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## 1 EXECUTIVE SUMMARY

The Wood Window Alliance (WWA) commissioned Davis Langdon in January 2009 to undertake a comparative Environmental assessment of a WWA accredited window with a PVC-U window of a similar size and standard. The comparison involved an analysis of through life embodied CO<sub>2</sub>e emissions.

The study was undertaken using a Life Cycle Assessment (LCA) methodology to estimate embodied CO<sub>2</sub>e.

WWA confirmed that all its member manufacturers use wood sourced from sustainably managed forests and are required to have Chain-of-Custody evidence to demonstrate that only certificated timber is used in their products. Such timber can be credited with sequestration of CO<sub>2</sub> from the atmosphere. Additionally, and in line with developing practice, timber has been credited with the beneficial effect of incineration for energy production at end-of-life and, where disposed of in landfill, with the consequential benefit of the capping and use of methane arising from decomposition. The assessment of PVC-U also includes a credit for beneficial incineration for energy production at end of life, but this is not so great as for timber.

The study has broken new ground in the Life Cycle Assessment of timber, and full details of the model developed for the analysis are provided in this report.

The results demonstrate that the timber window has a positive embodied CO<sub>2</sub>e impact over its life cycle, in contrast to the negative embodied CO<sub>2</sub>e impact of the PVC-U window. The difference is significant and due mainly to both the sequestration of atmospheric CO<sub>2</sub> during the growing phase of timber, and the beneficial incineration of timber waste and/or the capping and use of methane from decomposing timber in landfill at end-of-life. This difference in embodied CO<sub>2</sub>e between the timber and PVC-U windows holds good across all exposure levels examined (sheltered, moderate and severe) as well as across different levels of care/maintenance (good, average and poor) and over a range of time horizons (30, 60 and 100 years).

## 2 INTRODUCTION

### 2.1 Aims and objectives

This report presents the results of a study into the environmental impact of timber and PVC-U windows, undertaken for the Wood Window Alliance (WWA) by Davis Langdon during 2009.

Specifically, the study objectives were to examine and understand the differences between timber and PVC-U windows in terms of their environmental impacts, which include all activities up to and including construction on site, maintenance through life and end of life / disposal.

### 2.2 Overall scope and key assumptions

The study focused on the environmental impact of a 'standard' 1230mm wide by 1480mm high double glazed window unit<sup>1</sup> having a central mullion and one side-opening light, in both PVC-U and softwood. Key study assumptions were as follows:

- Both PVC-U and timber units were assumed to have identical glazed units and ironmongery, and these items were therefore ignored in the environmental impact assessment (which is on the basis of the window frame only)
- Environmental impact was assessed primarily in terms of embodied CO<sub>2</sub>e (CO<sub>2</sub> equivalent, which is a combination of all related emissions having a global warming affect, including methane and nitrous oxide) in accordance with a Life Cycle Assessment (LCA) approach based on the PAS 2050 measurement protocol (see Section 3.1.1 below)
- The different window specifications were assessed using a range of UK exposure conditions, as well as different maintenance regimes.

### 2.3 Why CO<sub>2</sub>?

The dominant greenhouse gas causing human-influenced global warming is considered to be CO<sub>2</sub>. This excludes water vapour, which although having a global warming effect and can be influenced by human actions, is natural and considered to be neutral in terms of climate modelling.

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<sup>1</sup> This size was selected because it provides an exact comparison with the window sizes used in the BRE *Green Guide* and those used by the British Fenestration Rating Council (BFRC) for Window Energy Rating calculations. The windows selected for assessment are those meeting an A to C energy rating. These differ from 'everyday' PVC-U and Timber framed windows, and will meet the minimum energy ratings required in Part L of the Building Regulations.

## 3 OUR APPROACH AND METHODOLOGY

### 3.1 Overview of Life Cycle Assessment (LCA) methodology

Life Cycle Assessment (LCA) is an environmental evaluation method in which environmental impacts arising from the manufacture, use and disposal of a product or service are quantified. These impacts include all extractions from the environment (i.e. resources) and all emissions to it (i.e. pollution) throughout the whole life cycle of the product. An LCA is carried out by:

- Collecting an inventory of relevant inputs (materials, fuels, energy) and outputs (pollution, waste) of a product or system
- Evaluating the potential environmental impact of those relevant inputs and outputs.
- Interpreting the results of the inventory analysis and impact assessment in relation to the objectives of the study.

Our approach follows guidance on LCA in the ISO14040 standardisation series and the Publicly Available Specification (PAS) 2050, published by the British Standards Institute and sponsored by Defra and the Carbon Trust<sup>2</sup>. PAS 2050 was released in draft form in 2008, and encourages an holistic approach as well as consideration of the wider impacts of harvesting organic products.

LCA results are typically expressed across a number of environmental impact categories. For this study CO<sub>2</sub>e (global warming impact) was the primary focus.

### 3.2 Scope of assessment

The assessment undertaken for this study focused on 'embodied' CO<sub>2</sub>e, ie the CO<sub>2</sub>e associated with the production, transportation, fixing in place, maintenance and eventual disposal of PVC-U and timber windows. The assessment covers the following key stages (sometimes referred to as system boundaries) in the product life cycle, and is essentially a 'cradle to grave' approach:

- Stage 1 – Raw material formation
- Stage 2 – Material extraction and manufacture, including
  - process energy during raw material extraction and manufacture
  - the transport of raw and semi-processed materials
  - transport of the final product to site (where data available)
  - Construction, including process energy used on site
- Stage 3 – Maintenance, including the materials (eg paint) and energy used in window maintenance
- Stage 4 – Demolition and disposal at end-of-life, including:
  - Recycling
  - Use as biomass energy in power stations
  - Disposal to landfill (including, in the case of timber, decomposition and methane generation for power).

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<sup>2</sup> The ISO standards specifically designed for LCA application are ISO/DIS 14040: Principles and Framework, and ISO/DIS 14044: Requirements and Guidelines

PAS 2050, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, British Standards Institute <http://shop.bsigroup.com/en/Browse-by-Sector/Energy--Utilities/PAS-2050/>

### 3.3 Data Sources

For this study Davis Langdon used a number of data sources, including the Ecoinvent database in SimaPro version 7.0.2, one of the leading LCA software tools, as well as the Bath University ICE Inventory (Ref 15) and the firm’s own assessments of CO2e for key building materials.

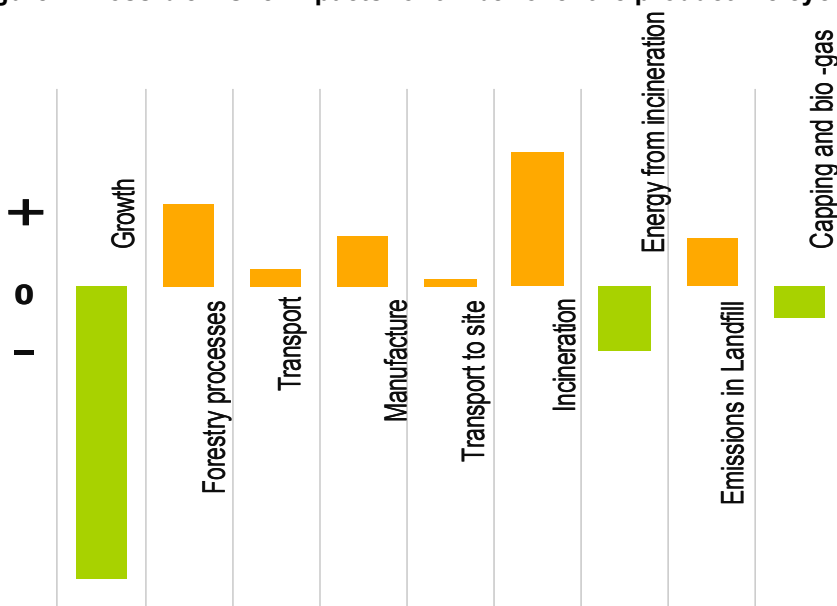
Average travel distances, obtained from the Davis Langdon database, were assumed for the transportation of raw and semi-processed materials, and for the transportation of the final product to the construction site. Site-specific travel related emissions may, of course, be used once the location of specific sites are known. An allowance, based on our experience, was made for energy used during the construction process (the transportation of site labour was excluded from this study).

### 3.4 Issues with Timber

The Life Cycle Assessment of timber poses a number of challenges for LCA practitioners. Whilst for most products a ‘cradle to grave’ approach is preferred, this has not always been possible for timber, partly because the end of life assessment was often speculative and not well understood. Timber absorbs CO2 from the atmosphere as trees grow, though it is sometimes argued that the benefit of this carbon sequestration in growth is lost at the end of life, either through incineration or decomposition in landfill – the latter producing methane, a powerful greenhouse gas. In this scenario, some practitioners have assumed that both CO2 sequestration and end of life emissions could be ignored since they would roughly cancel each other out. However, the combined affects of increased regulation and incentives to avoid waste are changing the end of life treatment of timber. In particular, through the capture and beneficial incineration of methane from decomposing timber in landfill, timber can become a power source that will displace the use of fossil fuels.

In this study, therefore, we have accounted for carbon sequestration and all the subsequent processes through to a mix of end of life scenarios. Figure 1 provides an illustration of the positive and negative impacts over the timber life cycle.

**Figure 1: Possible CO2e impacts for timber over the product life cycle**



The provenance of timber exerts a dominant influence on the embodied CO<sub>2</sub>e calculation. A key assumption in our assessment is that timber comes from sustainably managed forests in line with the Central Point of Expertise on Timber (CPET)<sup>3</sup> guidelines and thus can be attributed with the benefit of CO<sub>2</sub> sequestration<sup>4</sup>. CPET includes the Forestry Stewardship Council (FSC) and the Programme for the Endorsement of Certified Timber (PEFC)<sup>5</sup> as approved schemes.

### 3.5 Issues with PVC-U

Compared to timber, data on the Life Cycle Assessment of PVC-U is more readily available. For this study we used data from the SimaPro/Ecoinvent database to assess the embodied CO<sub>2</sub>e of PVC-U, primarily because the system boundaries are clear. The Bath University ICE Inventory data for PVC-U shows considerable variability (of +/- 30%), partly because the system boundaries are unclear, and we have not used this data.

We have also considered different end of life scenarios for PVC-U. Some PVC-U is crumbed at end of life for further use, but this tends to be considered as downcycling, and the resulting material is not used for windows or products of equivalent quality. We have not, therefore, included for any recycled content in PVC-U windows. Of course, the benefit that another product may get from using crumbed PVC-U should be included in an LCA of that product, but not the product from which the crumbed PVC-U was derived. PVC-U may also be incinerated for energy production, and this will displace fossil fuel incineration and thus has a CO<sub>2</sub>e benefit. Ecoinvent data excludes this benefit. Currently, this kind of beneficial incineration is limited to about 12% of waste PVC-U as there are difficulties in dealing with emissions such as dioxins which are a human carcinogen. We have, therefore, made an adjustment to the Ecoinvent data to reflect this benefit.

### 3.6 Assessment periods: key assumptions

The assessment undertaken for this study focused on the likely initial impacts, subsequent maintenance and end of life impacts of PVC-U and timber windows.

The different window specifications were assessed over a range of time periods, as follows:

- Up to 100 years
- Up to 80 years
- Up to 60 years
- Up to 30 years.

These different time horizons provide a wide range over which the embodied CO<sub>2</sub>e of timber and PVC-U windows can be compared. While the life of the building in which windows are

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<sup>3</sup> The Central Point of Expertise on Timber Procurement (CPET) provides information and advice on meeting the UK Government's Timber Procurement Policy. CPET is funded by the Department for Environment, Food and Rural Affairs, and is operated by ProForest – see <http://www.proforest.net/cpet>

<sup>4</sup> Deforestation can be harmful to the environment, not just because of the carbon extracted or given off by burning, but because of consequential impact on other trees and shrubs damaged during extraction. Additionally a further impact is felt as the carbon in the soil may tend to leach out through increased soil respiration. Some experts maintain that as the global demand for wood exceeds supply, any increase in demand will inevitably encourage further deforestation. We feel that, provided timber comes from sustainably managed forests – with any extraction counterbalanced by replanting and good management – then deforestation is avoided and afforestation encouraged.

<sup>5</sup> FSC is an international forest certification programme; PEFC is an international umbrella organisation for the mutual recognition of independent national forest certification schemes – see <http://www.proforest.net/cpet/evidence-of-compliance/category-a-evidence/approved-schemes>

incorporated is a key determinant of the extent of window maintenance and/or replacement, this cannot be known in advance.

## 4 ANALYSIS AND RESULTS

### 4.1 Overall results

The overall results of our analysis are presented in Table 1 below. These demonstrate that, adopting the evaluation methodologies and key assumptions discussed in Section 3 of this report, the timber window assessed has significant CO<sub>2</sub>e benefits over its PVC-U counterpart.

**Table 1 Comparative embodied CO<sub>2</sub>e/window**

		Embodied CO <sub>2</sub> e/Window	
Stage	Description	Timber	PVC-U
1, 2	Material Formation Process/Manufacture, etc	-18.95 (Incl end of life)	46.0
3	Maintenance/replacement(60 years, with moderate exposure & average maintenance)	6.76	46.0
4	End of life	(Incl in 1,2)	-15.36
Total per window		-12.19 Kgs CO <sub>2</sub> e	76.64Kgs CO <sub>2</sub> e

These results are examined in further detail in the Sections following. Section 4.2 deals with embodied CO<sub>2</sub>e assessments and Section 4.3 provides more detailed results for different exposure and maintenance conditions.

### 4.2 Assessment of embodied CO<sub>2</sub>e – summary results

#### 4.2.1 Notes on the assessment

Our assessment of embodied CO<sub>2</sub>e presented in this report is considerably more extensive on timber than on PVC-U. There is a good deal of published data on PVC-U, with general agreement among practitioners about the method of measurement as well as the results arising. This is not the case with timber, on which there have been disagreements about whether and how to include CO<sub>2</sub> sequestration and end of life issues. We have, therefore, undertaken an extensive study to assess the cradle-to-grave impact of timber which we believe breaks new ground, particularly in respect of end of life treatment, and makes a valuable and much needed contribution to knowledge in this area.

A comprehensive mathematical model was developed to model the timber process. A draft was demonstrated to the CeCops group<sup>6</sup>, and various members have provided comment and advice. The general approach was to start with one tonne of felled timber, assuming that as much as possible would be used for window manufacture. As timber is trimmed at each stage of the logging/manufacturing process, the further use of off-cuts as biofuel for manufacturing,

<sup>6</sup> The Construction Emissions Community of Practitioners (CeCops) as a voluntary grouping of LCA practitioners in construction. Davis Langdon is a member.

incineration for energy, or disposal to landfill are all accounted for. By-products with no commercial value, such as animal bedding, are counted as waste, though in this case we assume they are eventually incinerated for energy, and counted accordingly. With this approach, the embodied CO<sub>2</sub>e value of timber is presented in the form of a CO<sub>2</sub>e 'account', with a running total that is progressively modified at each key stage in the cradle-to-grave life cycle (see also Table 4 below).

Our timber assessment also accounts for the improved performance of modern, high performance timber windows compared to their more traditional counterparts, and specifically takes account of:

- Use of heartwood only with no use of sapwood
- Improved timber window design, such as increased slopes on cills
- Improvements in paint technology and application, especially factory applied as opposed to site applied paint<sup>7</sup>.

#### 4.2.2 Embodied CO<sub>2</sub>e for timber windows

Using the CO<sub>2</sub>e accounting approach, the assessment of a tonne of timber at each of the key stages in the product life cycle is summarised in Table 2 below. Points to note include:

- The country of origin is assumed to be Finland
- In country transportation is by road; between country transportation is by sea
- The original tonne of harvested timber reduces in mass as the manufacturing process progresses; in summary:
  - Some 655kg (65%) of the original tonne of harvested timber is not suitable for window manufacture
  - The remaining 345kg is delivered to the window manufacturer; of this:
    - 181kg (51%) further waste is generated, either as offcuts or sawdust, and
    - 173kg is used to produce some 12 windows of the type described in Section 2.2 above, each weighing 14.4kg net.

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<sup>7</sup> Our estimates of component lives and maintenance cycles assume that Sikkens' recommendations for the painting regime were followed for the "averagely maintained" scenario, and we assume that the paint is to Sikkens standards or better.

**Table 2 Embodied CO2e of timber (per original tonne)**

		Embodied CO2e/original tonne timber	
Stage	Description	Impact of process Kgs Co2e	Running total Kgs CO2e
	CO2e sequestration value (opening balance)	-1870 (see App A)	-1870
1	Material Formation	+558	-1312
	Forestry Processes		-761
	Production of co-products	(see App A)	
2	Process / manufacturing / transport / construction		
	Transport to manufacturer	+33	-728
	Manufacture (excl painting)	+175	-553
	Transport to site/construction	+8	-545
		(see App B-C)	
3	Maintenance (over 60 years, with moderate exposure & average maintenance)	n/a	n/a
		(see Table 4)	
4	End of Life		
	Incineration for energy	265	-280
	Landfill, incl methane extraction and use	35	-245
		(see App D-E)	
Final total per original tonne of timber			-245Kgs CO2e

The embodied CO2e for the original tonne of harvested timber consumed in the production of twelve windows comes to some -245kgsCO2e. This works out at -20.3kg per window. Allowing for initial painting (1.35kg CO2e per window) and maintenance over a 60 year life in moderate exposure (6.76kg per window) results in a net CO2e per window of -12.19kg (Table4).

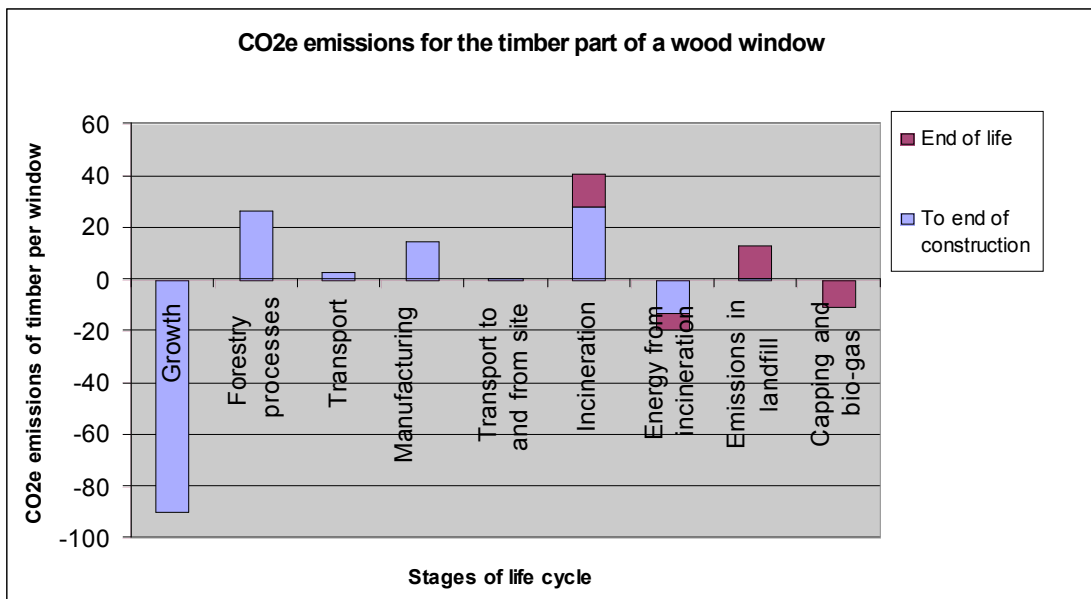
**Table 3 Embodied CO2e of timber (per window)**

		Embodied CO2e/Window	
Stage	Description	Total Kgs Co2e/ tonne timber	Total Kgs CO2e/ Window
1, 2 (part) and 4	Material Formation  Process/Manufacture, etc (excluding painting)  End of Life	-245  (1 tonne timber yields ≈12 windows)	-20.30
2 (part)	Painting during manufacture	(see App F)	+1.35
3	Maintenance (over 60 years, with moderate exposure & average maintenance)	(see App F)	+6.76
Final total per window			-12.19 Kgs CO2e

The embodied CO2e ‘account’ for the timber window – with the positive and negative carbon impacts at each detailed stage of the process - is shown schematically in Figure 2 below.

The embodied CO2e of the timber window expressed in terms of the net (timber) weight of the window is therefore some -1.41kg (-20.30/14.4kg) excluding painting and maintenance (-0.85kg including painting and maintenance). This contrasts with a number of sources which do not include carbon sequestration. For example, the beta version 2.0 of the Bath University ICE embodied carbon inventory shows a range from 0.3 to 13 kgsCO2e/kg, with an average 5.55 kgsCO2e/kg (Ref 15). However, this excludes CO2 sequestration and end of life emissions.

**Figure 2 Embodied CO2e ‘account’ for timber window.**



**4.2.3 Embodied CO2e for PVC-U windows**

The embodied CO2e for PVC (per kg and per window) for each key stage in the product life cycle is shown in Tables 1 and 2 above (Section 4.1). Data on embodied energy/CO2e is taken from the Ecoinvent database in Sima Pro. The Ecoinvent figure for PVC-U is about 2.0 kgsCO2e/kg. However, this does not account for end of life situations, where some improvements have been made. Specifically, it was found that in 2009 in the UK, 12% of PVC-U was downcycled by crumbing, and about 12% of PVC-U is used for incineration to produce energy, and so displacing the use of fossil fuel (Ref 12). Accounting for this practice produces a negative impact of -0.44 kgCO2/kg.

**Table 4. Benefit/ burden at end of life for PVC-U**

	Proportion	Process kWHrs/kg	Net (process - feedstock)	Grid rating kgCO2/kWHr	CO2e/kg
Incineration for energy (Ref 11)	12%	0.5	-7.31	0.54	-0.47
Recycled (Ref 12)	12%	0.5	0.50	0.54	0.03
				TOTAL	-0.44

The weight of PVC-U in the window was taken as 17.45kgs, which was based on a 70mm A-rated Rehau window (Ref 10). The weight of mild steel reinforcement was taken at 4kgs, based on BRE’s report in 2008 for the BWF “Report on BRE Generic Environmental Profiles of Timber Windows” (Ref 19). The embodied CO2e of the PVC-U window is shown in Table 6.

**Table 5 Embodied CO2e of PVC-U (per window)**

		Embodied CO2e/Window	
Stage	Description	Total Kgs Co2e/Kg material	Total Kgs CO2e/ window
1, 2	Material Formation	PVC-U 2.0	34.9
	Process/Manufacture, etc	Steel 2.75	11.1
3	Maintenance/replacement	PVC-U 2.0	34.9
	(up to 60 years, with moderate exposure & average maintenance)	Steel 2.75	11.1
4	End of life	PVC-U -0.44	-15.36
Final total per window			76.64Kgs CO2e

### 4.3 Embodied CO2e under a range of exposure and maintenance conditions

There is a need to consider the embodied CO2e of timber and PVC-U windows under different exposure and care/maintenance regimes, as these have an impact on the durability and maintainability of the different products. The life expectancies and maintenance cycles for timber and PVC-U windows were assessed in terms of three exposure conditions, as follows:

- **Sheltered** means non-coastal areas at low altitude
- **Moderate** would include areas within ½ mile of coastline but not directly exposed to the landward gales
- **Severe** would include coastal areas and areas at high altitude.

Life expectancies and maintenance cycles were also assessed in terms of three levels of care in use: **Good**, **Average** and **Poor**. These are defined (for each of the exposure conditions) in terms of the maintenance and replacement frequencies.

Assessments of embodied CO2e were therefore undertaken for 27 scenarios for each of timber and PVC-U to reflect 3 levels of exposure, 3 levels of maintenance and 3 time horizons – 30, 60 and 100 years. The exercise was repeated for 30 and 100 years, and is summarised in Tables 6-8.

**Table 6 Embodied CO2e of Timber and PVC-U windows over 30 years kgs CO2e**

Maintenance regime	Good		Average		Poor	
	Wood	PVC-U	Wood	PVC-U	Wood	PVC-U
Exposure						
Sheltered	-16.2	38.2	-17.6	38.2	-17.6	38.2
Moderate	-15.6	38.2	-16.2	38.2	-17.6	38.2
Severe	-13.5	38.2	-14.9	38.2	-36.6	76.41

**Table 7 Embodied CO2e of Timber and PVC-U windows over 60 years kgs CO2e**

Maintenance regime	Good		Average		Poor	
	Wood	PVC-U	Wood	PVC-U	Wood	PVC-U
Exposure						
Sheltered	-13.55	76.41	-14.22	76.41	-16.25	76.41
Moderate	-10.17	76.41	-12.19	76.41	-35.20	76.41
Severe	-27.09	76.41	-30.47	76.41	-53.48	114.61

**Table 8 Embodied CO2e of Timber and PVC-U windows over 100 years kgs CO2e**

Maintenance regime	Good		Average		Poor	
	Wood	PVC-U	Wood	PVC-U	Wood	PVC-U
Exposure						
Sheltered	-29.1	114.61	-31.1	114.61	-33.2	152.82
Moderate	-23.71	114.61	-27.1	114.61	-52.1	152.82
Severe	-38.6	152.82	-44.0	152.82	-69.7	191.02

While not included in the calculations, we acknowledge that timber windows have an advantage in the case of damage to the frames or ironmongery through misuse or vandalism. The frames can be repaired more easily, including attachments with ironmongery. Indeed, English Heritage

for example, prefers to maintain and repair timber windows over long periods and is very reluctant to recommend replacement.

## 5 CONCLUSIONS

### 5.1 Environmental impact: embodied CO<sub>2</sub>e

Our results show that the timber window has a positive embodied CO<sub>2</sub>e impact (ie its estimated embodied CO<sub>2</sub>e is negative) over its life cycle. This is in contrast to the negative embodied CO<sub>2</sub>e impact of the PVC-U window. The difference is significant and due mainly to both the sequestration of atmospheric CO<sub>2</sub> during the growing phase of timber, and the beneficial incineration of timber waste and/or the capping and use of methane from decomposing timber in landfill at end-of-life. Our assessment assumes that timber for the window is sustainably sourced in line with CPET guidelines (see 3.1.4 above).

The difference in embodied CO<sub>2</sub>e between the timber and PVC-U windows holds good across all exposure levels examined (sheltered, moderate and severe) as well as across different levels of care/maintenance (good, average and poor) and over a range of time horizons (30, 60 and 100 years). The embodied CO<sub>2</sub>e impact of maintaining (painting) the timber window, even over long periods of time (up to 100 years) is more than offset by the sequestration effect of timber and its beneficial use as a non-fossil fuel. Indeed, continued maintenance to extend the life of the timber window is beneficial in embodied CO<sub>2</sub>e terms, as the 'carbon store' effect is prolonged and the release of CO<sub>2</sub> at end of life is deferred.

So long as the timber window examined in this study is sustainably sourced, then over the whole life cycle, it is liable to be either carbon negative or close to zero carbon. The dominant influences in this are the carbon sequestration in growth and the benefit in use as a fuel at end of life. The latter negates about half of the CO<sub>2</sub> emissions if used as biomass, and rather more when disposed of in a well-managed landfill site with the methane tapped for energy.