THE CARBON FOOTPRINT OF A NEW COMMERCIAL BUILDING

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Commercial buildings are significant users of energy. The resultant greenhouse gas emissions in carbon dioxide equivalent are quantified in order to assess how it may be absorbed by forest creation, the chosen method of the Australian Government in addressing its Greenhouse protocol targets. With the aim of neutral greenhouse gas emission to the upper atmosphere, a ratio of built floor area to forest acreage is established. It was found that considerable areas of forest would be required to achieve a neutral balance in construction of a typical new commercial building.

Keywords: carbon footprint, commercial building, energy, greenhouse gas, forest.

INTRODUCTION

This paper seeks to identify the greenhouse gas generations of the creation and use of a building so as to quantify its impact in terms of trees which can absorb equivalent amounts of greenhouse gas. The focus is on a typical Australian commercial office building.

The impact of the built environment on the natural environment has long been a topic of investigation. Over the life of a building, there are many inputs and outputs; all necessary to its function and the activities it supports. These flows of energy and materials have various impacts; diminution of resources, degradation of natural environments, loss of habitats, and as more recently identified, additional carbon dioxide and other unwanted gases in the atmosphere which lead to global warming. This impact is most significant since it has no boundaries and transfers its effect far from its source. World conferences have focussed on this issue, and the protocol agreed at the Kyoto meeting established a target for developed countries of 10% reduction in Greenhouse gas emissions based on consumption in 1990.

Whilst energy consumption has been of concern ever since energy scarcity was identified as a global problem, the current global focus is now on the environmental impact of energy use. Fossil fuels supply a clear majority of our current energy needs. Carbon dioxide (CO_2) a major product of the use of fossil fuels, is now clearly established as the major element in climate change through its accumulation in the earths upper atmosphere leading to global warming. At present, the building sector accounts for approximately 27% of all energy related emissions. It is estimated (AGO 1999: 1) that in 1990, non-residential buildings generated an annual greenhouse gas emission of 32.2 Mt of CO_2 . Of this sum, about 27% or 8.69 Mt were attributable to office buildings. Significantly, there is a projected (94%) increase in these commercial numbers by 2010.

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CARBON FOOTPRINTING

Australia, like most developed nations is now attending to its Kyoto target. Our government has chosen to focus on carbon sinks as a means to absorb carbon entering the atmosphere. Trees are known to absorb carbon dioxide and bind carbon. It is thus suggested that emissions targets can be addressed by the planting of trees. This activity is attractive to a country which has plentiful land, excessive land clearing, a need to address erosion and salinity problems and a heavy reliance on fossil fuel production, use and export. To date, few if any studies have sought to measure the carbon budget of a building in terms of trees planted to absorb carbon dioxide.

To measure the carbon impact of a building, the major energy uses of a building are chosen for scrutiny. These are the Operational Energy, Capital Energy and Transport Energy, described as follows.

Operational Energy

This is all the energy used to make a building function. It includes base energy loads such as security lighting and variable loads which the owner or tenant may seek to minimise. Electricity, because of its great versatility and relative safety, is the major form of operational energy used in a building. Previous studies of the impact of buildings were mostly focussed on their operational phase. Many of these were interested in the energy use, since energy is costly and subject to economic analysis. This led to investigations into types of energy used and the consequent emissions created. It is now possible to assess with some accuracy the various operational energies of a building and thus the level of greenhouse gas emission.

Capital Energy

More recently, we have come to identify the creation and disposal of the physical elements of the built environment as significant contributors to the flows of energy. The creation and of a building, although a one off event, involves the intensive confluence of matter and energy. Referred to here as Capital Energy, it is estimated to be equal to between 10 and 30 years Operational Energy. Whilst for dwellings, Operational Energy exceeds Capital Energy in about the 20th year of building life (Fay 1999: 324), it is estimated to be sooner for Commercial buildings which are subject more to economic forces. Capital Energy includes building disposal, which includes the dismantling and reprocessing of materials. By investigating the amounts and types of energy used in the sourcing, manufacture and installation of all materials in a building, it is possible to estimate the capital greenhouse gas budget.

Transport Energy

Commercial buildings are usually accessed 5 to 7 days every week by tenants and visitors. In a city, the normal occupants of a commercial building choose a variety of means to commute to and from their workplace. During a workday they will also take excursions from the building for meetings or for the delivery of goods and services. Visitors will similarly attend the building in a variety of ways, mostly by fossil fuel based transport modes. Over a building lifetime, many passenger kilometres are accrued amounting to a significant energy use. The location of the building relative to the dwellings of its users and the nature of the commercial activities it supports leads to the quantification of the Transport Energy and consequent greenhouse gas emissions related to the use of the building.

There are certainly more than three types of greenhouse gas emission involved in the life cycle of a building. It is believed however, that the three investigated here account for the majority of carbon and that they are reasonably quantifiable. This study thus limits its boundaries to those identified above. It is obvious that buildings do not exist in isolation. Clearly they are supported by infrastructure which itself has carbon impacts. Although significant, these impacts are more difficult to measure and apportion to individual buildings. Infrastructure is however not included in the overall scope of this study.

Increasing numbers of developments are aiming to significantly improve building energy use. In so doing they set and or establish targets for constituent energy consumption. In order to establish what gain has been achieved, comparison with benchmarks are made. Benchmarks represent established use of ‘typical’ buildings. This study seeks to identify the performance benchmarks of an ‘average/typical’ building, based on statistical data. Beyond this, discussion will look at how a ‘green’ building may vary from standard by alternative sourcing and use of energy.

METHOD

Each of the main three greenhouse gas sources will be discussed, identifying methods and limitations of application and measurement. The carbon sequestering capacity of trees will also be investigated. Calculations are supported by known data and related investigations. A carbon budget for new buildings is established. This will be in equivalent tonnes of carbon dioxide per square metre of gross floor area, units readily identified by the Property, Construction and Energy industries. This sum will be translated into required land areas and units of plantation trees to compensate the building greenhouse gas generation. Finally a ratio of land area of trees to area of building can be established. This figure will be discussed in terms of its accuracy and application.

Life Cycle of a Building

Measuring energy use over the lifecycle of a building is difficult when the lifecycle itself is difficult to measure. The life of a building can be measured in two ways. The Physical life of a building covers the time between construction and demolition of the structure. It includes refurbishment and retrofit to new functions. If Life Cycle Cost is defined as:

> *‘The total cost of an item throughout its life, including the costs of planning, design, acquisition, operation, maintenance, and disposal less residual value’ (Bromilow et al. 1995).*

then all of these functions should be considered part of the ‘life’.

Buildings are complex assemblages of items, each with its natural physical life. This makes life cycle measurement of embodied energy a complex exercise. Carpet, for example, although considered part of the building rather than a disposable item, is changed several times over the structural life of a commercial building. However, since the structural life ultimately determines the life of most items or components, this will be taken to represent the Physical life.

The Economic Life of a building is the period in which, as an asset, it makes positive economic return on its initial and upkeep investment cost. Some buildings are demolished however, inside this time because the value of the site occupied by the asset increases disproportionately, substantiating demolition and new investment.

Most buildings have longer Physical lives than Economic lives. Alternatively, many buildings have multiple economic lives as they pass through various ownerships and functions.

With respect to this study, the average Physical life of the building is considered most appropriate to represent the life cycle. This is not however easily ascertained. As previously stated, buildings have multiple ‘settings’ over their actual lives supporting one or many functions. Refurbishments can be as minor as repainting or as comprehensive as to leave only the façade. This leads to taking the average age of the commercial building stock as the best estimate of the average life expectancy or life cycle of a building. Whilst open to further investigation, an estimate of 25 years is used for this study.

REVIEW OF ENERGY USE IN COMMERCIAL BUILDINGS

Operational Energy

The Operational energy of a building is that energy it consumes in providing the accommodation for which it is designed. For a commercial building there are energy costs associated with the base building (usually borne by the owner) and ones associated with tenancies. These are aggregated to ascertain the total operational energy. On a general level, the range of energy consumption for Australian office buildings has been estimated to be between 400-700 MJ/m^2 per annum (ERDC 1995). Whilst the scrutiny of accounts can give some indication of the direct operational energy, indirect energies also exist. For example, for every kWh of electricity delivered to a commercial building in Melbourne, about 3 kWh of primary energy is consumed in generation at power plant. Should this, and the proportional capital cost of a power station, be attributable to the operational energy? In this case it is significant, and thus included in the CO_2 emissions for electricity.

Another aspect to operational energy is the mix of energy sources and their consequent respective outputs of CO_2. It is known that Electricity generation in Victoria from brown coal generates far more greenhouse gas than equivalent electrical energy provided by natural gas. In the non-residential sector, it is estimated that 0.21 tonnes of CO_2 is emitted for every GJ energy used (AGO 1999 p13). Taking these issues into account, a survey of Commercial buildings in Melbourne (BOMA 1996) indicates that every year (2500 working hours) a square meter of office space consumes an average of 268 MJ gas and 313 MJ Electricity; a total of 581 MJ/m^2 which lies amid the range earlier noted. Using values of 55 and 333 kg CO_2/ GJ respectively for emissions due to natural gas heating and coal fired electricity (Lawson 1996), a lifetime (25 years) value of 2974 kg CO_2 / m^2 is attained.

Capital Energy

Otherwise known as Embodied Energy, Capital Energy can be measured in a number of ways, depending on the analysis ‘pathway’ and the level of complexity desired. Whilst Gross Energy Requirement (GER) seeks to cover the energy input of most phases of a material, the Process Energy Requirement (PER) of a particular material is more readily assessable but confined to production and excludes on site energy. Input-Output Analysis looks at the flow of materials based on statistics and assumed energy tariffs. Hybrid models seek to overcome inadequacies in these methods by combination and adaptation.

Clearly, while the energy of a material may be reasonably calculated, and a building component containing a number of materials estimated, the Capital energy as a function of the area of a building is more problematic and design specific.

A number of studies have analysed the Total Embodied Energy of a standard dwelling, but few have sought to approximate the energy of commercial buildings other than on an elemental basis.

Whilst early estimates of Capital energy indicate intensity of 5000 kWh/m^2, (18 GJ/m^2) for office buildings, more recent studies have calculated a rate of 4.45 GJ/m^2 (Jacques 1996) This includes the energy invested during construction, demolition and disposal, expressed as a GER which sums Direct (site electricity, transport) and Indirect (extraction, manufacturing and machinery) energy inputs. Malaysian architect Ken Yeang (1999) is more conservative, suggesting 5-10 GJ/m^2 Embodied Energy. Considering the known but unquantifiable multiplier effects of embodied energy, 5 GJ of electricity/m^2 represents a reasonable, if optimistic value to work with.

Transport Energy

ABS data shows the average commuting distance (one way) to be 9.9 km, a distance of 19.8 km return /day. Allowing for holidays, telecommuting, sick leave and flexible employment, it may be reasonable to assume a 200-day working year, each worker totalling 3960 km per annum. Over a building life cycle of 25 years, 99,000 km per occupant is attained.

It is further estimated that the occupant of a commercial building may account for an average of 11m^2 of the total floor area. This is based on an average benchmark of 10 m^2 per tenant employee plus a 10% allowance for public areas. Dividing the total km by the area gives 9000 occupant km/m^2. In order to ascertain the CO_2 impact of this sum, the various modes of transport, and their CO_2 impacts must be identified.

Newman and Kenworthy (1999) estimate that about 79.8 (say 80)% of commuting km are by private transport (car) whilst train and tram account for 15.9 (say16) %. The remaining 4% is by non motorised pedestrian and bicycle transport. Considering urban vehicle efficiencies. Evans (1992) cites rates of 0.21 and 0.15 kg CO_{2e} / passenger-km for passenger car and train modes respectively. Since these figures are taken from 1987-88, increased motor efficiencies and lighter vehicles in the last decade lead to 10% improvements, resulting in rates of 0.189 and 0.135 kg CO_{2e} / passenger-km for car and train modes respectively. The consequent carbon allocation for a square metre of office area can be estimated. The estimated greenhouse gas emission for 25 years from personal transports related to the building was found to be 1555 kg CO_{2e}/m^2.

CARBON AND FORESTS

The amount of carbon absorbed by trees is obviously related to their age, type, and density in addition to the climate and soils in which they are planted. The figures obtained from Kirschbaum (1996) indicate that forests of plantation softwood in Australia can sequester a lifetime maximum of 300 tonnes Carbon per hectare planted. However, plantation trees seldom now reach maturity and are often harvested inside 20 years of growth. In this study a plantation cycle of 25 years was assumed and during this period about 100 tonnes Carbon per hectare on average may be achieved via a typical growth pattern.

Total standing biomass including leaves, branches, stems, bark and roots, *B*, is calculated using the following equation provided by Kirschbaum (2000):

$$B = B_{\max}\left[1 - \exp(-0.02t)\right]^{1.25} \qquad (1)$$

where B_{max} is maximum standing biomass at maturity, and t is time in years.

The amount of biomass in stem wood, assuming leaves, branches, bark and roots are left on the ground to rot, *W*, is calculated as:

$$W = 0.7B\left(\frac{B}{B_{\max}}\right)^{0.2} \qquad (2)$$

A value of B_{max} = 400 tC per ha, which is consistent with those reported through the National Greenhouse Gas Inventory (Kirschbaum 2000), is used here to estimate carbon uptake rates.

Assuming the proportional carbon component of the CO_2 molecule and assuming a 100% take up rate by the trees of a forest, the carbon sequestration of a plantation forest is calculated.

RESULTS

The values attained for the three energies investigated were applied to a spreadsheet that enables quick and interactive calculation of sums. The results are shown in Table 1.

Table 1: Life cycle energy

	kg CO_{2e} / m^2 (over a 25 year building life)	**Percentage**
Operational Energy	2974	48
Capital Energy	1665	27
Transport Energy	1555	25
Total	6194	100

The relative percentages of carbon produced for each energy use was within predicted limits. Based on these figures, it is further extrapolated that the operational CO_2 overtakes the Capital sum in about the 14th of a 25-year building life. For a 25 years managed plantation cycle, it was calculated in (1) above that B = 124.65 tC/ha and, substituting this in (2), W = 69 tC/ha. Thus 69 tonnes of Carbon is sequestered in the form of stem wood per hectare of forest and binds 253 tonnes CO_2. It follows that the estimated carbon dioxide uptake of the plantation is about 25 kg CO_2 / m^2.

ANALYSIS

If a building generates about 6194 kg CO_{2e} / m^2, then the required ratio of planted area to built is the ratio 6194/25 or about 250/1 This indicates that for every m^2 built area, an area of 250 m^2 forest must be planted to absorb an equivalent amount of carbon.

For a proposed building of say 3500 m^2 this means a tree plantation of approx. 87.5 ha. (~0.875 km^2). Accurate numbers of trees would depend on site and species considerations which are not explored here.

DISCUSSION

Capital Energy remains the most difficult area of estimation. Although hybrid models are being developed, measurement is ultimately design specific. Only rough estimates are available at present. Operational Energy measurement is increasingly accurate as improved surveying and monitoring systems are applied. Increasing focus on bottom line accounting has brought into focus operational costs including energy. The figures used in this study are specific to Melbourne CBD and come as the result of an owner survey. Transport energy is also assumed to be fairly accurate, yet changes in efficiencies are ongoing. The final results give an ‘order of magnitude’ result and they do not seek to be strictly accurate or comprehensive as it is virtually impossible for them to be so. They do however allow one to measure one significant impact of the built environment.

Green building

The results enable a benchmark to be set regarding the energy used by typical buildings enabling comparisons to be made with new projects seeking to improve carbon emissions. Further work, investigating green power, demand management, and alternative sourcing of energy may establish the potential of new buildings to reduce emissions and thus reduce the need to absorb carbon.

It should be remembered that trees only store carbon whilst growing. Once harvested, carbon is released if the timber is burnt or left to decompose. The actual emission impact of harvested timber requires further investigation. To adequately account for construction-based emissions therefore, a net increase of forest by about 0.025 ha for every square meter of new commercial building would be required.

SUMMARY

The investigation has given some scale to the issue of “carbon footprinting”. It can be seen that despite known exclusions and necessarily approximated figures any project to plant trees to absorb carbon would require considerable land resources. It is nonetheless useful to have established a benchmark which can be refined by further analysis of constituents and by which new projects, ‘green’ or otherwise can be compared.

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