

The Spatial Representation of Embodied Energy of Residential Areas in the Urban Environment

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CD Rom	Spatial representation of embodied energy data in the Adelaide metropolitan area (for use with ArcView 3.3 software)	Removed

Abstract

The motivation for the research described in this thesis is the imperative to minimise energy consumption of buildings in the urban environment. A comprehensive approach to analysing energy usage involves the whole life cycle of buildings and infrastructure including embodied energy consumption. Embodied energy represents all of the energy consumed in the production of building materials and components, as well as the energy used to assemble them into the built form. This thesis describes the development and application of a model which spatially depicts embodied energy as a basis for undertaking more holistic analyses of urban energy consumption.

The need for comprehensive analyses of energy consumption is initially explored. Such analyses would enable more favourable energy outcomes to be achieved when making decisions about urban planning and development. Research on the value of representing energy usage in a spatial format is reviewed and the case is made for modelling the embodied energy as a contribution to the broader understanding of urban energy consumption. This thesis concentrates on residential areas of the urban environment.

The model for spatially representing the embodied energy consumption of residential areas has three components which are embodied energy theory, property register data and geographical information software. A methodology is described which commences with hybrid embodied energy coefficients, integrates these with property register data for a metropolitan area and displays the results using GIS techniques in the form of maps. The model is general but developed using information pertaining to the Adelaide metropolitan area and tested using data from both Adelaide and Sydney.

To show that the model can usefully contribute to life cycle energy analyses in the urban environment, it is applied to three case studies involving current urban planning issues involving the densification of dwellings in cities and the redevelopment of older residential areas. These show that such analyses can represent embodied energy spatially and with sufficient accuracy to inform urban planning and development decisions aimed at reducing overall energy usage.

In summary, the research has extended knowledge on the embodied energy of the built form by focusing on residential areas which include urban infrastructure rather than just individual buildings. It has provided new insights into the significance of embodied energy of the existing built form by considering it as a 'sunk cost' which may be partially recovered and form part of the energy flows in the urban environment. The mapping of embodied energy of the existing built form also offers the potential for quantifying resources which can be re-used to modify total energy consumption of new developments.

Published Papers

The following two papers were written as a direct result of the research carried out and described in this thesis.

- Pullen S. A Tool for Depicting the Embodied Energy of the Adelaide Urban Environment. *Proceedings of 2007 Australian Institute of Building Surveyors International Transitions Conference*. Adelaide. March 2007.
- Pullen S, Holloway D, Randolph B and Troy P. Energy Profiles of Selected Residential Developments in Sydney with Special Reference to Embodied Energy. *Proceedings of the Australian & New Zealand Architectural Science Association (ANZAScA) 40th Annual Conference 'Challenges for architectural science in changing climates' 22-25 November 2006*¹.

The following paper was written during the early stages of the research described in this thesis and draws upon preliminary research methodology.

- Pullen S, Troy P, Holloway D & Bunker R. Estimating Energy Consumption in the Urban Environment with a focus on Embodied Energy. *Proceedings of ANZAScA 2002. 36th Annual Conference of the Australia & New Zealand Architectural Science Association*. Deakin University, Geelong, Australia. November 1-4, 2002².

¹ This paper was based on research supported by an ARC Linkage grant with B Randolph, P Troy and S.Pullen as Chief Investigators. The methodology for deriving the embodied energy component of the research was developed by the author of this thesis as well as the acquisition of data for the embodied energy evaluation of the case studies. Further information can be found on p118.

² This paper was based on pilot study research led by Prof. P Troy and supported by Planning SA with a similar input on embodied energy methodology and data acquisition provided by the author of this thesis.

Signed Statement

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text. I consent to this thesis being made available for photocopying and loan.

Stephen Frederick Pullen

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Glossary of abbreviations and terms

ABARE	Australian Bureau of Agricultural and Resource Economics
ASD	Adelaide Statistical Division. The metropolitan area of Adelaide as defined by the Australian Bureau of Statistics
ASEAN	Association of Southeast Asian Nations includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam.
Coefficient of Performance (COP)	Measure of efficiency of reverse cycle air conditioning unit being the division of the heat energy transferred by the operational energy.
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
Delivered energy	The quantity of energy consumed directly by the end user and not counting the additional energy required to produce and deliver that energy to the end user.
Direct energy intensity	A term used in energy input-output analysis to describe the amount of direct energy supplied to a particular industrial sector per fiscal unit of output (MJ/\$)
Embodied emissions	The greenhouse gas emissions caused associated with the embodied energy of a material or component normally expressed in terms of carbon dioxide equivalents (kg of CO ₂ -e or tonnes of CO ₂ -e)
Embodied energy	The embodied energy of a material or component is the energy consumed in its production including upstream activities such as raw material extraction, transport, manufacturing and assembly.
Embodied energy coefficient	A number expressing the embodied energy of a material per unit eg MJ/kg, GJ/tonne, GJ/m ³ .
Energy Intensity	The amount of energy required to produce one unit of output eg MJ/\$.
GIS	Geographical Information Systems.
Grillage raft footing	Reinforced concrete raft with deep narrow beams which have a structural and moisture barrier effect. Used for reactive and collapsing soils.

HFCs	Hydrofluorocarbons are used primarily as chlorofluorocarbon (CFC) substitutes which were formerly used widely in industry, for example as refrigerants, propellants, and cleaning solvents. .
Indirect energy intensity	The difference between the total energy intensity and the direct energy intensity.
Input-output analysis	A technique for describing the fiscal interactions between industrial sectors in a national economy. With modifications, it can also be used for the analysis of energy consumption by particular industrial sectors.
IPCC	Intergovernmental Panel on Climate Change
NatHERS	Nationwide House Energy Rating Scheme
OECD	Organisation for Economic Co-operation and Development
Pier and beam footing	Reinforced concrete beams set clear of the soil on deep seated piers. The piers are seated on sub-surface stable layers.
PFCs	Perfluorocarbons are compounds derived from hydrocarbons by replacement of hydrogen atoms by fluorine atoms. PFC is 6500-9200 times more effective than carbon dioxide at trapping heat in the atmosphere.
Primary energy	The total quantity of energy used including the energy required to produce and deliver energy to the end user.
Primary energy factor	The ratio of the primary energy to delivered energy indicating the amount of energy used in manufacturing, distributing and supplying one unit of energy which is used by the consumer.
Total energy intensity	A term used in energy input-output analysis to describe the amount of direct and indirect energy supplied to a particular industrial sector per fiscal unit of output (MJ/\$).
Urban heat island effect	The increase in urban temperature compared with surrounding region resulting from heat generation and retention in the built environment