</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>2</td>
<td>16.81</td>
<td>16.81</td>
<td>16.81</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Brass</td>
<td>44</td>
<td>2.42 (?)</td>
<td>Cradle to Gate</td>
<td>Low EE</td>
<td>60% recycled material assumed</td>
</tr>
<tr>
<td>Primary Brass</td>
<td>80</td>
<td>4.39 (?)</td>
<td></td>
<td>High EE</td>
<td>100</td>
</tr>
<tr>
<td>Secondary Brass</td>
<td>20</td>
<td>1.1 (?)</td>
<td></td>
<td></td>
<td>30 ?</td>
</tr>
</tbody>
</table>

### Comments

Largely dependent upon ore grade. Very poor carbon data, which made estimating the carbon emissions difficult. This was estimated based on the mix of fuels in the UK brass industry. This method was not ideal but was all that could be estimated in the time available. Assumed recycled content of 60%.

### Material Scatter Graph

#### EE Scatter Graph - Brass

![EE Scatter Graph - Brass](image)

### Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>4.0%</td>
<td>5.9%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>10.8%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>19.0%</td>
<td>16.1%</td>
</tr>
<tr>
<td>Electricity</td>
<td>66.2%</td>
<td>65.6%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

#### Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in the closest available industry (Copper).

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m·K)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg·K)</th>
<th>Thermal Diffusivity (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td></td>
<td>110</td>
<td>8500</td>
<td>390</td>
<td>3.31825E-05</td>
</tr>
</tbody>
</table>
NOTE: Bronze only had two data sources, hence a material profile could not be produced

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronze</td>
<td>2</td>
<td>69.34</td>
<td>10.37</td>
<td>62.00</td>
<td>76.67</td>
</tr>
<tr>
<td>Bronze, general</td>
<td>2</td>
<td>69.34</td>
<td>10.37</td>
<td>62.00</td>
<td>76.67</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1</td>
<td>76.67</td>
<td>76.67</td>
<td>76.67</td>
<td>76.67</td>
</tr>
<tr>
<td>Virgin</td>
<td>1</td>
<td>62.00</td>
<td>62.00</td>
<td>62.00</td>
<td>62.00</td>
</tr>
</tbody>
</table>

**Material Properties (CIBSE Data)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (M² S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronze</td>
<td></td>
<td>64</td>
<td>8150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Material Profile: Carpets

**Embodied Energy (EE) Database Statistics - MJ/Kg**

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet</td>
<td>20</td>
<td>99.41</td>
<td>3.00</td>
<td>390.00</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>20</td>
<td>99.41</td>
<td>3.00</td>
<td>390.00</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

**Selected Embodied Energy & Carbon Values and Associated Data**

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Carpet</td>
<td>74.4 (186.7 per sqm)</td>
<td>3.09 (9.76 per sqm)</td>
<td>Cradle to Cradle</td>
<td>Low EE 44.4 High EE 104.4</td>
<td>Reference 77</td>
</tr>
<tr>
<td>Felt (Hair and Jute) Underlay</td>
<td>18.5</td>
<td>0.98</td>
<td>-</td>
<td>-</td>
<td>Very difficult to select value, few sources, large data range, value includes feedstocks</td>
</tr>
<tr>
<td>Nylon</td>
<td>67.9 to 149</td>
<td>3.55 to 7.31</td>
<td>-</td>
<td>-</td>
<td>Includes feedstocks</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>95.4 (120 MJ/sqm)</td>
<td>5.03</td>
<td>-</td>
<td>-</td>
<td>Includes feedstocks</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>72.1</td>
<td>3.78</td>
<td>-</td>
<td>-</td>
<td>Includes feedstocks</td>
</tr>
<tr>
<td>Rubber</td>
<td>67.5 to 140</td>
<td>3.91 to 8.11</td>
<td>-</td>
<td>-</td>
<td>Reference 77</td>
</tr>
<tr>
<td>Saturated Felt Underlay (impregnated with Asphalt or tar)</td>
<td>31.7</td>
<td>1.7</td>
<td>-</td>
<td>-</td>
<td>References 77, 165 &amp; 234</td>
</tr>
<tr>
<td>Wool</td>
<td>100 (64 MJ/sqm)</td>
<td>5.48</td>
<td>-</td>
<td>-</td>
<td>References 57, 165 &amp; 234</td>
</tr>
</tbody>
</table>

**Material Properties (CIBSE Data)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>with cellular rubber underlay</td>
<td>-</td>
<td>0.2</td>
<td>400</td>
<td>1350</td>
<td>1.83E-06</td>
</tr>
<tr>
<td>synthetic</td>
<td>-</td>
<td>0.06</td>
<td>160</td>
<td>2500</td>
<td>0.00000010</td>
</tr>
<tr>
<td>polyurethane board, cellular</td>
<td>-</td>
<td>0.024</td>
<td>32</td>
<td>920</td>
<td>6.79E-07</td>
</tr>
<tr>
<td>polyurethane</td>
<td>-</td>
<td>0.02</td>
<td>32</td>
<td>920</td>
<td>6.45E-07</td>
</tr>
<tr>
<td>polyurethane, expanded (EPS)</td>
<td>-</td>
<td>0.05</td>
<td>23</td>
<td>1470</td>
<td>6.79E-07</td>
</tr>
<tr>
<td>polystyrene, extruded (EPS)</td>
<td>-</td>
<td>0.22</td>
<td>35</td>
<td>1470</td>
<td>6.33E-07</td>
</tr>
<tr>
<td>polyethylene, expanded (PEX)</td>
<td>-</td>
<td>0.04</td>
<td>100</td>
<td>750</td>
<td>6.33E-07</td>
</tr>
<tr>
<td>balsa, expanded, panels</td>
<td>-</td>
<td>0.18</td>
<td>355</td>
<td>840</td>
<td>2.78E-07</td>
</tr>
<tr>
<td>balsa, expanded, pure</td>
<td>-</td>
<td>0.20</td>
<td>355</td>
<td>840</td>
<td>1.93E-07</td>
</tr>
<tr>
<td>silicon</td>
<td>-</td>
<td>0.18</td>
<td>700</td>
<td>1000</td>
<td>2.37E-07</td>
</tr>
</tbody>
</table>

The majority of the above data was selected from the American institute of Architects Environmental Resource Guide (Reference 77). There was a shortage of quality data on carpets.

The embodied carbon was estimated by using the UK typical fuel split in this industry.
### Material Profile: Cement

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>112</td>
<td>5.08</td>
<td>2.54</td>
<td>0.10</td>
<td>11.73</td>
</tr>
<tr>
<td>Cement Mortar</td>
<td>11</td>
<td>1.54</td>
<td>0.91</td>
<td>0.10</td>
<td>3.49</td>
</tr>
<tr>
<td>Unspecified</td>
<td>9</td>
<td>1.30</td>
<td>0.70</td>
<td>0.10</td>
<td>2.10</td>
</tr>
<tr>
<td>Virgin</td>
<td>2</td>
<td>2.63</td>
<td>1.22</td>
<td>1.77</td>
<td>3.49</td>
</tr>
<tr>
<td>Cement, Fibre Cement</td>
<td>1</td>
<td>4.60</td>
<td>4.60</td>
<td>4.60</td>
<td>-</td>
</tr>
<tr>
<td>Virgin</td>
<td>1</td>
<td>4.60</td>
<td>4.60</td>
<td>4.60</td>
<td>-</td>
</tr>
<tr>
<td>Cement, Fibre Cement</td>
<td>6</td>
<td>9.57</td>
<td>1.22</td>
<td>7.60</td>
<td>10.90</td>
</tr>
<tr>
<td>Unspecified</td>
<td>4</td>
<td>9.71</td>
<td>1.55</td>
<td>7.60</td>
<td>10.90</td>
</tr>
<tr>
<td>Virgin</td>
<td>2</td>
<td>9.28</td>
<td>0.17</td>
<td>9.16</td>
<td>9.40</td>
</tr>
<tr>
<td>Cement, General</td>
<td>92</td>
<td>5.32</td>
<td>2.05</td>
<td>1.42</td>
<td>11.73</td>
</tr>
<tr>
<td>Market Average</td>
<td>7</td>
<td>5.02</td>
<td>0.66</td>
<td>4.29</td>
<td>6.20</td>
</tr>
<tr>
<td>Unspecified</td>
<td>65</td>
<td>5.46</td>
<td>2.27</td>
<td>1.42</td>
<td>11.73</td>
</tr>
<tr>
<td>Virgin</td>
<td>20</td>
<td>4.82</td>
<td>1.07</td>
<td>3.00</td>
<td>6.50</td>
</tr>
<tr>
<td>Cement, Soil-Cement</td>
<td>2</td>
<td>0.85</td>
<td>0.21</td>
<td>0.70</td>
<td>1.00</td>
</tr>
<tr>
<td>Unspecified</td>
<td>2</td>
<td>0.85</td>
<td>0.21</td>
<td>0.70</td>
<td>1.00</td>
</tr>
</tbody>
</table>

#### Comments on the Database Statistics:
- There was an excellent sample size of data for cement.

---

### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy (EE) Database Statistics - MJ/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>5.08 ± 2.54</td>
</tr>
<tr>
<td>Cement Mortar</td>
<td>1.54 ± 0.91</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1.30 ± 0.70</td>
</tr>
<tr>
<td>Virgin</td>
<td>2.63 ± 1.22</td>
</tr>
<tr>
<td>Cement, Fibre Cement</td>
<td>4.60 ± 4.60</td>
</tr>
<tr>
<td>Virgin</td>
<td>4.60 ± 4.60</td>
</tr>
<tr>
<td>Cement, Fibre Cement</td>
<td>9.57 ± 1.22</td>
</tr>
<tr>
<td>Unspecified</td>
<td>9.71 ± 1.55</td>
</tr>
<tr>
<td>Virgin</td>
<td>9.28 ± 0.17</td>
</tr>
<tr>
<td>Cement, General</td>
<td>5.32 ± 2.05</td>
</tr>
<tr>
<td>Market Average</td>
<td>5.02 ± 0.66</td>
</tr>
<tr>
<td>Unspecified</td>
<td>5.46 ± 2.27</td>
</tr>
<tr>
<td>Virgin</td>
<td>4.82 ± 1.07</td>
</tr>
<tr>
<td>Cement, Soil-Cement</td>
<td>0.85 ± 0.21</td>
</tr>
<tr>
<td>Unspecified</td>
<td>0.85 ± 0.21</td>
</tr>
</tbody>
</table>

---

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m·K, at 20°C)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Dry</td>
<td>0.72</td>
<td>1900</td>
<td>840</td>
<td>4.6502E-09</td>
</tr>
<tr>
<td>Cement blocks, cellular</td>
<td>Cool</td>
<td>0.29</td>
<td>1300</td>
<td>3.044E-09</td>
<td></td>
</tr>
<tr>
<td>Cement block, magnesium oxychloride sulphate</td>
<td>Cool</td>
<td>0.81</td>
<td>2000</td>
<td>1.8022E-07</td>
<td></td>
</tr>
<tr>
<td>Cement mortar</td>
<td>Dry</td>
<td>0.72</td>
<td>1900</td>
<td>840</td>
<td>4.7420E-09</td>
</tr>
<tr>
<td>Cement mortar</td>
<td>Moist</td>
<td>0.93</td>
<td>1900</td>
<td>840</td>
<td>5.8270E-09</td>
</tr>
<tr>
<td>Concrete masonry, wood fiber A</td>
<td>Dry</td>
<td>0.89</td>
<td>350</td>
<td>1.2023E-07</td>
<td></td>
</tr>
<tr>
<td>Concrete masonry, wood fiber B</td>
<td>Moist</td>
<td>0.90</td>
<td>350</td>
<td>1.1278E-07</td>
<td></td>
</tr>
<tr>
<td>Concrete masonry, wood fiber C</td>
<td>Dry</td>
<td>0.12</td>
<td>400</td>
<td>2.0428E-07</td>
<td></td>
</tr>
<tr>
<td>Concrete masonry, wood fiber D</td>
<td>Dry</td>
<td>0.35</td>
<td>1650</td>
<td>2.5232E-07</td>
<td></td>
</tr>
<tr>
<td>Cement Screed</td>
<td>1.4</td>
<td>2100</td>
<td>654</td>
<td></td>
<td>1.02384E-07</td>
</tr>
</tbody>
</table>

---

**Material Properties:** Cement is an important building material due to its use in the manufacture of concrete. There are a wide range of cement types with a large variation in the embodied energy and carbon, but the typical cement (general category above) provides a good value to use in the absence of knowing which type of cement has been used in construction. This typical value is consistent with the database statistics and modern sources of data. The scatter graph shows a large amount of modern data.

---

**Fuel Split & Embodied Carbon Data:**

- 0.51 KgCO₂/Kg is released by de-carbonation in manufacture of clinker, which is the main constituent of cement. This has been represented in the row labelled 'other' above.

---

**Material Energy Source % of Embodied Energy from source**

- Coal: 70.9%
- LPG: 31.1%
- Natural gas: 31.1%
- Electricity: 12%
- Other: 0.5% (Non-fuel emission)

---

**Material Energy Source % of Embodied Carbon from source**

- Coal: 0.0%
- LPG: 0.0%
- Natural gas: 61%
- Electricity: 30%
- Other: 0.5% (Non-fuel emission)

---

**Material Energy Source Total**

- 100.0%

---

**Material Energy Source Total (Non-fuel emission)**

- 61%

---

**Material Energy Source Total (Estimated from the ICE Cement, Mortar & Concrete Model)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy Source</th>
<th>% of Embodied Energy from source</th>
<th>% of Embodied Carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Coal</td>
<td>70.9%</td>
<td>31.1%</td>
</tr>
<tr>
<td>Cement-mortar</td>
<td>LPG</td>
<td>31.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Cement, General</td>
<td>Natural gas</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Cement, Soil-Cement</td>
<td>Electricity</td>
<td>12%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Cement, General</td>
<td>Other</td>
<td>0.5% (Non-fuel emission)</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

---

### ICE V1.6a

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Material Profile: Ceramics

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic</td>
<td>17</td>
<td>10.01</td>
<td>8.27</td>
<td>2.50</td>
<td>29.07</td>
<td>None</td>
</tr>
<tr>
<td>Ceramic, General</td>
<td>17</td>
<td>10.01</td>
<td>8.27</td>
<td>2.50</td>
<td>29.07</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>15</td>
<td>10.96</td>
<td>8.36</td>
<td>2.50</td>
<td>29.07</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>2</td>
<td>2.90</td>
<td>0.57</td>
<td>2.50</td>
<td>3.30</td>
<td>None</td>
</tr>
</tbody>
</table>

Low EE High EE

General Ceramics

There was an incredible data range, which made selection of a single value difficult.

Fittings

Reference 1

Refractory products

Estimated Range (+/- 30%)

Sanitary Products

Tile

The scatter graph displays a large data range, which made selection of a best value difficult. The large range may be attributed to different types of ceramic products.

Material Scatter Graph

Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Ceramics</td>
<td>10</td>
<td>0.65</td>
<td>Cradle to Gate</td>
<td>2.5, 29.1</td>
<td>There was an incredible data range, which made selection of a single value difficult.</td>
</tr>
<tr>
<td>Fittings</td>
<td>20</td>
<td>1.05</td>
<td></td>
<td></td>
<td>Reference 1</td>
</tr>
<tr>
<td>Refractory products</td>
<td>5.5</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanitary Products</td>
<td>29</td>
<td>1.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tile</td>
<td>9</td>
<td>0.59</td>
<td></td>
<td>2.5, 19.5</td>
<td></td>
</tr>
</tbody>
</table>

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m-1 K-1)</th>
<th>Density (kg m-3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (m² S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic tiles</td>
<td>Dry</td>
<td>1.2</td>
<td>2000</td>
<td>1000</td>
<td>7.05882E-07</td>
</tr>
<tr>
<td>Ceramic floor tiles</td>
<td>Dry</td>
<td>0.6</td>
<td>1150</td>
<td>1150</td>
<td>5.53633E-07</td>
</tr>
<tr>
<td>Clay tiles</td>
<td>Dry</td>
<td>0.65</td>
<td>1990</td>
<td>1150</td>
<td>5.32581E-07</td>
</tr>
<tr>
<td>Clay tiles, burnt</td>
<td></td>
<td>1.3</td>
<td>2000</td>
<td>1150</td>
<td>7.7381E-07</td>
</tr>
<tr>
<td>Clay tile, hollow, 10.2mm, 1 cell</td>
<td></td>
<td>0.52</td>
<td>1120</td>
<td>1120</td>
<td>5.52721E-07</td>
</tr>
<tr>
<td>Clay tile, hollow, 20.3mm, 2 cells</td>
<td></td>
<td>0.625</td>
<td>1120</td>
<td>1120</td>
<td>6.62202E-07</td>
</tr>
<tr>
<td>Clay tile, hollow, 32.5mm, 3 cells</td>
<td></td>
<td>0.695</td>
<td>1120</td>
<td>1120</td>
<td>7.36607E-07</td>
</tr>
<tr>
<td>Clay tile, parlor</td>
<td></td>
<td>1.810</td>
<td>1020</td>
<td>1150</td>
<td>1.11793E-06</td>
</tr>
</tbody>
</table>

The embodied carbon was estimated by using the UK typical fuel split in this industry. The fuel split is for general ceramics.

Historical embodied carbon per unit fuel use

Material (CIBSE Data)
### Material Profile: Clay (including Bricks)

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material Profile</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>79</td>
<td>4.30</td>
<td>0.02</td>
<td>32.40</td>
<td>37.40</td>
<td>There was a good sample size</td>
</tr>
<tr>
<td>Clay, General</td>
<td>79</td>
<td>4.30</td>
<td>0.02</td>
<td>32.40</td>
<td>37.40</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>58</td>
<td>4.53</td>
<td>0.07</td>
<td>32.40</td>
<td>37.40</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>21</td>
<td>3.59</td>
<td>0.02</td>
<td>7.60</td>
<td>5.60</td>
<td></td>
</tr>
</tbody>
</table>

#### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General simple baked clay products</td>
<td>3</td>
<td>0.22</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Vitrified clay pipe DN 100 &amp; DN 150</td>
<td>6.2</td>
<td>0.46</td>
<td>2.68</td>
<td>11.7</td>
</tr>
<tr>
<td>Vitrified clay pipe DN 200 &amp; DN 300</td>
<td>7</td>
<td>0.49</td>
<td>Estimated range +/- 30%</td>
<td></td>
</tr>
<tr>
<td>Vitrified clay pipe DN 500</td>
<td>7.9</td>
<td>0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Clay Bricks</td>
<td>3 +/-1</td>
<td>0.22</td>
<td>0.63</td>
<td>6</td>
</tr>
<tr>
<td>EXAMPLE: Single Brick</td>
<td>8.4 per brick</td>
<td>0.62 per brick</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Assum ing 2.8 kg per brick</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facing Bricks</td>
<td>8.2</td>
<td>0.52</td>
<td>4.5</td>
<td>11.7</td>
</tr>
<tr>
<td>Very small sample size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXAMPLE: Single Facing Brick</td>
<td>23 per brick</td>
<td>1.46 per brick</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Assum ing 2.8 kg per brick</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone Bricks</td>
<td>0.85</td>
<td>7</td>
<td>Cradle to Gate</td>
<td>0.7</td>
</tr>
</tbody>
</table>

#### Comments

Clay products experience process related carbon dioxide emissions. There was a large data range associated with all ceramic and brick products.

#### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W-m-K-1)</th>
<th>Density (kg m-3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (m2 S-1)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Brick</td>
<td>0.72</td>
<td>1907</td>
<td>840</td>
<td>The CIBSE guide presented multiple values for brick</td>
<td></td>
</tr>
<tr>
<td>Brick A</td>
<td>1.31</td>
<td>2006</td>
<td>921</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick B</td>
<td>1.75</td>
<td>1301</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick C</td>
<td>1.85</td>
<td>1507</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone</td>
<td>0.75</td>
<td>1739</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td>0.8</td>
<td>1992</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slate</td>
<td>0.8</td>
<td>1892</td>
<td>840</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Material Profile: Concrete

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material Description</th>
<th>No. Records</th>
<th>Average EE (MJ/Kg)</th>
<th>Standard Deviation</th>
<th>Minimum EE (MJ/Kg)</th>
<th>Maximum EE (MJ/Kg)</th>
<th>Comments on the Database Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>122</td>
<td>2.91</td>
<td>0.97</td>
<td>1.09</td>
<td>4.39</td>
<td>None</td>
</tr>
<tr>
<td>Concrete, General</td>
<td>112</td>
<td>3.01</td>
<td>0.97</td>
<td>1.09</td>
<td>4.39</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>85</td>
<td>2.12</td>
<td>0.85</td>
<td>1.09</td>
<td>3.07</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>27</td>
<td>6.02</td>
<td>1.87</td>
<td>2.01</td>
<td>7.77</td>
<td>None</td>
</tr>
<tr>
<td>Concrete, Pre-Cast</td>
<td>10</td>
<td>1.89</td>
<td>0.43</td>
<td>0.63</td>
<td>2.00</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>6</td>
<td>2.01</td>
<td>0.43</td>
<td>0.63</td>
<td>2.00</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>4</td>
<td>1.72</td>
<td>0.42</td>
<td>0.63</td>
<td>2.00</td>
<td>None</td>
</tr>
</tbody>
</table>

#### Selected Embodied Energy & Carbon Values and Associated Data

- **Boundaries Data Range**
  - **Material**
  - **General Concrete**
  
- **Specific Comments**
  - Selection of a specific concrete type will give greater accuracy; please see comments

#### Concrete Block Mixes (ICE CMC Model Values)

- **Example:** Reinforced RC25 (See Below) with 150kg Rebar
  - Compressive Strength: 2.0 (1.0 + 0.2 * 4) MJ/Sqm
  - Embodied Carbon: 0.041 (0.153 + 0.018 * 4) Kg CO2/Sqm

#### Miscellaneous Values

- **Pre-fabricated Concrete:** 2.80 MJ/Kg
- **Concrete Road & Pavement:** 1.24 MJ/Kg
- **Wood/Wood Reinforced:** 2.08 MJ/Kg

#### ALTERNATIVE CONCRETE MIXES (ICE Ciment, Mortar & Concrete Model Results)

- **BS 590-2004 SPECIFICATIONS**
  - **Fly Ash**
    - % Cement Replacement - Fly Ash % | 0% | 20% | 50% | 90% | 20% | 50% | Note 5% is a standard concrete
    - **GEN 5** | 0.64 | 0.07 | 0.50 | 0.07 | 0.08 | 0.08 | Embodied Energy - MJ/Kg
    - **GEN 9** | 0.64 | 0.07 | 0.50 | 0.07 | 0.08 | 0.08 | Embodied Carbon - Kg CO2/Kg

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Aerated, cellular Concrete, cast:
- tiles
- block, with perlite, medium weight, 150 mm
- block, with perlite, lightweight, 150 mm
- block, perlite-filled, medium weight, 150 mm
- block, perlite-filled, lightweight, 150 mm
- block, partially filled, medium weight, 300 mm
- block, partially filled, medium weight, 150 mm
- block, partially filled, lightweight, 300 mm
- block, partially filled, lightweight, 150 mm
- block, hollow, medium weight, 150 mm
- block, hollow, lightweight, 300 mm
- block, hollow, lightweight, 150 mm
- block, hollow, heavyweight, 300 mm
- block, medium weight, 300 mm
- block, lightweight, 150 mm
- block, heavyweight, 300 mm

Concrete blocks/tiles

The ICE Cement, Mortar & Concrete Model was used to estimate these values. It was assumed that there will be no changes in the quantities of water, aggregates or plasticiser/additives due to the use of cementitious replacement materials.

Some of the descriptions or comments above help then you may wish to apply the above general value, which is for a typical concrete mix. But in doing so (and in an extreme case) you may inadvertently add up to +/-50% additional error bars to your concrete results. Please note the suggested possible uses of each strength class of concrete is a rough guide only, this does depend upon the building type and height.

<table>
<thead>
<tr>
<th>% Cement Replacement - Blast Furnace Slag</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>Note 6% is a standard concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEN 0</td>
<td>0.64</td>
<td>0.59</td>
<td>0.54</td>
<td>0.671</td>
<td>0.058</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>GEN 1</td>
<td>0.77</td>
<td>0.68</td>
<td>0.62</td>
<td>0.695</td>
<td>0.078</td>
<td>0.361</td>
<td>CAS 10: Possible uses: mass Concrete, mass fill, mass foundation.</td>
</tr>
<tr>
<td>GEN 2</td>
<td>0.81</td>
<td>0.70</td>
<td>0.65</td>
<td>0.163</td>
<td>0.083</td>
<td>0.665</td>
<td>C15/20</td>
</tr>
<tr>
<td>GEN 3</td>
<td>0.85</td>
<td>0.76</td>
<td>0.67</td>
<td>0.112</td>
<td>0.081</td>
<td>0.070</td>
<td>C16/20</td>
</tr>
<tr>
<td>RC20</td>
<td>0.95</td>
<td>0.84</td>
<td>0.73</td>
<td>0.120</td>
<td>0.103</td>
<td>0.079</td>
<td>C20/25</td>
</tr>
<tr>
<td>RC25</td>
<td>0.98</td>
<td>0.86</td>
<td>0.76</td>
<td>0.130</td>
<td>0.110</td>
<td>0.083</td>
<td>C30/30</td>
</tr>
<tr>
<td>RC30</td>
<td>1.08</td>
<td>0.96</td>
<td>0.82</td>
<td>0.153</td>
<td>0.123</td>
<td>0.092</td>
<td>C30/37: Possible uses foundations</td>
</tr>
<tr>
<td>RC35</td>
<td>1.13</td>
<td>0.98</td>
<td>0.85</td>
<td>0.161</td>
<td>0.129</td>
<td>0.096</td>
<td>C35/40: Possible uses: found floor</td>
</tr>
<tr>
<td>RC40</td>
<td>1.17</td>
<td>1.03</td>
<td>0.80</td>
<td>0.160</td>
<td>0.135</td>
<td>0.101</td>
<td>C40/50: Possible uses: structural purposes, in-situ floor, walls, superstructure</td>
</tr>
<tr>
<td>PC20</td>
<td>1.41</td>
<td>1.22</td>
<td>1.03</td>
<td>0.212</td>
<td>0.168</td>
<td>0.124</td>
<td>C50</td>
</tr>
<tr>
<td>PC25</td>
<td>1.04</td>
<td>0.91</td>
<td>0.79</td>
<td>0.145</td>
<td>0.116</td>
<td>0.088</td>
<td>C50</td>
</tr>
<tr>
<td>PC30</td>
<td>1.06</td>
<td>0.96</td>
<td>0.82</td>
<td>0.153</td>
<td>0.123</td>
<td>0.092</td>
<td>C60</td>
</tr>
</tbody>
</table>

Comment on above data structure

The first column represents standard concrete created with 100% Portland cement. The other columns are based on a direct substitution of fly ash or blast furnace slag in place of cement. They have been modelled on the fraction of cement replacement material (fly ash or slag). However, there are thresholds on the upper limit that each of these replacement materials can contribute. This threshold is thought to be linked to the strength class of the concrete. It is understood that fly ash, which has a lower embodied energy and carbon, has a lower threshold than for blast furnace slag. This implies that less fly ash can be used for a particular concrete mix. In certain circumstances blast furnace slag could reach 70-80% replacement, this is much higher than the upper limits of fly ash.

It should be noted that blast furnace slag and fly ash are both carbon negative over their lifetimes due to the use of cementitious replacement materials. The above data is offered as a what if guideline only. The user must ensure that any quantity of cement substitution is suitable for the specific application.

Material Scatter Graph - Concrete

Fuel Split & Embodied Carbon Data

This fuel mix was estimated based on the fuel mix of the constituent materials for concrete, including aggregates, sand and cement. The values of embodied energy and carbon produced by this model are in good agreement with those calculated by the ICE Cement, Mortar & Concrete Model.

The values of embodied carbon all exclude re-carbonation of concrete in use, which is application dependent. The majority of these concrete values were taken from the University of Bath’s ICE Cement, Mortar and Concrete Model. It operates using the quantities of constituent material inputs. As a result these values are dependent upon the selected coefficients of embodied energy and carbon of cement, sand and aggregates, which are the main constituent materials for concrete. The values of embodied energy and carbon produced by this model are in good agreement with those calculated by the ICE Cement, Mortar and Concrete Model.

The ICE V1.6a model includes the following energy sources as a fuel split for concrete:
- Natural gas
- Electricity
- Other

Total

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>61.2%</td>
<td>26.1%</td>
</tr>
<tr>
<td>Oil</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>29.2%</td>
<td>12.2%</td>
</tr>
<tr>
<td>Electricity</td>
<td>9.4%</td>
<td>51.8% (Non-carbonation)</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Note: 6% is a standard concrete.
<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>vermiculite</td>
<td>dry</td>
<td>0.14</td>
<td>480</td>
<td>840</td>
<td>3.9682E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>0.10</td>
<td>700</td>
<td>1050</td>
<td>2.2893E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>wet</td>
<td>0.10</td>
<td>690</td>
<td>1050</td>
<td>2.0891E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>wet</td>
<td>1.3</td>
<td>2200</td>
<td>840</td>
<td>9.1991E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>1.2</td>
<td>2400</td>
<td>840</td>
<td>9.5317E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>1.5</td>
<td>2300</td>
<td>840</td>
<td>9.3471E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>2.2</td>
<td>2800</td>
<td>840</td>
<td>1.8983E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>2.0</td>
<td>2900</td>
<td>840</td>
<td>1.8983E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>3.4</td>
<td>1450</td>
<td>840</td>
<td>5.1009E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>0.7</td>
<td>440</td>
<td>800</td>
<td>2.0772E-06</td>
</tr>
<tr>
<td>vermiculite, bonded</td>
<td>dry</td>
<td>0.6</td>
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<td>5.0408E-06</td>
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<td>2050</td>
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<td>7.1759E-06</td>
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<td>1000</td>
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<td>1000</td>
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<td>5.0408E-06</td>
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<td>1000</td>
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<td>5.0408E-06</td>
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<td>750</td>
<td>840</td>
<td>5.0408E-06</td>
</tr>
<tr>
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<td>dry</td>
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<td>2050</td>
<td>840</td>
<td>7.1759E-06</td>
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</tbody>
</table>
Material Profile: Copper

<table>
<thead>
<tr>
<th>Material Profile: Copper</th>
<th>Embodied Energy (EE) Database Statistics - MJ/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Material</td>
<td>No. Records</td>
</tr>
<tr>
<td>Copper</td>
<td>58</td>
</tr>
<tr>
<td>Copper General</td>
<td>58</td>
</tr>
<tr>
<td>50% Recycled</td>
<td>1</td>
</tr>
<tr>
<td>Market Average</td>
<td>1</td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>11</td>
</tr>
<tr>
<td>Unspecified</td>
<td>20</td>
</tr>
<tr>
<td>Virgin</td>
<td>25</td>
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</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Copper</td>
<td>40 to 55</td>
<td>2.19 to 3.83 (?)</td>
<td>Cradle to Gate</td>
<td>-</td>
<td>Assumes recycled materials of 46% (source: The environment agency).</td>
</tr>
<tr>
<td>Primary Copper</td>
<td>70 (?)</td>
<td>3.83 (?)</td>
<td>45</td>
<td>153</td>
<td>Large data range because the embodied energy is dependent upon ore grade</td>
</tr>
<tr>
<td>Secondary from low grade scrap</td>
<td>50 (?)</td>
<td>2.75 (?)</td>
<td>-</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Secondary from high grade scrap</td>
<td>17.5 (?)</td>
<td>0.96 (?)</td>
<td>-</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

Comments

The embodied energy of copper displays a very large data range. This is possibly due to variations in the grade of copper ore and copper scrap. There was poor data on the typical embodied carbon of copper, consequently the embodied carbon data is uncertain.

Material Scatter Graph

Embodied Energy (EE) - MJ/Kg

Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>4.0%</td>
<td>5.9%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>10.8%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>19.0%</td>
<td>16.1%</td>
</tr>
<tr>
<td>Electricity</td>
<td>66.2%</td>
<td>65.6%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Fuel Split & Embodied Carbon Comments:

The embodied carbon was estimated by using the UK typical fuel split in the copper industry.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m-1 K-1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg.1 K-1)</th>
<th>Thermal Diffusivity (M^2 S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>350</td>
<td>84600</td>
<td>390</td>
<td>0.00011449</td>
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Material Profile: Glass

Embodied Energy (EE) Database Statistics - MJ/Kg

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<tr>
<th>Material Description</th>
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<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
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<tbody>
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<td>Glass</td>
<td>95</td>
<td>20.08</td>
<td>9.13</td>
<td>11.00</td>
<td>41.81</td>
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<tr>
<td>Glass, Fibreglass</td>
<td>22</td>
<td>25.58</td>
<td>8.53</td>
<td>11.00</td>
<td>41.81</td>
<td>None</td>
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<td>Market Average</td>
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<td>30.00</td>
<td>30.00</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Predominantly Recycled</td>
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<td>25.09</td>
<td>4.07</td>
<td>21.00</td>
<td>30.00</td>
<td>Virgin</td>
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<tr>
<td>Unspecified</td>
<td>16</td>
<td>26.24</td>
<td>8.41</td>
<td>11.00</td>
<td>41.81</td>
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<td>Virgin</td>
<td>3</td>
<td>24.85</td>
<td>10.25</td>
<td>17.60</td>
<td>32.10</td>
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<td>73</td>
<td>18.50</td>
<td>8.73</td>
<td>2.56</td>
<td>62.10</td>
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<td>50% Recycled</td>
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<td>7.00</td>
<td>7.00</td>
<td>-</td>
<td>-</td>
<td>Predominantly Recycled</td>
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<td>Market Average</td>
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<td>16.81</td>
<td>5.87</td>
<td>12.30</td>
<td>25.09</td>
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<td>6.63</td>
<td>4.07</td>
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<td>10.70</td>
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<td>29</td>
<td>17.98</td>
<td>6.15</td>
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<td>31.42</td>
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Selected Embodied Energy & Carbon Values and Associated Data

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<tr>
<th>Material Description</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Low EE Range - MJ/Kg</th>
<th>High EE Range - MJ/Kg</th>
<th>Specific Comments</th>
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<tbody>
<tr>
<td>General Glass</td>
<td>15</td>
<td>0.85</td>
<td>Cradle to Gate</td>
<td>16.5</td>
<td>42</td>
<td>Only three data sources</td>
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<tr>
<td>Fibreglass</td>
<td>28</td>
<td>1.53</td>
<td>Cradle to Gate</td>
<td>-</td>
<td>-</td>
<td>Predominantly Recycled</td>
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<td>Toughened Glass</td>
<td>23.5</td>
<td>1.27</td>
<td>Cradle to Gate</td>
<td>-</td>
<td>-</td>
<td>Only three data sources</td>
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Comments: Poor data availability on recycled glass.

Material Scatter Graph

EE Scatter Graph - Glass

Embodied Energy (EE) - MJ/Kg

Year of Data

EE Scatter Graph - Fibre Glass

Embodied Energy (EE) - MJ/Kg

Year of Data

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material Description</th>
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<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² s⁻¹)</th>
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</thead>
<tbody>
<tr>
<td>Alumina cloth</td>
<td></td>
<td>0.018</td>
<td>1100</td>
<td>800</td>
<td>0.000012</td>
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<tr>
<td>Brick</td>
<td>At 50°C</td>
<td>0.019</td>
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<td>0.019</td>
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<td>800</td>
<td>4.42775E⁻⁰⁷</td>
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<td>800</td>
<td>7.39805E⁻⁰⁷</td>
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<td>Glass, fibre quilt</td>
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<td>2.0</td>
<td>1300</td>
<td>800</td>
<td>7.39805E⁻⁰⁷</td>
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<td>Glass, resin bonded</td>
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<td>2.0</td>
<td>1300</td>
<td>800</td>
<td>7.39805E⁻⁰⁷</td>
</tr>
</tbody>
</table>

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### Material Profile: Insulation

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
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<td>Composite Insulation</td>
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<td>35.27</td>
<td>55.00</td>
<td>None</td>
</tr>
</tbody>
</table>

#### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Insulation</td>
<td>45</td>
<td>16.5</td>
<td>1.86</td>
<td>Cradle to Gate</td>
<td>Low EE</td>
<td>Estimated from typical consumption mix of insulation materials in the UK</td>
<td></td>
</tr>
<tr>
<td>Cellular Glass</td>
<td>27</td>
<td>-</td>
<td>-</td>
<td>Cradle to Gate</td>
<td>High EE</td>
<td>Reference 48</td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>0.94 to 3.3</td>
<td>-</td>
<td>-</td>
<td>Cradle to Gate</td>
<td></td>
<td>Reference 49</td>
<td></td>
</tr>
<tr>
<td>Cork</td>
<td>4</td>
<td>-</td>
<td>0.19</td>
<td>Cradle to Site</td>
<td>(-10%)</td>
<td>Reference 49</td>
<td></td>
</tr>
<tr>
<td>Fibreglass (Glasswool)</td>
<td>28</td>
<td>-</td>
<td>1.35</td>
<td>Cradle to Site</td>
<td>(+/- 40%)</td>
<td>Rockwool is a type of mineral wool (Brand)</td>
<td></td>
</tr>
<tr>
<td>Flax (Insulation)</td>
<td>39.5</td>
<td>5.97</td>
<td>1.7</td>
<td>Cradle to Grave</td>
<td></td>
<td>Reference 2</td>
<td></td>
</tr>
<tr>
<td>Mineral wool</td>
<td>16.6</td>
<td>-</td>
<td>1.2</td>
<td>Cradle to Gate</td>
<td></td>
<td>Reference 2</td>
<td></td>
</tr>
<tr>
<td>Rockwool (stonewool)</td>
<td>16.8</td>
<td>-</td>
<td>1.05</td>
<td>Cradle to Site</td>
<td>(+/- 40%)</td>
<td>Rockwool is a type of mineral wool (Brand)</td>
<td></td>
</tr>
<tr>
<td>Paper wool</td>
<td>20.2</td>
<td>-</td>
<td>0.63</td>
<td>Cradle to Grave</td>
<td></td>
<td>Reference 2</td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td>See Plastics for a range of polyurethane data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodwool (loose)</td>
<td>10.8</td>
<td>-</td>
<td>-</td>
<td>Cradle to Gate</td>
<td>(+/- 40%)</td>
<td>Reference 168</td>
<td></td>
</tr>
<tr>
<td>Woodwool (Board)</td>
<td>20</td>
<td>-</td>
<td>0.96</td>
<td>Cradle to Gate</td>
<td></td>
<td>Reference 49</td>
<td></td>
</tr>
<tr>
<td>Recycled Wool</td>
<td>20.9</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td>References 57, 168 &amp; 224</td>
<td></td>
</tr>
</tbody>
</table>

#### Material Scatters Graph

**EE Scatter Graph - Insulation**

- **Year of Data**: 1970 to 2010
- **Embodied Energy (EE) - MJ/Kg**: 0 to 180

#### Fuel Split & Embodied Carbon Data

- **Unknown fuel split, embodied carbon was estimated from the data available in the database**

#### Material Properties (CIBSE Data) for Insulation

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m-1 K-1)</th>
<th>Density (kg m-3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (M²/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenol</td>
<td></td>
<td>0.64</td>
<td>932</td>
<td>1400</td>
<td>9.5267E+07</td>
</tr>
<tr>
<td>Phenol, rigid</td>
<td></td>
<td>0.035</td>
<td>110</td>
<td>1470</td>
<td>2.1656E+07</td>
</tr>
<tr>
<td>Phenol, crysorlite</td>
<td></td>
<td>0.03</td>
<td>45</td>
<td>1470</td>
<td>4.3951E+07</td>
</tr>
<tr>
<td>Phenol, crysorlite, freon-filled</td>
<td></td>
<td>0.03</td>
<td>37</td>
<td>1470</td>
<td>6.3551E+07</td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
<td>0.035</td>
<td>140</td>
<td>1470</td>
<td>2.8571E+08</td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
<td>0.035</td>
<td>45</td>
<td>1470</td>
<td>6.3551E+07</td>
</tr>
<tr>
<td>Polyurethane, freon-filled</td>
<td></td>
<td>0.035</td>
<td>37</td>
<td>1470</td>
<td>6.3551E+07</td>
</tr>
<tr>
<td>Fluoropolymer</td>
<td></td>
<td>0.035</td>
<td>10</td>
<td>1470</td>
<td>2.8571E+08</td>
</tr>
<tr>
<td>Fluoropolymer</td>
<td></td>
<td>0.035</td>
<td>45</td>
<td>1470</td>
<td>6.3551E+07</td>
</tr>
</tbody>
</table>

#### Material Properties (CIBSE Data) for Insulation

- **Material**
  - Insulation
  - Polyurethane
  - Woodwool (loose)
  - Woodwool (Board)
  - Recycled Wool

#### Comments

- Embodied energy and carbon data for insulation materials was relatively poor. This may be a result of the fact that insulation materials save energy and will almost always payback the embodied energy during the lifetime of the insulation. But by comparing the embodied energy of insulation materials and considering U-values energy & carbon savings could still be made. It is important to consider space constraints in an embodied energy and carbon analysis of insulation. If there is only a fixed space, say 50mm, available then U-Value must be considered alongside embodied energy and carbon.

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<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W·m⁻¹·K⁻¹)</th>
<th>Density (kg·m⁻³)</th>
<th>Specific heat (J·kg⁻¹·K⁻¹)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At 23.8°C</td>
<td>0.048</td>
<td>200</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At 93.3°C</td>
<td>0.048</td>
<td>100</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At 93.3°C</td>
<td>0.065</td>
<td>200</td>
<td>710</td>
</tr>
<tr>
<td>Cork expanded</td>
<td></td>
<td>0.038</td>
<td>140</td>
<td></td>
<td>840</td>
</tr>
<tr>
<td>Cork, fibrous</td>
<td></td>
<td>0.043</td>
<td>96</td>
<td></td>
<td>840</td>
</tr>
<tr>
<td>Cork, resin bonded</td>
<td></td>
<td>0.038</td>
<td>96</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Rock wool</td>
<td></td>
<td>At 12°C</td>
<td>0.037</td>
<td>25</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At 12°C</td>
<td>0.033</td>
<td>60</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At 10°C</td>
<td>0.033</td>
<td>100</td>
<td>710</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td>At 10°C</td>
<td>0.034</td>
<td>200</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At 10°C</td>
<td>0.047</td>
<td>92</td>
<td>840</td>
</tr>
<tr>
<td>Expanded</td>
<td></td>
<td>0.043</td>
<td>150</td>
<td></td>
<td>840</td>
</tr>
<tr>
<td>Expanded, impregnated</td>
<td></td>
<td>0.043</td>
<td>150</td>
<td></td>
<td>1760</td>
</tr>
<tr>
<td>Insulation</td>
<td></td>
<td>0.043</td>
<td>150</td>
<td></td>
<td>1760</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.043</td>
<td>150</td>
<td></td>
<td>1760</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.043</td>
<td>150</td>
<td></td>
<td>1760</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
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<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
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<tr>
<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
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<tr>
<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.055</td>
<td>300</td>
<td></td>
<td>960</td>
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<tr>
<td></td>
<td></td>
<td>Conditioned</td>
<td>0.03</td>
<td>930</td>
<td>1800</td>
</tr>
</tbody>
</table>
Material Profile: Iron

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>21</td>
<td>24.62</td>
<td>7.50</td>
<td>11.70</td>
<td>36.30</td>
<td>The collected data was not sufficient to estimate coefficients for a broad range of iron products.</td>
</tr>
<tr>
<td>Iron, General</td>
<td>21</td>
<td>24.62</td>
<td>7.50</td>
<td>11.70</td>
<td>36.30</td>
<td></td>
</tr>
<tr>
<td>Other Specification</td>
<td>1</td>
<td>20.50</td>
<td>20.50</td>
<td>20.50</td>
<td>20.50</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>8</td>
<td>29.80</td>
<td>5.18</td>
<td>23.80</td>
<td>35.00</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>12</td>
<td>21.50</td>
<td>7.32</td>
<td>11.70</td>
<td>36.30</td>
<td></td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Virgin) Iron - Statistical Average</td>
<td>25</td>
<td>1.91 (?)</td>
<td>Cradle to Gate</td>
<td>11.7</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Comments

It is important to note that data for iron is not of high enough quality to accurately estimate the embodied energy and carbon coefficients for a broad range of iron products. Iron shares the same ore as steel but the latter normally undergoes an extra processing operation, as such it would be expected to have a lower embodied energy and carbon than steel. Unfortunately and as a consequence of their similarities many people confuse the two materials. It was considered a possibility that some of the embodied energy data collected and categorised as iron where in fact steel. Nevertheless the data available was insufficient to accurately determine the embodied energy and carbon of iron. In the absence of improved data the selected embodied energy coefficient represents the average of the data within the database. Although it can't be stated with absolute certainty (because of ICE's reliance on secondary data resources) it was estimated that the selected value represents virgin iron. This would appear to be in line with the expectation that steel requires more processing energy than iron.

Material Scatter Graph

![EE Scatter Graph - Iron](image)

Year of Data

Fuel Split & Embodied Carbon Data

Unknown fuel split.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (M²S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td></td>
<td>78.70</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Material Profile: Lead

### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead General</td>
<td>33</td>
<td>45.17</td>
<td>43.72</td>
<td>7.20</td>
<td>190.00</td>
<td>None</td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>6</td>
<td>14.30</td>
<td>10.93</td>
<td>7.20</td>
<td>38.53</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>9</td>
<td>41.83</td>
<td>35.63</td>
<td>20.00</td>
<td>134.00</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>18</td>
<td>57.14</td>
<td>49.72</td>
<td>22.00</td>
<td>190.00</td>
<td></td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy MJ/Kg</th>
<th>Embodied Carbon Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Lead</td>
<td>25</td>
<td>1.33</td>
<td>Low EE</td>
<td>16</td>
</tr>
<tr>
<td>Primary Lead</td>
<td>40</td>
<td>2.61</td>
<td>High EE</td>
<td>33</td>
</tr>
<tr>
<td>Secondary Lead</td>
<td>10</td>
<td>0.53</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Primary Lead Produced with Zinc</td>
<td>13.6 to 23.6</td>
<td>0.72 to 1.25</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

**Cradle to Gate**

- Assumes recycling rate of 61.5%
- Selected value is representative of a small band of frequently quoted values.
- These values assumed that the energy allocated to the lead and zinc was divided assuming that the energy attributable to zinc was equal to that from other methods of producing zinc. The other values (above) assumed a mass based allocation.

**Comments**

Due to one of the methods of producing lead (lead can be produced in a process that also produces zinc) there is difficulty defining the energy attributable to the lead and the zinc. Some authors will assume that the energy is divided equally between the masses of each metal (or even on an economic basis). Others will assume that the zinc has the same energy as would be required to produce the zinc by other processes. The values above have assumed that the energy was divided upon a mass basis unless otherwise stated.

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m-K)</th>
<th>Density (kg m^-3)</th>
<th>Specific heat (J kg^-1 K^-1)</th>
<th>Thermal Diffusivity (m^2 s^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td></td>
<td>31</td>
<td>11.24</td>
<td>120</td>
<td>2.37E-05</td>
</tr>
</tbody>
</table>

**ICE V1.6a**

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Material Profile: Lime

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>39</td>
<td>4.57</td>
<td>2.79</td>
<td>0.04</td>
<td>10.24</td>
<td>None</td>
</tr>
<tr>
<td>Lime, General</td>
<td>39</td>
<td>4.57</td>
<td>2.79</td>
<td>0.04</td>
<td>10.24</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>4</td>
<td>6.51</td>
<td>4.36</td>
<td>0.20</td>
<td>10.24</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>35</td>
<td>4.24</td>
<td>2.40</td>
<td>0.04</td>
<td>9.10</td>
<td>None</td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Lime</td>
<td>5.3</td>
<td>0.74</td>
<td>Cradle to Gate</td>
<td>4</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Comments

Lime is often chosen as an environmentally friendly material. It was therefore surprising to learn that the embodied energy of lime was slightly higher than for cement. This was observed from the respectable sample size of 39 data records. Lime is fired in the kiln to a lower temperature than cement, which is often misconceived as proof for a lower embodied energy. Yield, density, and time in the kiln are all vital parameters to total energy consumption. This is presented as a possibility for the higher embodied energy. It should be noted that embodied energy is, in itself, is not evidence to discredit lime's environmental claims. Due to a more favourable fuel mix and slightly lower process related carbon dioxide emissions lime has a lower embodied carbon than cement. Additional benefits of using lime based mortar would include the increased ability for deconstruction, rather than demolition. The re-carbonation that occurs over the lifetimes of both cement and lime based mortars (when exposed to air) will reduce the embodied carbon impact of the materials. Examination of lime's full carbon cycle may be necessary.

Material Scatter Graph

Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>2.2%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>78.6%</td>
<td>75.4%</td>
</tr>
<tr>
<td>Electricity</td>
<td>19.3%</td>
<td>21.7%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100.1%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK lime industry. Lime releases approximately 0.48 kg CO2/kg lime produced. This is a process related emission and is additional to the fuel related CO2.
### Material Profile: Linoleum

**Embodied Energy (EE) Database Statistics - MJ/Kg**

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linoleum</td>
<td>9</td>
<td>30.49</td>
<td>1.00</td>
<td>1.00</td>
<td>116.00</td>
<td>There is a very large data range due to one record which is much higher than other sources of data, see scatter graph.</td>
</tr>
<tr>
<td>Linoleum, General</td>
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</tbody>
</table>

**Selected Embodied Energy & Carbon Values and Associated Data**

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Linoleum</td>
<td>25</td>
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<td>Cradle to Grave</td>
<td>Low EE</td>
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</table>

**Comments**

The estimate of embodied carbon was uncertain. It is an estimate based on the data available within the database. It is common practice to analyse linoleum from cradle to grave over an assumed lifetime of the product. The above values exclude any feedstock energy from the use of linseed oil in manufacture.

**Material Properties (CIBSE Data)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linoleum</td>
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<td>0.19</td>
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</table>
### Material Profile: Miscellaneous Materials

NOTE: These database statistics have been presented here for a number of miscellaneous materials, it was not possible to create a standard material profile.

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
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<td>11.95</td>
<td>10.82</td>
<td>4.30</td>
<td>19.60</td>
</tr>
</tbody>
</table>
Material Profile: Paint

### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
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</thead>
<tbody>
<tr>
<td>Paint</td>
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<td>67.55</td>
<td>29.95</td>
<td>3.11</td>
<td>117.00</td>
<td>None</td>
</tr>
<tr>
<td>Paint, General</td>
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<td>67.55</td>
<td>29.95</td>
<td>3.11</td>
<td>117.00</td>
<td>None</td>
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<td>Unspecified</td>
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<td>93.00</td>
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</table>

### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Paint</td>
<td>68</td>
<td>3.56</td>
<td></td>
<td>Low EE: 0.50 - 2.50</td>
<td>Large variations in data, especially for embodied carbon.</td>
</tr>
<tr>
<td>EXAMPLE: Single Coat</td>
<td>10.2 MJ/Sqm</td>
<td>0.53 kgCO2/Sqm</td>
<td>Cradle to Gate</td>
<td>High EE: 2.50 - 3.50</td>
<td>Assume 6.66 Sqm Coverage per kg</td>
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<tr>
<td>EXAMPLE: Double Coat</td>
<td>20.4 MJ/Sqm</td>
<td>1.06 kgCO2/Sqm</td>
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<td></td>
<td>Assume 3.33 Sqm Coverage per kg</td>
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<tr>
<td>EXAMPLE: Triple Coat</td>
<td>30.6 MJ/Sqm</td>
<td>1.60 kgCO2/Sqm</td>
<td></td>
<td></td>
<td>Assume 2.22 Sqm Coverage per kg</td>
</tr>
</tbody>
</table>

Comments
- Embodied Carbon values experience a particularly large data range for embodied carbon.

### Material Scatter Graph

#### EE Scatter Graph - Paint

![EE Scatter Graph - Paint](image)

### Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>2.0%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>25.5%</td>
<td>22.5%</td>
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<tr>
<td>Electricity</td>
<td>72.5%</td>
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</tr>
<tr>
<td>Other</td>
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<td>0.0%</td>
</tr>
</tbody>
</table>

Total: 100.0% 100.0%

Fuel Split & Embodied Carbon Comments:
- The embodied carbon was estimated by using the UK typical fuel split in this industry.
Material Profile: Paper

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
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</thead>
<tbody>
<tr>
<td>Paper</td>
<td>27.35</td>
<td>14.07</td>
<td>5.18</td>
<td>61.26</td>
<td></td>
</tr>
<tr>
<td>Paper, Cardboard</td>
<td>22.39</td>
<td>14.51</td>
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<td>60.00</td>
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<tr>
<td>Other Specification</td>
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<tr>
<td>Predominantly Recycled</td>
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<td>Paper, General Purpose</td>
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<td>Market Average</td>
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Selected Embodied Energy & Carbon Values and Associated Data

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<tr>
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<th>Embodied Energy - MJ/Kg</th>
<th>CO2/Kg</th>
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<tbody>
<tr>
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<td>Wallpaper</td>
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Material Scatter Graph

Fuel Split & Embodied Carbon Data

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<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from energy source</th>
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</thead>
<tbody>
<tr>
<td>Coal</td>
<td>4.3%</td>
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<td>LPG</td>
<td>0.0%</td>
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</tr>
<tr>
<td>Natural gas</td>
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<tr>
<td>Electricity</td>
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Historical embodied carbon per unit fuel use

Material Properties (CIBSE Data)

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<th>Condition</th>
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<th>Density (kg m -3)</th>
<th>Specific heat (J kg-1 K-1)</th>
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<td>Bitumen impregnated paper</td>
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<td>0.06</td>
<td>1090</td>
<td>1000</td>
<td>5.5045E-09</td>
</tr>
<tr>
<td>Treated paper</td>
<td></td>
<td>0.072</td>
<td>490</td>
<td>1380</td>
<td>1.0869E-07</td>
</tr>
</tbody>
</table>

Comments

Much of the data in the database was outdated for paper. Notable improvements have been made within this industry in this time period. The best values in the database were selected and then modified to take into account the current situation. The values exclude the CV (Calorific Value) of wood and the effect of carbon sequestration, which is a complex discussion (see the material profile for timber).

© University of Bath 2008 41
Material Profile: Plaster

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m·K)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement plaster</td>
<td></td>
<td>0.72</td>
<td>1765</td>
<td>840</td>
<td>4.870×10⁻⁷</td>
</tr>
<tr>
<td>Cement plaster, sand aggregate</td>
<td></td>
<td>0.72</td>
<td>1800</td>
<td>840</td>
<td>4.608×10⁻⁷</td>
</tr>
<tr>
<td>Cement screed</td>
<td></td>
<td>1.4</td>
<td>2100</td>
<td>650</td>
<td>1.026×10⁻⁷</td>
</tr>
<tr>
<td>Gypsum</td>
<td></td>
<td>0.42</td>
<td>1200</td>
<td>840</td>
<td>4.166×10⁻⁷</td>
</tr>
<tr>
<td>Gypsum plaster</td>
<td></td>
<td>0.51</td>
<td>1120</td>
<td>900</td>
<td>4.743×10⁻⁷</td>
</tr>
<tr>
<td>Gypsum plaster, perlite aggregate</td>
<td></td>
<td>0.22</td>
<td>720</td>
<td>1340</td>
<td>2.28×10⁻⁷</td>
</tr>
<tr>
<td>Gypsum plaster, sand aggregate</td>
<td></td>
<td>0.81</td>
<td>1680</td>
<td>840</td>
<td>5.739×10⁻⁷</td>
</tr>
<tr>
<td>Gypsum Plasterboard</td>
<td></td>
<td>0.16</td>
<td>800</td>
<td>840</td>
<td>2.38×10⁻⁷</td>
</tr>
<tr>
<td>Limestone mortar</td>
<td></td>
<td>0.7</td>
<td>1600</td>
<td>840</td>
<td>5.208×10⁻⁷</td>
</tr>
<tr>
<td>Plaster</td>
<td></td>
<td>0.22</td>
<td>800</td>
<td>840</td>
<td>3.27×10⁻⁷</td>
</tr>
<tr>
<td>Plaster ceiling tiles</td>
<td></td>
<td>0.35</td>
<td>960</td>
<td>840</td>
<td>4.38×10⁻⁷</td>
</tr>
<tr>
<td>Plaster, lightweight aggregate</td>
<td></td>
<td>0.35</td>
<td>1120</td>
<td>840</td>
<td>4.039×10⁻⁷</td>
</tr>
<tr>
<td>Plaster, sand aggregate</td>
<td></td>
<td>0.22</td>
<td>720</td>
<td>840</td>
<td>3.802×10⁻⁷</td>
</tr>
<tr>
<td>Plasterboard</td>
<td></td>
<td>0.19</td>
<td>960</td>
<td>840</td>
<td>2.00×10⁻⁷</td>
</tr>
<tr>
<td>Plaster, synthetic resin, exterior insulation</td>
<td></td>
<td>0.1</td>
<td>1100</td>
<td>840</td>
<td>7.07×10⁻⁷</td>
</tr>
<tr>
<td>Plastering</td>
<td>Moisture content 1%</td>
<td>0.15</td>
<td>1430</td>
<td>1000</td>
<td>5.902×10⁻⁷</td>
</tr>
<tr>
<td></td>
<td>Moisture content 8%</td>
<td>0.15</td>
<td>1330</td>
<td>1000</td>
<td>5.938×10⁻⁷</td>
</tr>
</tbody>
</table>

Material Scatter Graph

Fuel Split & Embodied Carbon Data

Selected Embodied Energy & Carbon Values and Associated Data

Comments

The values quoted in the literature display a large variation. West et al believe this is because of past aggregation of plaster data with cement. The net effect of separating these industries would be to reduce the embodied energy of plaster. There was very poor background data on carbon, only a few authors specified the embodied carbon.
Material Profile: Plastics

<table>
<thead>
<tr>
<th>Material Profile: Plastics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selected Embodied Energy &amp; Carbon Values and Associated Data</strong></td>
</tr>
</tbody>
</table>

- **General Plastic**: 80.5 (35.6 - 2.53) type of plastic used in the European construction industry. Average density 960 kg/m³.
- **ABS**: 95.3 (40.6 - 3.1) based on average use of types of PE in European construction.
- **General Polyethylene (HDPE)**: 83.1 (54.4 - 1.9) based on average use of types of PE in European construction.
- **High Density Polyethylene (LDPE)**: 76.7 (54.3 - 1.6) based on average use of types of PE in European construction.
- **HDPE Pipe**: 84.4 (55.1 - 2) based on average use of types of PE in European construction.
- **LDPE Film**: 89.3 (55.2 - 1.9) based on average use of types of PE in European construction.
- **Nylon 6**: 120.5 (38.6 - 5.5) based on average use of types of PE in European construction.
- **Nylon 6.6**: 138.6 (50.7 - 6.5) based on average use of types of PE in European construction.
- **Polycarbonate**: 112.9 (36.7 - 6) based on average use of types of PE in European construction.
- **Polypropylene, Oriented Films**: 93.2 (55.7 - 2.7) based on average use of types of PE in European construction.
- **Polypropylene, Injection Moulding**: 115.1 (54 - 3.9) based on average use of types of PE in European construction.
- **Expanded Polythene**: 88.6 (46.2 - 2.5) based on average use of types of PE in European construction.
- **General Purpose Polythene**: 88.4 (46.3 - 2.7) based on average use of types of PE in European construction.
- **High Impact Polythene**: 87.4 (46.4 - 2.8) based on average use of types of PE in European construction.
- **Thermoformed Expanded Polythene**: 109.2 (49.7 - 3.4) based on average use of types of PE in European construction.
- **Polyurethane**: 72.1 (34.87 - 3) based on average use of types of PE in European construction.
- **PVC General**: 77.2 (26.1 - 2.41) based on average use of types of PE in European construction.
- **PVC Pipe**: 67.5 (24.4 - 2.5) based on average use of types of PE in European construction.
- **Calendered Sheet PVC**: 68.6 (24.4 - 2.6) based on average use of types of PE in European construction.
- **PVC Injection Moulding**: 95.1 (35.1 - 2.2) based on average use of types of PE in European construction.
- **UPVC Film**: 69.4 (25.3 - 2.5) based on average use of types of PE in European construction.

For more information, visit [www.ice-database.com](http://www.ice-database.com) for detailed data and statistics.
Material Profile: Plastics

<table>
<thead>
<tr>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 10°C</td>
<td>0.16</td>
<td>1000</td>
<td>1050</td>
<td>1.15942E-07</td>
</tr>
<tr>
<td>At 11°C</td>
<td>0.19</td>
<td>1470</td>
<td>1.0771E-07</td>
<td></td>
</tr>
<tr>
<td>At 9°C</td>
<td>0.04</td>
<td>1400</td>
<td>9.52381E-07</td>
<td></td>
</tr>
<tr>
<td>At 8°C</td>
<td>0.035</td>
<td>1470</td>
<td>2.1645E-07</td>
<td></td>
</tr>
<tr>
<td>At 7°C</td>
<td>0.03</td>
<td>1470</td>
<td>4.53515E-07</td>
<td></td>
</tr>
<tr>
<td>At 6°C</td>
<td>0.035</td>
<td>1470</td>
<td>6.43501E-07</td>
<td></td>
</tr>
<tr>
<td>At 5°C</td>
<td>0.04</td>
<td>1400</td>
<td>2.85714E-06</td>
<td></td>
</tr>
<tr>
<td>At 4°C</td>
<td>0.054</td>
<td>1470</td>
<td>2.62391E-06</td>
<td></td>
</tr>
<tr>
<td>At 3°C</td>
<td>0.5</td>
<td>840</td>
<td>5.66893E-07</td>
<td></td>
</tr>
<tr>
<td>At 2°C</td>
<td>0.023</td>
<td>1590</td>
<td>6.02725E-07</td>
<td></td>
</tr>
<tr>
<td>At 1°C</td>
<td>0.023</td>
<td>1590</td>
<td>4.52044E-07</td>
<td></td>
</tr>
<tr>
<td>Polyurethane, unfaced plastic tiles</td>
<td>0.035</td>
<td>1470</td>
<td>4.53515E-07</td>
<td></td>
</tr>
<tr>
<td>Polyurethane, expanded</td>
<td>0.04</td>
<td>1400</td>
<td>2.85714E-06</td>
<td></td>
</tr>
<tr>
<td>Polyurethane, freon-filled</td>
<td>0.035</td>
<td>1470</td>
<td>4.53515E-07</td>
<td></td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td>0.03</td>
<td>1470</td>
<td>4.53515E-07</td>
<td></td>
</tr>
<tr>
<td>Urea formaldehyde resin</td>
<td>0.035</td>
<td>1470</td>
<td>4.53515E-07</td>
<td></td>
</tr>
</tbody>
</table>

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyvinylchloride (PVC)</td>
<td></td>
<td>0.11</td>
<td>1380</td>
<td>45</td>
<td>1.0771E-07</td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
<td>0.14</td>
<td>1230</td>
<td>1470</td>
<td>4.8051E-07</td>
</tr>
<tr>
<td>Polyurethane, rigid</td>
<td></td>
<td>0.05</td>
<td>90</td>
<td>1470</td>
<td>3.1005E-07</td>
</tr>
<tr>
<td>Polyurethane, rigid-filled</td>
<td></td>
<td>0.03</td>
<td>45</td>
<td>1470</td>
<td>4.5351E-07</td>
</tr>
<tr>
<td>Polyurethane, freon-filled</td>
<td></td>
<td>0.035</td>
<td>36</td>
<td>1470</td>
<td>6.34921E-07</td>
</tr>
<tr>
<td>Polyurethane, freeon-filled</td>
<td></td>
<td>0.035</td>
<td>36</td>
<td>1470</td>
<td>4.5351E-07</td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td></td>
<td>0.03</td>
<td>90</td>
<td>1471</td>
<td>6.43001E-07</td>
</tr>
<tr>
<td>Polystyrene</td>
<td></td>
<td>0.03</td>
<td>90</td>
<td>1471</td>
<td>2.0571E-08</td>
</tr>
<tr>
<td>Polystyrene, rigid</td>
<td></td>
<td>0.03</td>
<td>90</td>
<td>1471</td>
<td>2.0571E-08</td>
</tr>
<tr>
<td>Polystyrene, freeon-filled</td>
<td></td>
<td>0.035</td>
<td>36</td>
<td>1471</td>
<td>6.02725E-07</td>
</tr>
<tr>
<td>Polystyrene, unfilled</td>
<td></td>
<td>0.035</td>
<td>36</td>
<td>1471</td>
<td>4.52044E-07</td>
</tr>
</tbody>
</table>

Most of the selected values are from the Association of Plastic Manufacturers in Europe (APME), see www.plasticseurope.org, who have completed many detailed LCA studies for plastics. Their data is available freely on the internet. With the selected mix of plastics the average density for general plastic was 990 kg/m³.

The fuel split data was estimated from the data available from the APME and the assumed use of plastic types in the construction industry. The APME did not provide details of the embodied carbon split or information about the emission factors they apply. The above carbon values are an estimation. They exclude the feedstock energy (59.6% Oil, 40.4% oil fuels).
Material Profile: Rubber

Embodyied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber</td>
<td>16</td>
<td>96.88</td>
<td>28.22</td>
<td>40.30</td>
<td>150.40</td>
</tr>
<tr>
<td>Rubber, General</td>
<td>8</td>
<td>109.33</td>
<td>44.90</td>
<td>40.30</td>
<td>150.40</td>
</tr>
<tr>
<td>Unspecified</td>
<td>5</td>
<td>140.59</td>
<td>12.58</td>
<td>119.56</td>
<td>150.40</td>
</tr>
<tr>
<td>Rubber, Natural</td>
<td>4</td>
<td>68.98</td>
<td>1.68</td>
<td>67.50</td>
<td>70.80</td>
</tr>
<tr>
<td>Unspecified</td>
<td>4</td>
<td>68.98</td>
<td>1.68</td>
<td>67.50</td>
<td>70.80</td>
</tr>
<tr>
<td>Rubber, Synthetic</td>
<td>4</td>
<td>99.88</td>
<td>37.15</td>
<td>64.40</td>
<td>147.60</td>
</tr>
<tr>
<td>Unspecified</td>
<td>4</td>
<td>99.88</td>
<td>37.15</td>
<td>64.40</td>
<td>147.60</td>
</tr>
</tbody>
</table>

There must be taken with these statistics, some include and some exclude feedstock energy. The best indicators are those selected by the authors, who have analysed the data knowing which data points include feedstocks and which exclude them.

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>CO2/Kg</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Rubber</td>
<td>101.7</td>
<td>41.1</td>
<td>3.18</td>
<td></td>
<td>Cradle to Gate</td>
<td></td>
</tr>
<tr>
<td>Synthetic Rubber</td>
<td>120</td>
<td>42</td>
<td>4.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Rubber</td>
<td>67.6</td>
<td>39.43</td>
<td>1.63</td>
<td></td>
<td>The feedstock energy</td>
<td></td>
</tr>
</tbody>
</table>

Comments: It was difficult to estimate the carbon emissions.

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m-K)</th>
<th>Density (kg m-3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (m2 s-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber</td>
<td></td>
<td>0.17</td>
<td>1500</td>
<td>1500</td>
<td>7.5556E-06</td>
</tr>
<tr>
<td>expanded</td>
<td>rigid</td>
<td>0.032</td>
<td>70</td>
<td>70</td>
<td>6.5361E-06</td>
</tr>
<tr>
<td>hard</td>
<td></td>
<td>0.15</td>
<td>1200</td>
<td>1200</td>
<td>1.04167E-07</td>
</tr>
<tr>
<td>sis</td>
<td></td>
<td>0.23</td>
<td>1600</td>
<td>1600</td>
<td>1.17188E-07</td>
</tr>
</tbody>
</table>

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### Material Profile: Sand

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>17</td>
<td>0.22</td>
<td>0.23</td>
<td>0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>Sand, General</td>
<td>17</td>
<td>0.22</td>
<td>0.23</td>
<td>0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>Unspecified</td>
<td>12</td>
<td>0.24</td>
<td>0.24</td>
<td>0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>Virgin</td>
<td>5</td>
<td>0.16</td>
<td>0.22</td>
<td>0.02</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Comments on the Database Statistics:
- These statistics are obscured by a few high values (see scatter chart).

#### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>Boundaries</th>
<th>Low EE Range - MJ/Kg</th>
<th>High EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Sand</td>
<td>0.1</td>
<td>0.005</td>
<td>Cradle to Gate</td>
<td>0.05</td>
<td>0.15</td>
<td>None</td>
</tr>
</tbody>
</table>

#### Comments
- It can be observed from the scatter graph that the median is in the region of 0.1 MJ/kg. Transport will likely be significant for sand.

#### Material Scatter Graph

![EE Scatter Graph - Sand](image)

#### Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>19.6%</td>
<td>22.1%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>14.9%</td>
<td>12.6%</td>
</tr>
<tr>
<td>Electricity</td>
<td>65.3%</td>
<td>64.7%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

#### Fuel Split & Embodied Carbon Comments:
- The embodied carbon was estimated by using the UK typical fuel split in this industry.

#### Historical embodied carbon per unit fuel use

![Embodied carbon contributions per unit energy use for Aggregates, sand & gravel](image)

#### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (M²·S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td></td>
<td>1.74</td>
<td>2240</td>
<td>840</td>
<td>9.24745E-07</td>
</tr>
</tbody>
</table>

© University of Bath 2008
<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealants and adhesives, Epoxide Resin</td>
<td>2</td>
<td>139.32</td>
<td>4.46</td>
<td>139.32</td>
<td>140.92</td>
<td></td>
</tr>
<tr>
<td>Sealants and adhesives, General Adhesives, Mastic</td>
<td>2</td>
<td>62.28</td>
<td>1.34</td>
<td>61.95</td>
<td>62.60</td>
<td></td>
</tr>
<tr>
<td>Sealants and adhesives, General Adhesives</td>
<td>1</td>
<td>87.34</td>
<td>1.83</td>
<td>86.50</td>
<td>88.20</td>
<td></td>
</tr>
<tr>
<td>Sealants and adhesives, Melamine Resin</td>
<td>1</td>
<td>112.81</td>
<td>112.81</td>
<td>112.81</td>
<td>113.81</td>
<td></td>
</tr>
<tr>
<td>Sealants and adhesives, Phenol Formaldehyde</td>
<td>2</td>
<td>87.34</td>
<td>1.83</td>
<td>86.50</td>
<td>88.20</td>
<td></td>
</tr>
<tr>
<td>Sealants and adhesives, Urea Formaldehyde</td>
<td>5</td>
<td>40.00</td>
<td>1.34</td>
<td>38.60</td>
<td>41.40</td>
<td></td>
</tr>
</tbody>
</table>

### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Resin</td>
<td>139.32</td>
<td>42.6</td>
<td>5.91</td>
<td>Cradle to Gate</td>
<td>(5% 20%)</td>
<td></td>
</tr>
<tr>
<td>Mastic Sealant</td>
<td>62.28 to 200</td>
<td>?</td>
<td>?</td>
<td>Cralde to Gate</td>
<td>Only two data sources, with large range, data includes an unknown value of feedstock energy</td>
<td></td>
</tr>
<tr>
<td>Melamine Resin</td>
<td>113</td>
<td>?</td>
<td>?</td>
<td>Cradle to Gate</td>
<td>Reference 77</td>
<td></td>
</tr>
<tr>
<td>Phenol Formaldehyde</td>
<td>87 to 88.32</td>
<td>?</td>
<td>?</td>
<td>Cradle to Grave</td>
<td>Data includes an unknown value of feedstock energy</td>
<td></td>
</tr>
<tr>
<td>Urea Formaldehyde</td>
<td>40 to 78.3</td>
<td>1.3 to 2.26</td>
<td>?</td>
<td>Cradle to Site</td>
<td>Data includes an unknown value of feedstock energy</td>
<td></td>
</tr>
</tbody>
</table>

### Comments

The data on sealants & adhesives was very limited. There was very little feedstock and embodied energy data. The values for mastic sealant, phenol formaldehyde and urea formaldehyde include feedstock energy, which is an unknown quantity in these materials.
Material Profile: Soil

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE (MJ/Kg)</th>
<th>Standard Deviation</th>
<th>Minimum EE (MJ/Kg)</th>
<th>Maximum EE (MJ/Kg)</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>7</td>
<td>0.45</td>
<td>0.26</td>
<td>0.19</td>
<td>0.73</td>
<td>None</td>
</tr>
<tr>
<td>Soil, General</td>
<td>7</td>
<td>0.45</td>
<td>0.26</td>
<td>0.19</td>
<td>0.73</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>7</td>
<td>0.45</td>
<td>0.26</td>
<td>0.19</td>
<td>0.73</td>
<td>None</td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General (Rammed Soil)</td>
<td>0.45</td>
<td>0.023</td>
<td>Cradle to Site</td>
<td>0.15 0.73</td>
<td>-</td>
</tr>
</tbody>
</table>

Comments: See embodied carbon comments.

Material Scatter Graph

Embodied Energy (EE) - MJ/Kg

Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>19.8%</td>
<td>22.7%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>14.9%</td>
<td>12.8%</td>
</tr>
<tr>
<td>Electricity</td>
<td>65.3%</td>
<td>64.7%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Fuel Split & Embodied Carbon Comments:

There was almost no embodied carbon data for soil. It was assumed that soil had similar fuel use to the most closely related material, which was sand. The embodied carbon was estimated by using the UK typical fuel split in this industry. Assuming the average UK industrial fuel use (from all sectors) also produced similar results of embodied carbon. For this reason it is believed that this provides a sufficient estimate in the absence of quality data on embodied carbon.

Historical embodied carbon per unit fuel use

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m·K)</th>
<th>Density (kg·m⁻³)</th>
<th>Specific heat (J·kg⁻¹·K⁻¹)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth, common</td>
<td></td>
<td>1.29</td>
<td>1460</td>
<td>888</td>
<td>9.96264E-07</td>
</tr>
<tr>
<td>Earth, gravel-based</td>
<td></td>
<td>0.52</td>
<td>2050</td>
<td>180</td>
<td>1.40921E-06</td>
</tr>
</tbody>
</table>
**Material Profile: Steel**

### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, General</td>
<td>180</td>
<td>29.36</td>
<td>14.75</td>
<td>8.10</td>
<td>77.00</td>
<td>None</td>
</tr>
<tr>
<td>Market Average</td>
<td>11</td>
<td>31.95</td>
<td>7.25</td>
<td>18.00</td>
<td>39.20</td>
<td>None</td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>14</td>
<td>34.21</td>
<td>12.50</td>
<td>12.00</td>
<td>45.00</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>37</td>
<td>37.25</td>
<td>14.75</td>
<td>12.00</td>
<td>77.00</td>
<td>None</td>
</tr>
<tr>
<td>Surf. Recycled</td>
<td>25</td>
<td>41.55</td>
<td>20.00</td>
<td>12.00</td>
<td>51.50</td>
<td>None</td>
</tr>
<tr>
<td>Market Average</td>
<td>3</td>
<td>44.10</td>
<td>11.00</td>
<td>11.00</td>
<td>51.50</td>
<td>None</td>
</tr>
<tr>
<td>Virgin</td>
<td>5</td>
<td>47.50</td>
<td>14.75</td>
<td>12.00</td>
<td>77.00</td>
<td>None</td>
</tr>
</tbody>
</table>

### Selected Embodied Energy & Carbon Values and Associated Data

**Specific Comments**

- **Crude to Cradle**: Estimated from UK’s consumption of types of steel, and worldwide recycled content 42.7%.

**Specific Comments**

- **NTM = Not Typical Manufacturing Route**

**Specific Comments**

- Assumed 42.7% worldwide recycled material, as used to estimate the typical market values. The best data resource was from the International Iron & Steel Institute (IISI), who completed the most detailed steel LCI to date. Some of the IISI data has been processed to fit into the categories (Primary, secondary material). The results of this study are in line with those expected from other sources. Please see note on recycling methodology at the front of the document.

---

**Material Properties (CIBSE Data)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W m⁻¹ K⁻¹)</th>
<th>Density (kg m⁻³)</th>
<th>Specific heat (J kg⁻¹ K⁻¹)</th>
<th>Thermal Diffusivity (m² S⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel, 5% Ni</td>
<td>29</td>
<td>7850</td>
<td>485</td>
<td>7.06E-08</td>
<td></td>
</tr>
<tr>
<td>Stainless steel, 30% Ni</td>
<td>18</td>
<td>7620</td>
<td>485</td>
<td>4.48E-08</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>45</td>
<td>7850</td>
<td>485</td>
<td>1.20E-02</td>
<td></td>
</tr>
</tbody>
</table>
Material Profile: Stone

Selected Embodied Energy & Carbon Values and Associated Data

Material | Embodied Energy - MJ/Kg | Embodied Carbon - Kg | Boundaries | Best EE Range - MJ/Kg | Specific Comments
--- | --- | --- | --- | --- | ---
General Stone | 1 (7) | 0.056 (7) | Cradle to Gate | 0.1 | 3.6 | Wide data range.
Stone Gravel/Chippings | 0.3 | 0.017 | Cradle to Gate | Not enough data for accurate range. Estimated range +/- 30% Reference 22
Granite | 0.1 to 13.9 (77) | 0.006 to 0.781 (77) | Cradle to Gate | Not enough data for accurate range. Estimated range +/- 30% Reference 22
Limestone | 0.3 | 0.017 | Cradle to Gate | 0.14 | 0.34
Marble | 2 | 0.112 | Cradle to Gate | Not enough data for accurate range. Estimated range +/- 30% Reference 36
Marble tile | 3.33 | 0.187 | Cradle to grave | - | -
Shale | 0.03 | 0.002 | Cradle to Gate | - | -
Slate | 0.1 to 1.0 | 0.006 to 0.056 | Cradle to Gate | - | - | Large data range

Comments:
Several values were selected based on single sources of data, but because of the importance of stone in construction it was decided that these values should be used if they were from a quality data source. Data on stone is generally poor.

Material Scatter Graph

Fuel Split & Embodied Carbon Data

Energy source | % of Embodied Energy from energy source | % of embodied carbon from source
--- | --- | ---
Coal | 0.0% | 0.0%
LPG | 0.0% | 0.0%
Oil | 34.3% | 38.2%
Natural gas | 9.8% | 8.1%
Electricity | 55.9% | 53.7%
Other | 0.0% | 0.0%
Total | 100.0% | 100.0%

Historical embodied carbon per unit fuel use

Embodied carbon contributions per unit energy use for Stone

Material (CIBSE Data)

| Material | Condition | Thermal conductivity (W/m-K) | Density (kg/m³) | Specific heat (J/kg-K-1) | Thermal Diffusivity (m²S⁻¹)
--- | --- | --- | --- | --- | ---
Stone chippings for roofs | | | | | 3.333333E-01
Basalt | | | 2.40 | 2880 | 840
Granite | | | 2.40 | 2880 | 840
Slate | | | 2.40 | 2880 | 840

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<table>
<thead>
<tr>
<th>Material Profile: Stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>granite, red</td>
</tr>
<tr>
<td>hard stone (unspecified)</td>
</tr>
<tr>
<td>limestone</td>
</tr>
<tr>
<td>porphyry</td>
</tr>
<tr>
<td>marble, white</td>
</tr>
<tr>
<td>sandstone</td>
</tr>
<tr>
<td>sandstone tiles</td>
</tr>
<tr>
<td>slate</td>
</tr>
<tr>
<td>slate shale</td>
</tr>
<tr>
<td>tufa, soft</td>
</tr>
<tr>
<td>white calcareous stone</td>
</tr>
<tr>
<td>slate, soft</td>
</tr>
<tr>
<td>clay</td>
</tr>
<tr>
<td>marble, white</td>
</tr>
<tr>
<td>sandstone</td>
</tr>
<tr>
<td>sandstone tiles</td>
</tr>
<tr>
<td>slate</td>
</tr>
<tr>
<td>slate shale</td>
</tr>
<tr>
<td>tufa, soft</td>
</tr>
<tr>
<td>white calcareous stone</td>
</tr>
<tr>
<td>slate, soft</td>
</tr>
<tr>
<td>clay</td>
</tr>
</tbody>
</table>

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### Material Profile: Timber

#### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber</td>
<td>162</td>
<td>9.36</td>
<td>8.19</td>
<td>0.30</td>
<td>61.26</td>
<td></td>
</tr>
</tbody>
</table>

- **Unspecified**: 38
  - Embodied Energy: 6.76
  - Standard Deviation: 3.56
- Virgin: 25
  - Embodied Energy: 9.29
  - Standard Deviation: 6.07
  - Minimum EE: 3.43
  - Maximum EE: 21.30
- Predominantly Recycled: 1
  - Embodied Energy: 6.79
  - Standard Deviation: 4.00
- Unspecified: 6
  - Embodied Energy: 37.42
  - Standard Deviation: 26.68
  - Minimum EE: 16.12
  - Maximum EE: 61.25
- Predominantly Recycled: 1
  - Embodied Energy: 4.52
  - Standard Deviation: 4.41
- Virgin: 5
  - Embodied Energy: 5.33
  - Standard Deviation: 3.33
- Virgin: 4
  - Embodied Energy: 11.92
  - Standard Deviation: 1.40
- Virgin: 3
  - Embodied Energy: 10.12
  - Standard Deviation: 1.50
- Virgin: 23
  - Embodied Energy: 12.48
  - Standard Deviation: 2.14
- Predominantly Recycled: 1
  - Embodied Energy: 5.10
  - Standard Deviation: 5.10
- Virgin: 10
  - Embodied Energy: 10.23
  - Standard Deviation: 10.23
- Virgin: 11
  - Embodied Energy: 9.41
  - Standard Deviation: 9.41
- Virgin: 5
  - Embodied Energy: 17.82
  - Standard Deviation: 4.80
- Virgin: 12
  - Embodied Energy: 13.36
  - Standard Deviation: 6.34
- Virgin: 1
  - Embodied Energy: 11.90
  - Standard Deviation: 11.90

**Selected Embodied Energy & Carbon Values and Associated Data**

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>8.5</td>
<td></td>
<td></td>
<td>Low EE: 8 High EE: 14</td>
<td>Estimated from UK consumption of timber products in 2004</td>
</tr>
<tr>
<td>Glue Laminated timber</td>
<td>12</td>
<td>0.65 (?)</td>
<td>Cradle to Gate</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Hardboard</td>
<td>16</td>
<td>0.86</td>
<td></td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>Laminated Veneer Lumber</td>
<td>9.6</td>
<td>0.51 (?)</td>
<td>Cradle to Gate</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>MDF</td>
<td>11</td>
<td>0.59</td>
<td></td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Particle Board</td>
<td>9.5</td>
<td>0.51</td>
<td></td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Plywood</td>
<td>15</td>
<td>0.81</td>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Sawn Hardwood</td>
<td>7.8</td>
<td>0.47</td>
<td></td>
<td>0.72</td>
<td>16</td>
</tr>
<tr>
<td>Sawn Softwood</td>
<td>7.4</td>
<td>0.45</td>
<td></td>
<td>0.72</td>
<td>13</td>
</tr>
<tr>
<td>Veneer Particleboard (Furniture)</td>
<td>23</td>
<td>1.24</td>
<td></td>
<td>23</td>
<td>20.90</td>
</tr>
</tbody>
</table>

**Comments**

Data on timber was particularly difficult to select. Of all the major building materials timber presented the most difficulties. These values do not include the effect of carbon sequestration. The inclusion or exclusion of sequestered carbon is a complex argument. The following extract highlights some of the difficulties.

The following extract was taken from A. Amato “A comparative environmental appraisal of alternative framing systems for offices” 1996, Reference 1: “There are counter arguments against taking sequestered CO2 into consideration. In measuring embodied CO2, what is being sought is the CO2 burden to society which consequent upon society’s use of a particular material. The deduction of a CO2 value sequestered by the material during its manufacture from the total embodied CO2 burden is not appropriate just because a material is deemed renewable and is solely only appropriate when a world wide steady state has been achieved between consumption and production, i.e. it has achieved sustainability. Renewability does not automatically confer the attribute of sustainability to a material. If we consider the world resource of timber and its consumption as a complete system, then clearly much greater quantities of timber are being consumed than are being replenished at present, most being consumed as fuel in third world countries. Thus, in terms of anthropogenic CO2 resultant from the world’s use of its timber resource, more is being released into the atmosphere than is fixed by the renewal of timber in new plantations and by natural seeding. It therefore appears that the sequestered CO2 argument is only applicable where a world wide steady state has been achieved.

...Finally, it seems a somewhat dubious practice to credit timber benefit of sequestered CO2 without taking into account the methane emissions resultant from the disposal of timber. Methane, like CO2 is a greenhouse gas, but it is estimated as being 24 times more potent than carbon dioxide as stated previously. It is emitted in the UK, mainly from landfill waste, animals, coal mining, gas pipe leakage and offshore oil and gas operations. Methane is produces as timber bio-degrades in landfill sites.”

The focus of this study is on energy and carbon dioxide, but as the previous paragraph highlights the topic of carbon sequestration in an environmental context goes beyond this because of the importance of methane, which is considered outside the scope of this study. Furthermore it would be inappropriate to include carbon sequestration without considering the end of life of timber, which may or may not result in the release of methane. For the reasons highlighted above and the scope of this study the author chose to exclude the effects of carbon sequestration, this leaves it open for the user to decide if the effects of carbon sequestration should be included or excluded.
## Material Profile: Timber

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Condition</th>
<th>Thermal Conductivity (W/m·K-1)</th>
<th>Density (kg/m³)</th>
<th>Specific Heat (J/kg·K-1)</th>
<th>Thermal Diffusivity (m²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fir, pine</td>
<td>Dry</td>
<td>0.17</td>
<td>0.16</td>
<td>720</td>
<td>1250</td>
</tr>
<tr>
<td>Hardwood (unspecified)</td>
<td>Dry</td>
<td>0.09</td>
<td>0.09</td>
<td>750</td>
<td>1250</td>
</tr>
<tr>
<td>Maple, oak and ash hardwoods</td>
<td>Dry</td>
<td>0.13</td>
<td>0.24</td>
<td>850</td>
<td>1250</td>
</tr>
<tr>
<td>Birch, pitch pine</td>
<td>Dry</td>
<td>0.14</td>
<td>0.13</td>
<td>850</td>
<td>1250</td>
</tr>
<tr>
<td>Red fir, Oregon fir</td>
<td>Moist</td>
<td>0.14</td>
<td>0.25</td>
<td>850</td>
<td>1250</td>
</tr>
<tr>
<td>Exotic woods (spruce, sylvester pine)</td>
<td>Dry</td>
<td>0.16</td>
<td>0.15</td>
<td>830</td>
<td>2150</td>
</tr>
<tr>
<td>Melamine</td>
<td>Moist</td>
<td>0.14</td>
<td>0.15</td>
<td>830</td>
<td>2150</td>
</tr>
<tr>
<td>Particle board, glued with UF</td>
<td>Moist</td>
<td>0.12</td>
<td>0.13</td>
<td>830</td>
<td>2150</td>
</tr>
<tr>
<td>Flooring blocks</td>
<td>At 50°C</td>
<td>0.14</td>
<td>0.14</td>
<td>750</td>
<td>1250</td>
</tr>
<tr>
<td></td>
<td>At 55°C</td>
<td>0.14</td>
<td>0.14</td>
<td>750</td>
<td>1250</td>
</tr>
<tr>
<td>Chipboard, bonded with PF</td>
<td>Dry</td>
<td>0.25</td>
<td>0.25</td>
<td>850</td>
<td>2250</td>
</tr>
<tr>
<td>Chipboard, bonded with UF</td>
<td>Dry</td>
<td>0.12</td>
<td>0.25</td>
<td>830</td>
<td>2250</td>
</tr>
<tr>
<td>Melamine</td>
<td>Dry</td>
<td>0.16</td>
<td>0.13</td>
<td>830</td>
<td>2250</td>
</tr>
<tr>
<td>Melamine</td>
<td>Moist</td>
<td>0.14</td>
<td>0.15</td>
<td>830</td>
<td>2250</td>
</tr>
<tr>
<td>Chipboard, bonded with UF</td>
<td>Moist</td>
<td>0.12</td>
<td>0.12</td>
<td>830</td>
<td>2250</td>
</tr>
<tr>
<td>Chipboard, bonded with PF</td>
<td>Moist</td>
<td>0.12</td>
<td>0.12</td>
<td>830</td>
<td>2250</td>
</tr>
</tbody>
</table>

### Fuel Split & Embodied Carbon Data

#### Energy Source

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>% of Embodied Energy from Energy Source</th>
<th>% of Embodied Carbon from Energy Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>19.3%</td>
<td>19.3%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>28.5%</td>
<td>28.5%</td>
</tr>
<tr>
<td>Electricity</td>
<td>52.2%</td>
<td>52.2%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Total | 100.0% | 100.0% |
Material Profile: Tin

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin</td>
<td>12</td>
<td>84.44</td>
<td>87.83</td>
<td>19.11</td>
<td>284.30</td>
<td>None</td>
</tr>
<tr>
<td>Tin, General</td>
<td>12</td>
<td>84.44</td>
<td>87.83</td>
<td>19.11</td>
<td>284.30</td>
<td>None</td>
</tr>
<tr>
<td>Other Specification</td>
<td>1</td>
<td>36.11</td>
<td>36.11</td>
<td>36.11</td>
<td>36.11</td>
<td>None</td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>1</td>
<td>20.85</td>
<td>20.85</td>
<td>20.85</td>
<td>20.85</td>
<td>None</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1</td>
<td>20.85</td>
<td>20.85</td>
<td>20.85</td>
<td>20.85</td>
<td>None</td>
</tr>
<tr>
<td>Other</td>
<td>114</td>
<td>111.16</td>
<td>36.25</td>
<td>19.11</td>
<td>284.30</td>
<td>None</td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin Coated (Steel)</td>
<td>19.2 to 54.7</td>
<td>1.03 to 2.93</td>
<td>Cradle to Gate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tin</td>
<td>250</td>
<td>13.7</td>
<td>Cradle to Gate</td>
<td>19.5</td>
<td>55.5</td>
</tr>
</tbody>
</table>

Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m K-1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (M^2 S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin</td>
<td></td>
<td>65</td>
<td>7300</td>
<td>240</td>
<td>3.71005E-05</td>
</tr>
</tbody>
</table>

Comments

There was a lack of modern data on tin, as reflected in the scatter graph. There was also a very large range of data, which was considered to be a result of tin coated steel products. These products contain small amounts of tin and are predominantly steel.

Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>7.6%</td>
<td>11.7%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>4.5%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>44.3%</td>
<td>38.5%</td>
</tr>
<tr>
<td>Electricity</td>
<td>43.6%</td>
<td>44.5%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Historical embodied carbon per unit fuel use

The fuel split was taken from the typical UK fuel use in UK tin industry.

Material Scatter Graph

EE Scatter Graph - Tin

Fuel Split & Embodied Carbon Comments:

The fuel split was taken from the typical UK fuel use in UK tin industry.

Historical embodied carbon contributions per unit energy use for Lead, Zinc & Tin

Material Scatter Graph

ICE V1.6a

© University of Bath 2008
Material Profile: Titanium

Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
<th>Comments on the Database Statistics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>5</td>
<td>470.67</td>
<td>188.43</td>
<td>257.84</td>
<td>744.70</td>
<td></td>
</tr>
<tr>
<td>Titanium, General</td>
<td>5</td>
<td>470.67</td>
<td>188.43</td>
<td>257.84</td>
<td>744.70</td>
<td></td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>1</td>
<td>257.84</td>
<td>257.84</td>
<td>257.84</td>
<td>744.70</td>
<td>Very limited data</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1</td>
<td>361.00</td>
<td>361.00</td>
<td>361.00</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Virgin</td>
<td>3</td>
<td>578.17</td>
<td>158.15</td>
<td>430.00</td>
<td>744.70</td>
<td></td>
</tr>
</tbody>
</table>

Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Embodied Carbon - Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Primary Titanium</td>
<td>361 to 745</td>
<td>?</td>
<td>Cradle to Gate</td>
<td>Low EE</td>
<td>-</td>
</tr>
<tr>
<td>General Recycled Titanium</td>
<td>258</td>
<td>?</td>
<td></td>
<td>High EE</td>
<td>-</td>
</tr>
</tbody>
</table>

Comments

There was very limited data. Fortunately titanium is not an important building material, with very limited use in construction and in buildings. However, unlike aluminium it does not appear that the benefits of recycled material could help reduce the burden of primary material production. Both recycled and primary titanium have very high embodied energy.

Material Scatter Graph

Fuel Split & Embodied Carbon Data

Unknown fuel split and embodied carbon data
Material Profile: Vinyl Flooring

### Embodied Energy (EE) Database Statistics - MJ/Kg

<table>
<thead>
<tr>
<th>Main Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl</td>
<td>10</td>
<td>53.69</td>
<td>34.82</td>
<td>11.80</td>
<td>120.00</td>
</tr>
<tr>
<td>Vinyl, General</td>
<td>10</td>
<td>53.69</td>
<td>34.82</td>
<td>11.80</td>
<td>120.00</td>
</tr>
<tr>
<td>Unspecified</td>
<td>10</td>
<td>53.69</td>
<td>34.82</td>
<td>11.80</td>
<td>120.00</td>
</tr>
</tbody>
</table>

#### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy - MJ/Kg</th>
<th>Feedstock Energy (Included) - MJ/Kg</th>
<th>Embodied Carbon - Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Vinyl Flooring</td>
<td>65.64</td>
<td>23.58</td>
<td>2.29</td>
<td>Cradle to Gate</td>
<td>11.8</td>
<td>96</td>
</tr>
<tr>
<td>Vinyl Composite Tiles (VCT)</td>
<td>13.7</td>
<td>?</td>
<td>?</td>
<td>Cradle to Grave</td>
<td>Not enough data to specify a range.</td>
<td></td>
</tr>
</tbody>
</table>

#### Comments

It should be noted that in the scatter graph below most of the specified values include feedstock energy. It is not possible from the scatter graph alone to determine which include and which exclude feedstock energy. This data is stored within the ICE-Database.

---

### Material Scatter Graph

![EE Scatter Graph - Vinyl](#)

**Year of Data**

<table>
<thead>
<tr>
<th>Year of Data</th>
<th>Embodied Energy (EE) - MJ/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0.00</td>
</tr>
<tr>
<td>1992</td>
<td>140.00</td>
</tr>
<tr>
<td>1994</td>
<td>120.00</td>
</tr>
<tr>
<td>1996</td>
<td>0.00</td>
</tr>
<tr>
<td>1998</td>
<td>0.00</td>
</tr>
<tr>
<td>2000</td>
<td>0.00</td>
</tr>
<tr>
<td>2002</td>
<td>0.00</td>
</tr>
<tr>
<td>2004</td>
<td>0.00</td>
</tr>
<tr>
<td>2006</td>
<td>0.00</td>
</tr>
</tbody>
</table>

---

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W-m-1 K-1)</th>
<th>Density (kg m -3)</th>
<th>Specific heat (J kg-1 K-1)</th>
<th>Thermal Diffusivity (M^2 S-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl floor covering</td>
<td></td>
<td>0.18</td>
<td>1200</td>
<td>1470</td>
<td>1.0771E-07</td>
</tr>
</tbody>
</table>

---

### Comments on the Database Statistics:

Care needs to be taken when looking at these statistics due to feedstock energy. It is only apparent when examining the (separate) database records whether feedstock energy is included or excluded, sometimes it is not known and assumptions need to be made.

Same value as PVC calendared sheet, this value is in agreement with the other values in the database for vinyl flooring.

Not enough data to specify a range.

Reference 77

---

### Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>41.8%</td>
<td>39.3%</td>
</tr>
<tr>
<td>Oil fuels</td>
<td>15.1%</td>
<td>19.8%</td>
</tr>
<tr>
<td>Other Fuels</td>
<td>43.1%</td>
<td>40.9%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Fuel Split & Embodied Carbon Comments:

The energy split was specified in the literature, the carbon split is an estimate, although considered a good indicator. The main fuel classified under ‘other’ fuels was natural gas.
### Material Profile: Zinc

**Embodied Energy (EE) Database Statistics - MJ/Kg**

<table>
<thead>
<tr>
<th>Material</th>
<th>No. Records</th>
<th>Average EE</th>
<th>Standard Deviation</th>
<th>Minimum EE</th>
<th>Maximum EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>39</td>
<td>59.80</td>
<td>25.16</td>
<td>8.46</td>
<td>105.76</td>
</tr>
<tr>
<td>Zinc, General</td>
<td>39</td>
<td>59.80</td>
<td>25.16</td>
<td>8.46</td>
<td>105.76</td>
</tr>
<tr>
<td>Market Average</td>
<td>1</td>
<td>29.10</td>
<td>29.10</td>
<td>29.10</td>
<td>29.10</td>
</tr>
<tr>
<td>Predominantly Recycled</td>
<td>4</td>
<td>5.25</td>
<td>0.09</td>
<td>0.09</td>
<td>5.25</td>
</tr>
<tr>
<td>Unspecified</td>
<td>8</td>
<td>47.83</td>
<td>16.31</td>
<td>18.00</td>
<td>68.40</td>
</tr>
<tr>
<td>Virgin</td>
<td>26</td>
<td>72.44</td>
<td>15.13</td>
<td>46.00</td>
<td>105.76</td>
</tr>
</tbody>
</table>

**Comments on the Database Statistics:**
- None

### Selected Embodied Energy & Carbon Values and Associated Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy MJ/Kg</th>
<th>Embodied Carbon Kg CO2/Kg</th>
<th>Boundaries</th>
<th>Best EE Range - MJ/Kg</th>
<th>Specific Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Zinc</td>
<td>61.9</td>
<td>3.31</td>
<td>Cradle to Gate</td>
<td>57</td>
<td>87</td>
</tr>
<tr>
<td>Primary Zinc</td>
<td>72</td>
<td>3.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Zinc</td>
<td>9</td>
<td>0.48</td>
<td></td>
<td>7.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>

**Comments:** None

### Material Scatter Graph

![EE Scatter Graph - Zinc](image)

### Fuel Split & Embodied Carbon Data

<table>
<thead>
<tr>
<th>Energy source</th>
<th>% of Embodied Energy from energy source</th>
<th>% of embodied carbon from source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>7.6%</td>
<td>11.7%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Oil</td>
<td>4.5%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>46.3%</td>
<td>38.5%</td>
</tr>
<tr>
<td>Electricity</td>
<td>43.6%</td>
<td>44.5%</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>106.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Fuel Split & Embodied Carbon Comments:**
- The fuel split was taken from the typical UK fuel use in UK zinc industry.

### Historical embodied carbon per unit fuel use

![Embodied carbon contributions per unit energy use for Lead, Zinc & Tin](image)

### Material Properties (CIBSE Data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition</th>
<th>Thermal conductivity (W/m K)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg K)</th>
<th>Thermal Diffusivity (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td></td>
<td>110</td>
<td>1900</td>
<td>900</td>
<td>4.13E-04</td>
</tr>
</tbody>
</table>

© University of Bath 2008
<table>
<thead>
<tr>
<th>Ref No.</th>
<th>Title</th>
<th>Author</th>
<th>Year</th>
<th>Organisation/Publisher</th>
<th>ISBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>A comparative LCA of building insulation products made of stone wool, paper wool and fibreglass</td>
<td>Andersen Schmidt, Allan Jensen et al</td>
<td>2004</td>
<td>International Journal of LCA</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>A life cycle analysis of the environmental impacts of asphalt and concrete roads</td>
<td>Gianni Pontarollo &amp; Tim Smith</td>
<td>2001</td>
<td>IFR world road congress 2001</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A material flow analysis and an ecological footprint of the southeast region, chapter 3</td>
<td>John Barrett et al</td>
<td>2002</td>
<td>Taking stock, Biloxi</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Akyonite-Butilidene-Siopoymer (ABIS) LCI Data Summary</td>
<td>Bouleal</td>
<td>2005</td>
<td>APME, Association of Plastics Manufacturers in Europe</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Akyonite-Butilidene-Siopoymer (ABIS) LCI Data Summary</td>
<td>Bouleal</td>
<td>2005</td>
<td>APME, Association of Plastics Manufacturers in Europe</td>
<td></td>
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<tr>
<td>10</td>
<td>A material flow analysis and a life cycle perspective of the southern african region, chapter 3</td>
<td>John Barrett et al</td>
<td>2002</td>
<td>Taking stock, Biloxi</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>An ecological assessment of the vernacular architecture and of its embodied energy in Yunnan, China</td>
<td>Wang Ranping, Cai Zhenyu</td>
<td>2006</td>
<td>Building and environment 41, 2006, pg 687-697</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>An environmental comparison of bridge forms</td>
<td>J Collinge</td>
<td>2006</td>
<td>Bridge Engineering, 139, December 2006, Issue 864, Pg 163-168</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>An assessment of the environmental impact of metal production processes</td>
<td>I Emorgale, S Jahanahashi, W J Rankin</td>
<td>2006</td>
<td>Journal of Cleaner Production 15, 2007, Pg 838-848</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>An assessment of the automotive assembly paint process for energy, environmental and economic improvement</td>
<td>Steve In, J Koenig, Amber J Kampiansen and dave R Shonnard</td>
<td>2004</td>
<td>Journal of Industrial Ecology, Volume 8, Number 1-2</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Assessment of the decrease of CO2 emissions in the construction industry through the selection of materials. practical case study of three houses of low technology impact</td>
<td>Maria Jesus Gonzalez, Justo Garcia Navarro</td>
<td>2005</td>
<td>Building And Environment; Article in press</td>
<td></td>
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<tr>
<td>17</td>
<td>Australian LCA data - SimaPro Data</td>
<td>RMIT Uni Victoria Australia</td>
<td>1998</td>
<td>RMIT Uni Victoria Australia</td>
<td></td>
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<td>18</td>
<td>Background document for life cycle greenhouse gas emission factors for carpet and personal computers</td>
<td>US environment Protection Agency</td>
<td>2003</td>
<td>US environment protection agency</td>
<td></td>
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<td>20</td>
<td>Best Available Techniques for the Cement Industry</td>
<td>Centresbulo</td>
<td>1999</td>
<td>centresbulo</td>
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<tr>
<td>21</td>
<td>Birth to death analysis of the energy payback and CO2 gas emission rates from coal, fission, wind and DT fusion electrical power plants</td>
<td>Scott W White and Gerald L Kulicki</td>
<td>2005</td>
<td>Fusion engineering and design 48, 2000, Pg 472-481</td>
<td></td>
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<tr>
<td>22</td>
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