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ENERGY EFFICIENT MULTI STOREY RESIDENTIAL DEVELOPMENTS

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ABSTRACT

Worldwide, the current pattern of urban development is unsustainable and metropolitan planning and development strategies deliver poor environmental outcomes in relation to energy production. As a result, an increasing number of governments and private sector development companies are initiating projects that aim to deliver enhanced environmental outcomes rather than a 'business as usual' approach.

This paper will summarise the findings from a study that explored the link between building orientation and energy efficiencies in sub-tropical and tropical climates. The study used a new thermal modelling software tool developed by CSIRO that responds more accurately to residential heating and cooling energy performance in those climate zones. This software tool responds to industry criticisms regarding cold climate modelling systems that do not make sufficient allowance for natural ventilation. The study examined a range of low, medium and high-density dwelling types and investigated the impact of orientation, insulation, ventilation and shading devices on energy efficiencies. This paper will examine the findings from the medium and high-density case study developments as these are relevant to residential developments in many South East Asian countries, such as Singapore, Hong Kong and Malaysia.

Finally, the paper will explore the potential benefits that medium and high-density residential developments have in the development of 'solar cities' and 'solar suburbs'.

Keywords: Sustainable buildings, energy efficiency, solar cities.

1. Introduction

Australia's current pattern of residential development is resulting in urban sprawl and highlights the necessity for development to be sustainable to avoid unnecessary demand on natural resources and to prevent environmental degradation and to safeguard the environment for future generations. This becomes more apparent when noting facts such as:

- Australia's metropolitan planning and development strategies deliver poor environmental outcomes in relation to energy production and consumption;
- Australia's per capita consumption of space (floor space, private open space), energy and water rank among the highest in the world and are continuing to increase; Specifically
- There are an increasing percentage of new dwellings undergoing construction with the number of dwelling units approved increased from -6.5% in September 2001-2002 (ABS, 2003) to +26% (September 2002 to 2003). This totals 175,135 new dwelling units (ABS, 2003);
- This growth in housing stock is outstripping the population growth and while the average household size is decreasing, the floor space per person is increasing (AGO, 1999b); and

- In Queensland, the number of dwelling units approved in 2002-03 increased by 10.6% on the previous financial year to 39,347 and much of this growth concentrated in South-East Queensland (SEQ).

This paper will summarise the findings from a study that explored the link between energy efficiencies and building orientation in sub-tropical and tropical climates. The study used a new thermal modelling software tool developed by CSIRO that responds more accurately to residential heating and cooling energy performance in those climate zones. This software tool responds to industry criticisms regarding cold climate modelling systems that do not make sufficient allowance for natural ventilation. The tool was used to explore the link between building orientation, insulation, ventilation and energy efficiencies in a range of low, medium and high-density dwelling types in sub-tropical southeast Queensland. This paper will focus on the findings from the medium and high-density case study developments as this are relevant to residential developments in many South East Asian countries, such as Singapore, Hong Kong and Malaysia.

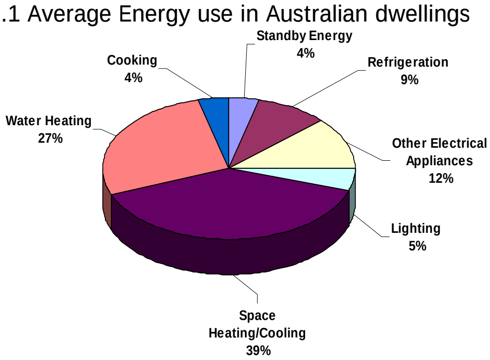
2. Energy use patterns in Australia

The essence of a solar suburb is one that maximizes the percentage of dwelling allotments having good solar access, which in turn facilitates the design of energy efficient dwellings. The study reported in this paper focused on examining dwelling heating and cooling energy efficiency as it relates to and did not examine the following factors that significantly affect the overall energy efficiency of a dwelling or development:

- The embodied energy of materials used in construction of the dwellings;
- The efficiency of heating and cooling appliances;
- The use of other electrical appliances within the dwelling; and
- Variations in dwelling occupant behaviour.

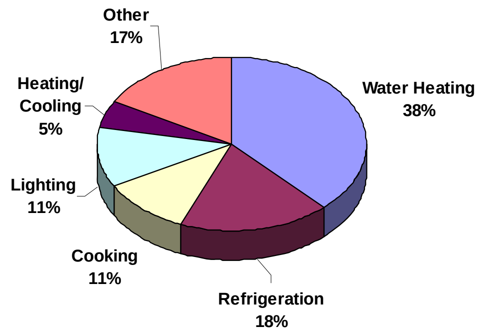
There are significant variations in energy use throughout Australia. Fig.1 shows the typical breakdown of energy consumption for Australian dwellings. The breakdown of energy use in Queensland is quite different with the amount used for heating and cooling being significantly lower. Fig.2 shows that heating and cooling energy accounts for only 5% of the total, compared with 39% as the Australian average.

Fig.1 Average Energy use in Australian dwellings



Source: (Reardon, 2001)

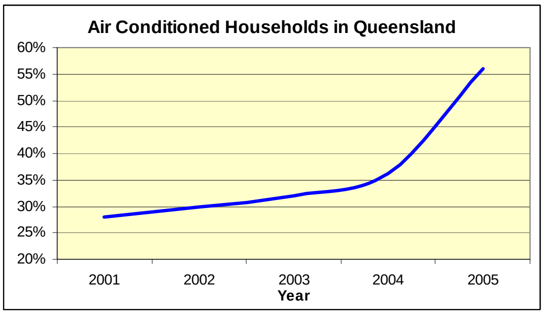
Fig.2 Queensland Household Energy Use



Source: (Queensland Conservation Council, 2004)

There has been a rapid increase in the number of air-conditioned dwellings in Queensland. Fig 3 shows that in 2001 around 28% of dwellings were air-conditioned, however, this has increased to 36% in 2004 and is expected to rise to 56% by May 2005 (Mickel, 2004).

Fig.3 Air-conditioned Households in Queensland



This increase in air conditioning coupled with an increasing population in SEQ will see cooling energy become more dominant and will also place increased stress on the existing power generation and distribution network. It has been estimated that for every new air-conditioner installed it costs the state about $13,000 to keep it running. This cost takes into consideration the cost of generation as well as distribution upgrades and augmentation (Mickel, 2004). These variations in energy consumption patterns for heating and cooling throughout Australia highlight the danger of sub-tropical and tropical regions, such as SEQ, adopting energy efficiency priorities that respond to different climatic requirements.

The increase in energy consumption and changing usage patterns in SEQ are also occurring throughout SouthEast Asia (SEA). In highly urbanized countries such as Singapore, it has been estimated that buildings consume more than half the electricity generated. Also in Singapore, an Energy Market Authority (EMA) survey found that since 1995, energy consumption has increased for all household type. EMA data shows that apartments with air-conditioning consume approximately 30% more energy than apartments without air-conditioning and that this increase is offset by only a minor decrease in the energy used for fans (EMA, 2003). The EMA survey also highlighted the difficulty of changing consumption habits, noting that people 'use electric blankets because the air-conditioning is too cold' (BCA-NUS 2003). Australia, in particular SEQ, needs to learn from the experience of its SEA neighbours and act to reduce the recent increase in air-conditioning before the trend becomes established.

3. Multi storey residential developments and energy efficiency

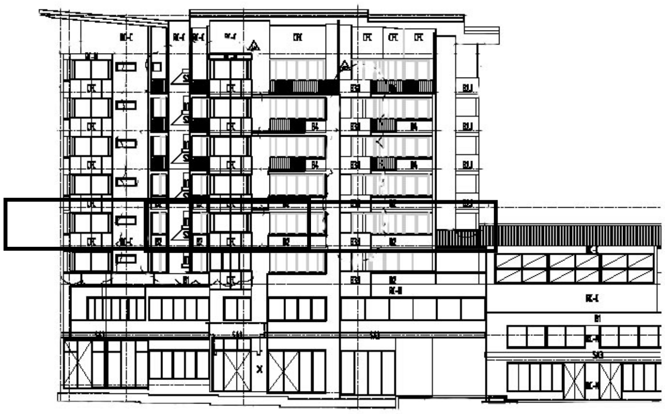
For the purposes of both the study and this paper, medium density is defined as two to three storey developments and typically walk up (Figs.4 and 5), while high density is defined as being four stories and over and typically serviced by a lift (Fig.6). These are common usage terms and may not correspond with definitions used by local authorities. According to the Australian Greenhouse Office (AGO), in 1998 these forms of attached dwellings accounted for 23% of the total housing stock and this was predicted to increase to 26% by 2010 (AGO, 1999). As urban densities increase, the impact of multi storey residential developments needs to be considered and the aim of this section is to examine a range of current design options in the context of the emerging energy code for medium and high-density dwellings.

Three multi-storey residential developments were selected for examination. All are of brick or block work construction, with suspended slab floors and plasterboard walls and ceilings. The floors were assumed to be carpet throughout with ceramic tiles in the wet areas. Other modelling assumptions include medium coloured surfaces throughout and the Holland blind window coverings. To eliminate variations based on differing climatic conditions, the apartments were modelled as if located in the same inner urban location, which was the Kelvin Grove Urban Village (KGUV). KGUV was launched in 2002 and comprises 16 hectares located 2 kilometres from the Brisbane Central Business District (CBD). The development is expected to deliver approximately 800 low, medium and high-rise residential units over the next six years. Case study 1 was a mid-level medium density one bedroom, one bathroom apartment, with approximately 58m² internal floor space. Case studies 2 to 4 (Fig.4) were three-bedroom, two bathroom apartments with 100 – 110m² internal space.

Fig.4 Case Studies 2 to 4 - Suburban or Inner Urban Medium Density Development

The high-density development (Fig.5) housed case studies 5 to 7 which were two, one bedroom, one-bathroom apartments with 48 – 55 m² internal space and a two bedroom, two-bathroom apartment with 77 m² internal space.

Fig.5 Case Studies 5 to 7 - Inner Urban or CBD High-Density Development

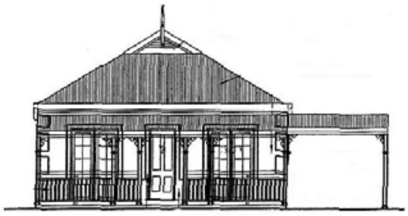


The case study dwellings vary in their degree of exposure to external climatic conditions. The medium density apartments open to covered stairwells, but have variations in the area of external wall and in the nature of adjoining spaces. Two of the apartments are located above another conditioned space and two are located partially over the garage area. The high-density apartments have conditioned spaces, in the form of other apartments alongside, above and below and open to an enclosed lift foyer, limiting the exposure to external climatic conditions.

Within Australia, a star based rating system is used to assess the relative energy efficiency of residential construction. The number of stars achieved is determined through a computer based thermal modelling program that determines average annual energy usage required to maintain a house within a particular thermal comfort range, over a set time and in a particular climate zone. Energy Efficiency Rating (EER) provisions for detached dwellings began to be introduced in the Building Code of Australia in 1991 and have been adopted by the States to varying degrees. EER provisions for multi storey residential developments are to be included in the BCA from 2005. Such provisions already exist in Victoria, where all dwellings must achieve an average house energy rating of at least 5 stars for all the dwellings in the building and a minimum house energy rating of at least 3 stars for each dwelling as determined by an accredited assessor. The range of possible star ratings is from 1 to 5, with 5 being the optimum level. The star rating is derived from the annual total energy load, expressed in megajoules per square metre per annum (MJ/m^2/annum). The new software is still in the development phase and calibration issues related to a pre-existing large area bias are yet to be resolved. As a result, the case study dwelling performances will be discussed in terms of the annual total energy loads and not in terms of the star ratings.

To set the context of this emerging energy code for medium and high-density dwelling, the energy efficiency of the case study attached dwellings was compared with that of a similarly constructed detached, brick veneer on slab dwelling (Fig. 6). This three-bedroom, one bathroom dwelling (case study 8) had a similar internal area (104 m^2) to a number of the apartments.

Fig.6 Case Study 8 – Comparative Detached Dwelling



5. Impact of improved ventilation modelling on apartment energy efficiency

One of the drivers to improve Australia's Nationwide House Energy Rating Scheme (NatHers) was the need to improve ventilation modelling in tropical and sub-tropical climates. This may also provide designers with a tool to augment passive design principles and improve the thermal performance of residential dwellings (Commonwealth of Australia, 2004). The development stage of the new software allows simulations using both the old and new ventilation models and the results of these simulations are shown in Table 1.

Table 1. Impact of Improved Ventilation Modelling on Energy Efficiencies

Case Study Dwelling	Heating Load MJ/m^2/annum	Cooling Load MJ/m^2/annum	Annual Total Load MJ/m^2/annum	Decrease in Annual Total Load
Attached 1	36.5 – 36.9	88.1 – 53.7	124.6 – 90.6	28%
2	16.5 – 16.5	54.6 – 43.8	71.1 – 60.4	15%
3	18.4 – 18.4	47.2 – 37.0	65.6 – 55.4	16%
4	40.3 – 40.3	72.9 – 67.3	113.2 – 107.9	5%
5	6.8 – 6.8	72.9 – 78.0	79.8 – 84.9	+6%
6	19.1 – 19.1	72.8 – 64.3	91.3 – 83.4	9%
7	21.2 – 21.2	55.5 – 65.5	76.7 – 77.7	+1%
Detached 8	17.0 – 17.3	125.1 – 97.4	142.1 – 114.8	20%

The study found that energy efficiencies improved between the two programs by an average of 16% for the medium density case studies. Except for case study 4, the energy loads for the attached dwellings in the new program are lower than those achieved for case study 8, the detached dwelling.

Modelling for improved natural ventilation assumes that the dwelling will have access to this ventilation. Increasing suburban and urban densities triggered an examination of the impact decreased access to natural ventilation on energy efficiency for the medium density dwellings. This was achieved by increasing the external shielding levels in the new software from moderate (suburban) to heavy (inner urban). This changes the patterns of airflow around the case study dwelling by replicating the impact of buildings located in close proximity as occurs in inner urban areas. The result was an increase of an average of 9% in the annual total energy loads for the medium density case studies 1 to 4.

Heavy external shielding, that is the close proximity of neighbouring buildings, was assumed for the high-density case studies and the impact of this can be seen in case studies 5 to 7 in Table 1. For two of the high-density dwellings, the cooling and annual total loads actually increased. These apartments have adjoining apartments or enclosed lift foyers on three sides, and so have almost no potential for cross ventilation. To increase ventilation, the designers included louvered doors behind the entry door to increase internal ventilation while retaining a degree of security. The potential impact of these doors could not be modelled. The designers also used a thermal modelling program to test a range of shading options, providing an example of the potential for the use of thermal modelling to augment passive design principles and address complex ventilation issues.

6. Impact of orientation on energy efficiency

The dwellings were modelled at eight orientations throughout 360°, corresponding with the four cardinal and four semi cardinal points of the compass and the results are as shown in Table 2.

Table 2. Impact of Orientation on Energy Efficiency

Case Study Dwelling	Heating Load MJ/m²/annum	Cooling Load MJ/m²/annum	Annual Total Load MJ/m²/annum	Increase in Annual Total Load
1	39.5 – 46.0	53.6 – 57.7	93.0 – 103.6	9%
2	12.7 – 17.6	46.9 – 55.8	59.6 – 73.4	27%
3	18.0 – 18.0	36.1 – 49.0	54.0 – 67.1	17%
4	39.6 – 59.4	68.8 – 83.5	108.3 – 143.0	32%
5	1.6 – 6.0	71.9 – 85.2	73.6 – 91.3	24%
6	5.7 – 16.3	53.9 – 63.7	59.0 – 80.2	35%
7	12.8 – 15.5	56.2 – 69.3	69.1 – 84.9	18%
8 (detached)	15.8 – 17.8	89.1 – 98.2	104.9 – 116.0	10%

Orientation plays a significant role in energy efficiency with the total annual energy loads at the worst orientations increasing above the optimum level by between 9 and 35%. For five of the attached dwellings, the increases were recorded against optimum performance totals that were low (54.0 to 69.1 MJ/m²/annum) when compared to the detached dwelling. Two dwellings achieved totals comparable with the attached dwelling and for case study 4; the annual total energy load at the worst orientation exceeded the levels achieved for case study 8, the comparison detached dwelling.

7. Impact of insulation on energy efficiency

Wall insulation is not required in attached dwellings in Queensland and ceiling insulation is not relevant to this discussion as none of the upper level apartments were examined. In this instance, insulation refers to the thermal insulating properties afforded by the apartment's proximity to adjoining conditioned spaces in the form of neighbouring apartments alongside, above or below the selected apartment. According to the AGO,

> *Modelling showed that attached dwellings were 36% more efficient on a per square metre basis in comparison with separate dwellings (AGO, 1999).*

When both the attached and detached case study dwellings were modelled at the presented orientations and with the same degree of external shielding (heavy), the attached dwellings were more efficient than the detached dwelling and by an average of 33.7%, as shown in Table 3.

Table 3. Impact of Insulation on Energy Efficiency

Case Study Dwelling	Heating Load MJ/m²/annum	Cooling Load MJ/m²/annum	Annual Total Load MJ/m²/annum	Improved Energy Efficiency
1	36.9	62.2	99.1	21%
2	16.5	57.5	67.6	47%
3	18.4	42.3	60.8	52%
4	40.3	76.3	116.4	7%
5	6.8	78.0	84.9	33%
6	19.1	64.3	83.4	33%
7	21.2	45.5	77.7	38%
8 (detached)	17.3	108.5	125.7	comparison

The least efficient attached dwelling was again case study 4, which is only 7% more efficient than the detached dwelling. The layout of this apartment exposes a long axis to external conditions. This apartment is also partially located above a garage and as a result, has the least area of wall, floor and ceiling spaces shared with adjacent insulating conditioned areas. The more attached dwellings resemble detached dwellings in their exposure to climatic conditions, the higher the annual total energy loads.

The number of simulations involved prevented the examination of more complex combinations of conditions such as the combined impact of poor orientation and increased external shielding, which would be the worst-case scenario for sub-tropical and tropical residential dwellings as urban densities increase.

8. Conclusions

The key assumption behind the research that underpins the study and this paper is that there is an expanding market in both Australia and elsewhere for information on energy efficient building practices. As energy efficiency regulations increase, this need will grow and create significant demand for information on available assessment tools for creating sustainable layouts (orientation, solar access and the like), rating energy efficient designs and products that deliver energy efficiency (solar technology).

Reducing energy consumption is by far the most practical and affordable way to reduce the environmental impact of residential development. Energy efficient design that removes the need for heating and cooling systems and the use of energy efficient lighting and appliances are solutions that are available immediately and often with little if any cost implication. While the percentage of energy use for heating and cooling is low by comparison with southern states, it is increasing and alternative solutions need to be developed before the trend for air-conditioning becomes a consumer expectation.

A number of potential benefits arise from the study that supports the notion that medium and high-density developments can contribute toward the goal of creating solar cities. These benefits include:

- The increasing percentage of medium and high-density apartments may reduce Australia's per capita consumption of personal floor space. The largest of the case study apartment had a similar internal floor area to case study 8, which was the smallest of the detached dwellings examined;
- Thermal modelling assumes the dwelling will be closed and conditioned when the temperature exceeds set parameters. The results indicate that the case study apartments are approximately 33.7 % more efficient than detached dwellings at maintaining the same internal temperature range; however,
- However this level of comparative efficiency reduced as the number of adjoining apartment (alongside, above or below) reduced and the apartment functioned more as a separate dwelling;

- The example of the use of thermal tools to assist designers assessing the impact of a range of ventilation and shading devices, demonstrates the potential for the use of programs to augment passive design principles in addressing complex ventilation issues;
- This combination of design tools is set to become increasingly important as increasing urban densities mean that access to natural ventilation is reduced.

In conclusion, while it is recognised that at the present, only a small percent of energy is used to heat and cool dwellings in tropical and sub-tropical climates such as in SEQ, this percentage is set to increase. Australia needs to learn from the experience of its SEA neighbours and act to reduce the recent increase in air-conditioning before the trend becomes established. It is critical that this aspect of energy consumption is reduced as Australia's ecological footprint is still far in excess of the world average, which is itself in excess of what the planet can actually support.

Acknowledgements

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