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ASSESSMENT OF EMBODIED CARBON IN CONVENTIONAL AND PERMEABLE PAVEMENTS SURFACED WITH PAVERS

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands.

Summary

The paper presents data showing the weight of Embodied Carbon in materials used in pavements surfaced with pavers. Embodied Carbon is the total weight of CO_2 used in the extraction, manufacture and delivery of the materials. There is a worldwide acceptance that CO_2 is a significant contributing factor to global warming and therefore a desire to quantify and minimise that weight of CO_2 involved in all aspects of life, including construction. The Authors have established Embodied Carbon levels in pavers, asphalt, in-situ concrete, geotextiles and aggregates. From this they have developed a means of calculating the total CO_2 produced for a unit area of a designed pavement. They present data showing total CO_2 embodied within a permeable pavement on a residential development.

They have applied their data to a typical medium sized residential project firstly assuming permeable paving and secondly assuming conventional drainage. They have considered both a detention pavement. They have concluded that there is approximately 50% saving in CO_2 when a permeable pavement is used instead of a conventionally drained pavement.

The Authors have considered the possibility of tree planting as a means of creating carbon neutral pavements and they have concluded that there are many categories of project where it would be a simple matter to plant sufficient trees to bring a permeable pavement to a carbon neutral condition. In the case of residential developments, the number and type of trees required is such that the quality of the development would be enhanced at minimal cost. They show that because trees absorb different levels of CO_2 at different ages, and because all of the CO_2 contributed by the pavement materials is “up-front”, there will be an initial carbon deficit but that after 50 years, the pavement/trees combination will begin to make a positive contribution to CO_2 levels.

The Authors conclude that wherever possible, permeable pavement design should include a requirement for long-term carbon neutrality or at least should include as much carbon offsetting as possible.

1. INTRODUCTION

The Authors have assessed the weight of Embedded Carbon within both permeable paving and conventional paving using data published by University of Bath, United Kingdom in September 2008 [Hammond and Jones (2008)].

The embedded carbon of a construction material is taken to be the total weight of carbon released over its life cycle. This includes extraction, manufacturing, transport, capital equipment, heating and lighting of factory/quarry, maintenance and disposal, sometimes termed "Cradle to Grave". The authors developed embedded carbon coefficients for construction materials mainly by firstly calculating embodied energy and then making estimates according to their understanding of the relationships between energy and carbon. In making their estimates, they took into account typical fuel mixes of the relevant industries (e.g. brick making is dominated by gas in the United Kingdom). Two factories might 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. Previous less accurate assessments have been based upon using a global conversion factor relating embodied energy, which is well understood, to embodied carbon.

The University of Bath study has identified the Embodied Carbon values shown in Table 1. The results are expressed in units of kg of CO_2 per kg of product. Table 1 shows the values which are relevant to assessing schemes in which pavements surfaced with pavers are used.

Table 1. Values of Embodied Carbon in Materials used commonly in paving.

MATERIAL CATEGORY	EMBODIED CARBON ($kgCO_2/kg$)	EMBODIED CARBON PER m^2 FOR THE THICKNESS STATED (kg)
Compacted Aggregate	0.03	6 kg for 100 mm thickness
Asphalt	0.14	28 kg for 100 mm thickness
Brick Pavers	0.22	34 kg for 65 mm thickness
Portland Cement	0.83	11 kg for 100 mm thickness of cement stabilized Coarse Graded Aggregate (CGA). Including the aggregate, the total for 100 mm thickness of compacted cement stabilized CGA is 17 kg.
Concrete Pavers	0.17	32 kg for 80 mm thickness
Pavement Quality Concrete	0.15	36 kg for 100 mm thickness
Lean Concrete	0.11	26 kg for 100 mm thickness
Polythene membrane	4.20	2 kg for 2 000 gauge polythene
Woven Geotextile	9.00	For Lotrak 1 800 (95 g/m^2) use 0.86 kg/m^2
Compacted Sand/Grit	0.03	3 kg for 50 mm thickness
Compacted Capping Material	0.02	4 kg for 100 mm thickness
Iron	1.91	
Plastic Pipe HDPE	2.00	
Removal of material and replacement with compacted aggregate	0.06	

2. APPLICATION TO PERMEABLE PAVEMENT PROJECT

The values shown in Table 1 are now applied in the case of a permeable pavement project which has been constructed on Jersey in The Channel Islands. Figure 1 shows the plan of the site. The site has a readily accessible watercourse, it is flat and the area of permeable paving is contiguous so a simple scheme with two discharge points was designed. A detention system was installed as follows:

3. SITE DIMENSIONS

- Area of site = 7 380 m^2.
- Area of permeable paving = 1 600 m^2.
- Area of impermeable surface (roofs mainly) = 1 600 m^2.
- Permitted discharge to achieve green fields level = 6 litre/s/ha (this is the commonly accepted figure).

Figure 1. The roads and parking areas on this project were surfaced with permeable paving.

4. PAVEMENT SECTION

The site comprised sand overlying peat. The sand had a high California Bearing Ratio (CBR) after proof rolling, but the underlying peat was weak. Normally, a CBR of 7% to 10% would be assumed for the sand and 1% for the peat. In this instance, the design assumed an effective CBR of 3% throughout. The areas of permeable paving were designed to withstand mainly light vehicles and an occasional heavy vehicle.

The pavement section required for both structural and hydraulic reasons was as follows.

- 65 mm thickness permeable brick paving.
- 50 mm thickness 6 mm grit.

- 125 mm thickness cement stabilised 20/5 mm Coarse Graded Aggregate (CGA) to BS882.
- 200 mm thickness 20/5 mm Coarse Graded Aggregate (CGA) to BS882.
- Layer of 2 000 gauge polythene.
- 150 mm thickness Type 1 crushed rock sub-base material.
- 250 mm thickness capping.
- 3% CBR subgrade assumed.

5. HYDRAULIC CALCULATIONS

Consider the above section from a water detention perspective and assume the following 1 in 80 years return period rainfall figures:

- 23 mm for 60 min storm.
- 36 mm for 4 h storm.
- 53 mm for 12 h storm.
- 64 mm for 24 h storm.

For this site, discharge allowed = 4.43 litre/s = 16 m^3/h.

Area for water collection = 1 600 m^2 x 2 = 3 200 m^2.

Consider storms of different length:

- 1 h: Rainfall = 73.6 m^3 Discharge = 16 m^3 Volume stored = 57.6 m^3.
- 4 h: Rainfall = 115.2 m^3 Discharge = 64 m^3 Volume stored = 51.2 m^3.
- 12 h: Rainfall = 169.6 m^3 Discharge = 192 m^3 Volume stored = none.
- 24 h: Rainfall = 204.8 m^3 Discharge = 384 m^3 Volume stored = none.

Therefore, the maximum volume to be stored is just over 57.6 m^3, say 65 m^3. For an area of 1 600 m^2 of permeable paving, the amount of water stored per m^2 = 65 m^3/1 600 m^2 = 41 mm.

The proposed section has 25% voids in the cement stabilised CGA and 32% voids in the CGA. Therefore, the storage capacity is: (125 x 0.25) + (200 x 0.32) = 31 + 64 = 95 mm.

Therefore, the proposed pavement is suitable hydraulically and in fact detained water will stand in only the unstabilised CGA, to a depth of 128 mm.

6. ASSESSMENT OF EMBODIED CARBON

Applying the Embodied Carbon values in Table 1 to the pavement section in the example leads to the figures in Table 2 which show that the total Embodied Carbon in the permeable pavement is 91 kg/m^2. The area of the permeable paving on the project is 1 600 m^2. Therefore, the total weight of Embodied Carbon is 146 t.

Table 2. Embodied Carbon for permeable pavement section.

PAVEMENT COURSE	EMBODIED CARBON (kg/m^2)
65 mm thickness brick pavers	34
50 mm thickness 6mm grit	3
125 mm thickness cement stabilized CGA	21
200 mm thickness CGA	12
Layer of 2 000 gauge polythene	2
150 mm thickness Type 1 crushed rock sub-base	9
250 mm thickness capping	10
TOTAL	**91**

7. EMBODIED CARBON IN TRADITIONAL DRAINAGE SOLUTION

Consider a traditionally drained pavement serving the same purpose. The following pavement section would have been required.

- 65 mm thickness conventional brick paving.
- 50 mm thickness laying course material (sand).
- 130 mm thickness lean concrete.
- 150 mm thickness Type 1 crushed rock sub-base material.
- 250 mm thickness capping.
- 3% CBR subgrade assumed.

Table 3. Embodied Carbon for permeable pavement section.

PAVEMENT COURSE	EMBODIED CARBON (kg/m^2)
65 mm thickness brick pavers	34
50 mm thickness sand	3
130 mm thickness lean concrete	34
150 mm thickness Type 1 crushed rock sub-base	9
250 mm thickness capping	10
TOTAL	**90**

Therefore, the total weight of Embodied Carbon in 1 600 m^2 is 144 t. To be added to this is the Embodied Carbon in the conventional drainage provision. This project would have required 10 road gulleys, five inspection pits and 400 m of 150 mm diameter pipe. The installation of the pipe runs would have involved 0.8m^3 excavation and backfilling per linear metre, i.e. 320 m^3 or 640 000 kg. Assuming cast iron gulley gratings/inspection pit covers and plastic pipes and inspection chambers, the weight of iron would have been 400 kg and the weight of plastic would have been 750 kg/100 m, i.e. 3 000 kg, say 3 200 allowing for the gulleys and inspection chambers. Additionally, say 3 m^3 (7 200 kg) of lean concrete would have been required for securing the plastic manholes. The Embodied Carbon values in the drainage would have been as shown in Table 4.

Table 4. Embodied Carbon in conventional drainage.

DRAINAGE ELEMENT	EMBODIED CARBON (kg)
750 kg iron	1 432
3200 kg plastic pipes/gulleys/inspection chambers	6 400
640 000 kg excavating and backfill	38 400
7 200 kg lean concrete	792
TOTAL	**47 024**

Therefore, on this project, the total Embodied Carbon in a conventionally designed drainage scheme would have been 191 t as against 146 t for a permeable pavement. The permeable pavement has saved 45 t of Embodied Carbon.

8. PLANTING TREES ON A PROJECT OF OFFSET EMBODIED CARBON

Estimates of the annual atmospheric carbon dioxide sequestration of trees varies from 10 kg/year to 30 kg/year and depends upon the weight of the tree. The weight of CO_2 sequestered can be calculated as follows:

This method is explained fully at:

http://www.plant-trees.org/resources/Calculating%20CO2%20Sequestration%20by%20Trees.pdf

<u>1/ Determine the total (green) weight of the tree</u>

For trees with D < 11 in, W = 0.25 D2H.

For trees with D ≥ 11 in, W = 0.15 D2H.

Where

W = weight of tree (lb).

D = diameter of trunk (inches).

H = height of tree (feet).

Add 20% to the calculated figure to account for the tree roots.

<u>2/ Determine the dry weight of the tree</u>

Trees typically comprise 27.5% moisture. Therefore, multiply the total weight calculated in step 1 by 0.725.

<u>3/ Determine the weight of carbon in the tree</u>

The average carbon content of a tree is 50% by weight. Therefore, multiply the dry weight calculated in step 2 by 0.5.

<u>4/ Determine the weight of CO_2 sequestered in the tree</u>

CO_2 comprises one atom of Carbon and two of Oxygen. The atomic weight of Carbon is 12.001 and the atomic weight of Oxygen is 15.99. Therefore the atomic weight of CO_2 is 43.99 (one carbon atom plus two Oxygen atoms). Therefore, the ratio of CO_2 to Carbon is 43.99/12.00 = 3.67. Therefore, to determine the weight of CO_2 sequestered by the tree, multiply the weight of Carbon in the tree by 3.67.

<u>5/ Determine the weight of CO_2 sequestered in the tree per year</u>

Divide the total obtained in step 4 by the age of the tree.

Consider an average tree which sequesters 20 kg of CO_2 per year and assume that the trees will be well managed over a 50 years period so that the tree will absorb 1 000 kg CO_2 in total. The number of trees required to entirely offset the Embodied CO_2 in a permeable paving scheme is 145.

By comparison, Victoria Roads Department (VicRoads), Australia has published data showing that a 2 400 m length of road construction project required 1 750 trees to offset the Embodied Carbon, see:

http://www.vicroads.vic.gov.au/NR/rdonlyres/98A26E5D-F884-49BB-A1B2-E4D55A56D574/0/CarbonFootprintofRoadConstructionMar08.pdf

Assuming the road to be of width 8 m, this represents an area of 19 200 m^2. Therefore, VicRoads' rate of tree planting is one tree per 11 m^2 of paving which is similar to the figure established in this paper.

The above analysis allows the following simple question to be addressed. If a permeable pavement is to be installed as a domestic driveway, how many trees should the householder plant to achieve a carbon neutral result? Assume that the drive comprises 80m^2 and that an infiltration scheme of the following section is to be installed:

- 65 mm thickness permeable brick pavers.
- 50 mm thickness 6 mm grit.
- 250 mm thickness Coarse Graded Aggregate.
- Layer of woven geotextile.
- 5% CBR subgrade assumed.

The Embodied Carbon for the above section is shown in Table 5 from which it can be concluded that the total Embodied Carbon in an 80 m^2 permeable driveway is 4 240 kg. Assuming that over a 50 years period each tree will absorb 1 000 kg CO_2 in total, the planting of four trees would achieve a carbon neutral result.

Table 5. Embodied Carbon for domestic driveway permeable pavement section.

PAVEMENT COURSE	EMBODIED CARBON (kg/m^2)
65 mm thickness brick pavers	34
50 mm thickness 6 mm grit	3
250 mm thickness CGA	15
Layer of Lotrak 1 800 woven geotextile	1
TOTAL	**53**

9. CONCLUSIONS

Permeable pavements constitute an efficient means of installing pavements in terms of Embodied Carbon as compared with conventionally drained pavements. This is largely a result of the elimination of conventional drainage provision. The saving in Embodied Carbon is approximately 50% of the Embodied Carbon in a permeable pavement. In the example described, all of the Embodied Carbon could have been offset by the planting and maintaining of trees over a 50 years period. For the project examined in the paper, this would have been a simple and cost effective strategy to implement and would have enhanced the quality of the development in several respects.

The Authors have used an example of a medium sized residential development to assess the viability of designing carbon neutral schemes and they have concluded that the number of trees required can be achieved by planting them at the properties. There is no need to find a special planting area, as might be the case with a conventionally drained pavement.

The Authors selected the site used in this Paper on the basis that it is typical of mid-sized residential developments and does not have features which militate unfairly in favour of or against the possibility of achieving carbon neutrality. Of course, some sites will easily allow the planting of sufficient trees and others will be more difficult.

On the basis of installing trafficked permeable pavements over poor ground, the Authors have concluded that 145 trees are required to offset the Embodied Carbon in 1 600 m^2 of permeable paving. On this basis, the paper suggests that approximately 90 trees are required to offset the Embodied Carbon for each 1 000 m^2 of permeable paving, although this will vary according to the species of trees planted, the strength/thickness of the permeable pavement and the successful management of the trees to ensure that they mature and remain healthy for at least 50 years. This figure of 1 tree per 11 m^2 has been established independently by VicRoads and is suggested by the Authors as a reasonable yardstick. The Authors have provided a method of calculation which allows an accurate number of trees to be calculated depending upon their anticipated size. The Authors have also established that for a typical 80 m^2 permeable driveway, a carbon neutral result can be achieved if four trees are planted.

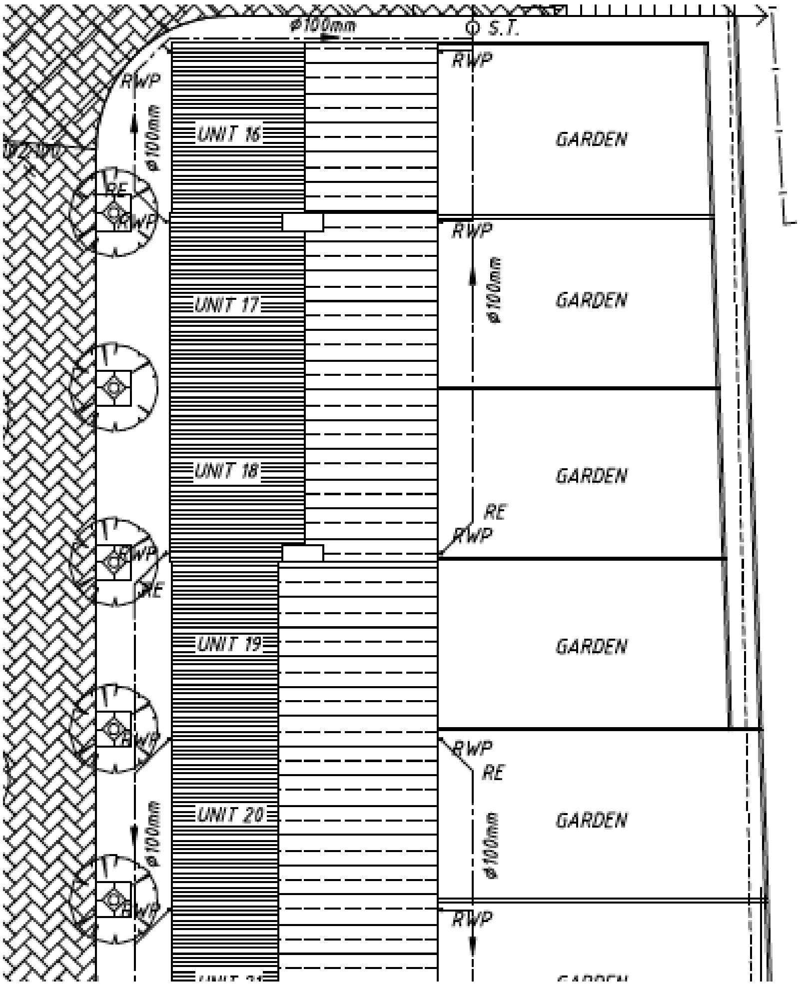

Figure 2. By planting one tree at the front and one tree to the rear of each property, the Embodied Carbon in the permeable paving scheme could be largely offset.

10. REFERENCES

HAMMOND G. AND JONES C., (2008). Inventory of Carbon & Energy (ICE) Version 1.6a. Sustainable Energy Research Team (SERT) University of Bath, United Kingdom. (Available at www.bath.ac.uk/mech-eng/sert/embodied/).