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Net Energy Analysis of Solar and Conventional Domestic Hot Water Systems in Melbourne, Australia

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Abstract

It is commonly assumed that solar hot water systems save energy and reduce greenhouse gas emissions. Very rarely has the life-cycle energy requirements of solar hot water systems been analysed, including their embodied energy. The extent to which solar hot water systems save energy compared to conventional systems in Melbourne, Australia, is shown through a comparative net energy analysis. The solar systems provided a net energy saving compared to the conventional systems after 0.5 to 2 years, for electricity and gas systems respectively.

1. INTRODUCTION

Energy consumption in Australia is steadily increasing, as a result of population growth and increasing standard of living (Bush *et al*, 1997). This trend is producing an increasing demand on our dwindling resources, and on the environment, with the use of mainly coal-fired electricity and natural gas in buildings (Harrington *et al*, 1999). In 1995-96 the operation of residential buildings in Australia accounted for around 2.4% of the greenhouse gas emissions from energy (Harrington *et al.*, 1999). Moreover, up to 28% of these emissions were from the operation of hot water systems in 1998.

There are several types of hot water systems, in terms of configuration and fuel source, including gas and electric storage systems, solar systems with either gas and electric auxiliary, and gas instantaneous systems. The primary energy requirements for the operation of electric storage hot water systems particularly are high, due to the inefficiency of the process of converting fossil fuels (mostly brown coal for Melbourne's supply) to electrical potential energy. Solar hot water systems employ solar energy at the point of use, thus substantially reducing the need for fossil fuels. However, operational energy is not the only form of energy associated with hot water systems. The energy consumed in the manufacture of hot water systems, commonly referred to as embodied energy of manufacture, includes the energy for assembly, and the energy embodied in the input of goods and services to the manufacturing process, including transportation at all mining and manufacturing phases.

This paper aims to present the results of a life-cycle energy analysis of solar hot water systems, comparing them with conventional hot water systems in Melbourne, Australia.

2. BACKGROUND

The main concern with hot water systems has been the energy used in their operation (Yang *et al*, 1997). The operational energy consumed at the point of use is lower than the actual energy required to supply this energy to the consumer. The energy used by the consumer is known as delivered energy, while the energy actually required in supplying this delivered energy is known as primary energy. Operational energy, and in particular the emissions produced, is of concern when attempting to minimise energy consumption of buildings and their equipment. Much is known about the energy requirements of hot water system operation.

The embodied energy of an entire building, or an item, or a basic material in a building, comprises of indirect and direct energy. Indirect energy is used to create the inputs of goods and services to the main process, whereas direct energy is the energy used for the main process, whether it be the construction of the building, product assembly, or material manufacture (Figure 1). The accuracy and extent of an embodied energy analysis is dependent on which of the three main methods is chosen: process analysis; input-output analysis or hybrid analysis. These methods are fully reviewed by Treloar (1997).

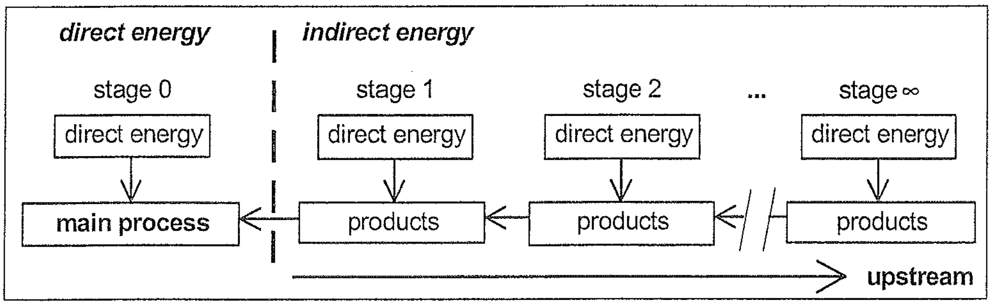

Figure 1 Embodied energy analysis system boundary (after Boustead and Hancock, 1979)

There have been several studies that have examined the need for improving energy conservation through the use of solar hot water systems than the more conventional electric and gas systems currently in use in the residential sector of Australia (Baron, 1978; Payne and Doyle, 1978; Barnes, 1979; O'Sullivan and Meldrum, 1982). Such studies have tended to focus on the operational energy consumed, which makes up only a portion of the total energy consumption of a hot water system. Baron (1978) and Payne and Doyle (1978) both questioned the ability of existing solar hot water systems to provide net energy savings. Barnes (1979) provided the annual energy consumption of various types of hot water systems available at the time. Barnes (1979) provided a much more generalised study of the energy efficiency of hot water systems. O'Sullivan and Meldrum (1982) provided a net energy analysis of a typical flat plate solar hot water system using the process analysis method for analysing embodied energy. O'Sullivan and Meldrum (1982) made no comparison between the solar hot water system under analysis and other more commonly used electric and gas hot water systems. The fact that the method used by O'Sullivan and Meldrum (1982) was incomplete may invalidate the conclusions drawn from this work; ie., that solar hot water systems pay back their embodied energy investment in a reasonable period of time.

These issues give rise to two research questions to be addressed in the remainder of the paper:
1. Is embodied energy a significant component of the life-cycle energy consumption of a solar hot water system?
2. Do solar hot water systems pay back in primary energy terms within ten years?

3. METHODOLOGY

Five hot water systems were chosen for this study. This included an electric-boosted solar hot water system, gas-boosted solar hot water system, electric storage hot water system, gas storage hot water system and a gas instantaneous hot water system. All systems were selected to provide an equivalent hot water supply to a typical four-person household sized according to the manufacturer's recommendations. They have not been named here for reasons of confidentiality, though all information used herein was in the public domain.

One Australian location was chosen: Melbourne (latitude 37.8°S). The average annual solar fraction used for the electric-boosted solar hot water system was 62% (Solahart Industries, 2000). The solar fraction for the gas-boosted solar hot water system was assumed to be 50%.

Operational energy is the energy consumed in the actual running of a hot water system, be it electricity or gas. Solar energy was considered 'environmentally free'. For Melbourne, the average annual operational energy consumption for the electric storage hot water system was obtained from Powercor Australia (2000). The average annual operational energy consumed by the electric-boosted solar hot water system was obtained from Solahart Industries (2000). The average annual operational energy of the gas storage and instantaneous systems was obtained from Energy Efficiency Victoria (1999). The average annual operational energy consumption of the gas-boosted solar hot water system was based on that for the gas instantaneous system, taking the revised solar fraction into consideration.

In order to undertake the embodied energy analysis, the quantities of materials used in the production of each of the five hot water systems were determined. Information regarding components, materials, masses, areas and volumes was obtained from the various manufacturers of the hot water systems. The embodied energy values were derived for materials using an input-output-based hybrid analysis method, as prescribed in Treloar (1997), using input-output data for Australia from the financial year 1992-93. Various process analysis embodied energy data (Grant, 2000) were also integrated with the input-output data. The quantities of the materials used in the manufacture of each system were multiplied by the appropriate embodied energy intensities. The sum of the results gave the total embodied energy for each hot water system. Using the method described in Treloar et al (2001), the gaps in this method were filled using input-output data for the 'household appliances' sector.

The life-cycle energy analysis combined both the operational energy and the embodied energy of the hot water systems. The life-cycle energy of each hot water system after x years comprised the embodied energy of the hot water system, using the input-output-based hybrid analysis method, and the operational primary energy consumption of the system for x years. For the purpose of this study and the comparison between systems, the period of the life-cycle energy results was ten years (*ie.*, the typical warrantee period). The net energy analysis comprised comparing each of the solar hot water systems with the corresponding conventional systems. The energy embodied in maintenance, refurbishment and decommissioning was ignored in this study, due to the relatively short product life considered.

4. RESULTS

The operational energy of the various hot water systems in Melbourne are given in Table 1. The units are gigajoules of primary energy (1 GJ = 1000 MJ). The primary energy factors used were 1.4 for gas and 3.4 for electricity (Treloar, 1997).

Table 1 Annual operational energy of hot water systems for Melbourne (in GJ of primary energy)

	Electric storage	Gas storage	Gas Instantaneous	Solar electric	Solar gas
Melbourne	22.94[1]	22.70[2]	20.85[2]	18.43[3]	10.43[2]

Sources:

1. Powercor Australia (2000)
2. Energy Efficiency Victoria (2000)
3. Solahart Industries (2000)

The life-cycle energy consumption of each hot water system installed in Melbourne consists of the initial embodied energy of each of the hot water systems together with their annual operational energy requirements. The energy embodied in maintenance, refurbishment and decommissioning was not included in this analysis. Figure 2 shows the life-cycle energy analysis of each hot water system over a ten-year period for Melbourne. The relative insignificance of the embodied energy is clear (*ie.*, in spite of the more comprehensive system boundary compared to previous studies by others).

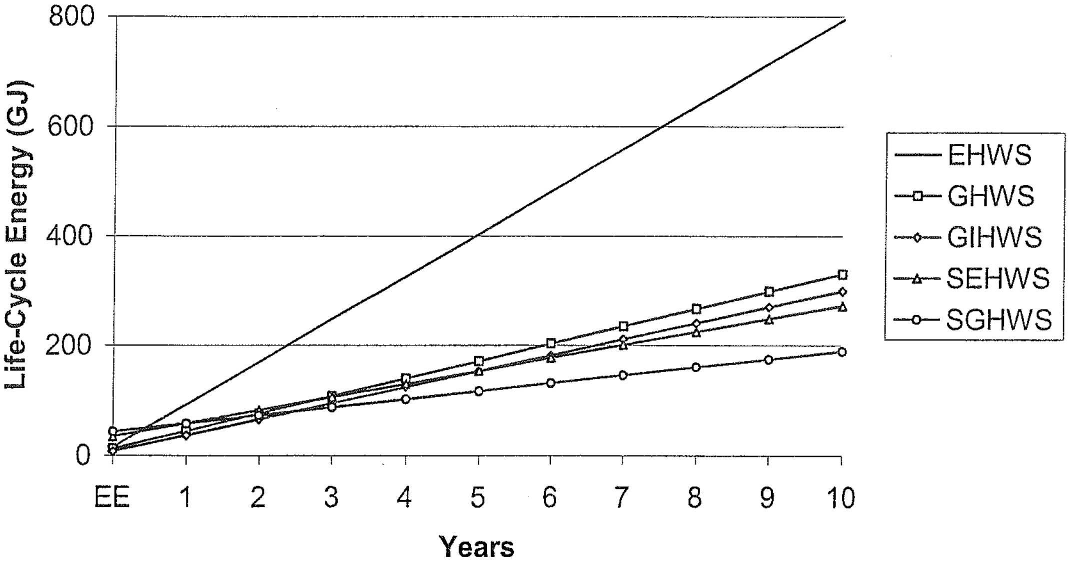

Figure 2 Life-cycle primary energy of hot water systems in Melbourne
NB 'EE' indicates the embodied energy of each system, in primary energy terms.
HWS = hot water system, E = electric, G = gas, I = instantaneous, S = solar.

Figure 2 shows that although electric storage hot water systems have one of the lowest amounts of embodied energy among the five systems (evident from the value intercepting the y-axis), they have an extremely high life-cycle energy usage. The electric- and gas-boosted solar hot water systems have energy payback periods of 0.5 and 2 years respectively, when compared to the non-solar conventional storage systems using the same fuel. These are the most significant results, because most purchasers begin from an equivalent fuel supply situation. (This is emphasised by government rebate criteria, such that a subsidy is not payable for an electric-boosted solar hot water system if reticulated gas is available.)

From a starting point of an electric storage system, all other options fare extremely well, paying back within 0.5 years in energy terms. However, from a starting point of a gas storage system:

- the gas instantaneous system is always lower in life cycle energy terms, diverging further over time;
- the electric-boosted solar hot water system pays back in around 3 years, in energy terms; and
- the gas-boosted solar hot water system pays back in around 2 years, in energy terms (as noted above).

From a starting point of a gas instantaneous system:

- the electric-boosted solar hot water system pays back in around 5 years, in energy terms; and
- the gas-boosted solar hot water system pays back in around 2.5 years, in energy terms.

5. DISCUSSION AND CONCLUSIONS

For the location analysed, it was evident that the embodied energy component of the life-cycle energy was relatively small, answering soundly the first research question stated earlier in the paper. It should be noted that the embodied energy may increase relatively:

- for low usage situations;
- in warmer and sunnier climates;
- if the quantity and mix of materials used in the manufacture of solar hot water systems are altered; or
- if the energy efficiency of the systems is increased further through operational or technological change.

For an electric-boosted solar hot water system, the energy payback period can be around 0.5 years; and for a gas-boosted solar hot water system, the energy payback period is around 2 years. Even considering error ranges for both the embodied energy and operational energy figures, the robustness of this result relative to the research question stated earlier in the paper is self-evident.

The net energy consumption of the hot water systems was performed over a relatively short period of ten years, representing the typical warranty period. As both electric- and gas-boosted solar hot water systems provide net energy savings within 2 years when compared to conventional electric and gas systems, a net energy analysis over more than 10 years would not alter the apparent advantages of installing a solar hot water system.

Therefore, the operational energy should be minimised, and solar systems appear to be the best way to achieve this aim. However, the auxiliary fuel selection is most important, due to extremely high greenhouse gas emissions from coal-fired electricity, particularly in Melbourne (due to the use of mainly wet, brown coal for electricity generation). Where electricity is the only option, occupants may also consider buying 'green' tariff electricity (which reduce dependence on fossil fuels and greenhouse gas emitting sources), to further reduce the emissions associated with the non-solar fraction.

Solar hot water systems are capable of achieving significant energy savings in various temperate locations around Australia. However, the extent of these energy savings is dependent on the location of the system and the hot water requirements of the individual household. Within a given location, it is important to optimise all the factors affecting the operational energy consumption of hot water systems: which include system type and size; system efficiency; hot water usage patterns; and auxiliary fuel source.

REFERENCES

Barnes, F.J. (1979) *Solar Water Heating*, Proceedings: Solar Energy Today Conference, Melbourne, February 18-21, 3.1-3.13.

Baron, S. (1978) *Public Utilities Fortnightly*, (U.S.A.), September 28, 31-36.

Boustead, I. and Hancock, G.F. (1979) *Handbook of Industrial Energy Analysis*, Ellis Horwood Limited, Chichester.

Bullard, C.W. and Herendeen, R.A. (1975) *The Energy Costs of Goods and Services*, Energy Policy, December, 268-278.

Bush, S., Harris, J. and Trieu, L. H. (1997) *Australian Energy Consumption and Production: Historical Trends and Projections to 2009-10*, ABARE Research Report, Canberra, Report 97.2.

Energy Efficiency Victoria (1999) *Hot Water Hints*, Energy Efficiency Victoria, Melbourne, September.

Energy Efficiency Victoria (2000) *Personal Communication.*

Grant, T. (2000) *Australian Material Inventory Database of Life Cycle Assessment Value for Materials*, RMIT, Melbourne, electronic SIMAPRO database.

Harrington, L., Foster, R., Wilkenfeld, G., Treloar, G.J., Lee, T. and Ellis, M. (1999) *Baseline Study of Greenhouse Gas Emissions from the Australian Residential Building Sector to 2010*, for the Australian Greenhouse Office, Canberra, February, 157.

O'Sullivan, R.A. and Meldrum, R.T. (1982) *Net Energy Analysis of Flat Plate Solar Water Heaters*, RMIT, Melbourne.

Payne, P.R. and Doyle, D.W. (1978) *The Fossil Fuel Cost of Solar Heating*, Proceedings: Energy Conversion Engineering Conference, August, 1650-1656.

Powercor Australia (2000) *Personal Communication.*

Solahart Industries (2000) *Personal Communication.*

Treloar, G.J. (1997) *Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input-Output-Based Hybrid Energy Analysis Method*, Economic Systems Research, 9, (4), 375-391.

Treloar, G.J., Love, P.E.D. and Holt, G. (2001) *Using National Input-output Data for Embodied Energy Analysis of Individual Residential Buildings*, Construction, Management and Economics, 19, 49-61.

Yang, L., Bøhm, B., Paulsen, O., and Frederiksen, S. (1997) *Evaluation of the Dynamic Performance of a Hot Water Tank with Built-In Heating Coil*, International Journal of Energy Research, 21, (3), 265-274.