# Multi-Unit Residential Building Energy & Peak Demand Study

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## INTRODUCTION

Only limited data is available relating to the energy consumption of multi-unit developments such as apartment blocks, villas and townhouses. Given that much of the growth in the residential sector in Sydney will consist of these higher-density housing forms, it is important to improve our understanding of the energy use of medium- and high-density housing developments and the likely impact such housing has on peak energy demand. In 2003, the NSW Department of Infrastructure, Planning and Natural Resources (now the NSW Department of Planning, or DoP) partnered with EnergyAustralia, Integral Energy, Agility and Sydney Water to deliver a study on the energy consumption of multi-unit developments. This project was funded under the $10 million Demand Management and Planning Project (DMPP) and project-managed by EnergyAustralia. The energy results from this study have been used to inform the development of the multi-unit section of the NSW Government's Building Sustainability Index (BASIX), as well as provide information relating to peak demand relevant to the planning of electricity networks.

Of the main findings from this study, it is the large potential for reduced greenhouse emissions for multi-unit dwellings that is of the most value. This can be achieved through the selection of efficient energy systems and apartment design.

## SAMPLE SITE SELECTION

Approximately 100 multi-unit residential buildings in the Sydney metropolitan region, spanning an area from the eastern coastline to Chatswood in the north, Rockdale in the south and extending inland to Westmead, were the subject of the study. The forms of these buildings (ie high-rise, villa, etc) were selected to ensure a relatively equal representation in each of the five building categories described in Table 1. Inclusion of a representative cross-section of building ages, building storeys and climate zones was an important consideration in the selection process.

TABLE 1: MULTI-UNIT BUILDING CATEGORIES

| Category | Description |
|---|---|
| High-rise | Residential apartment buildings 9 or more storeys high |
| Mid-rise | Residential apartment buildings 4-8 storeys high |
| Low-rise | Residential apartment buildings up to 3 storeys high |
| Townhouses | 2 or more attached dwellings with common or shared facilities (eg car-parking) |
| Villa | 2 or more detached dwellings with common or shared facilities (eg car-parking) |

A total of 52 sites (comprising 4,043 apartments) were involved in the overall study. Permission to perform walk-through energy audits were obtained through contact with body corporates, strata managers or building owners. As an incentive, each body corporate was offered an energy report at the conclusion of the project outlining various energy saving opportunities that had been identified during the audit of their building. Ultimately, 45 sites (comprising 3,854 apartments) were included in the energy audit, and data from this set of dwellings forms the core of the greenhouse results. Due to the small sample size and the similarity of the housing forms, the results from the townhouse and villa audits were combined for the purpose of analysis. For the peak demand component of the study, 24 sites (comprising 1,787 apartments) were subject to 'whole-of-building' power consumption monitoring.

## DATA COLLECTION

An energy auditing company was contracted to conduct walk-through energy audits of the sites, collecting information on all energy-consuming building services and equipment. These audits focussed on common areas of the buildings, including items such as lifts, pools and gyms, as well as central cooling and ventilation systems. However, some general information was also obtained from the audit concerning the individual apartments, such as type of cooking and individual hot water systems. The information gathered from the energy audits was used to prepare estimates of the energy consumption of key end-use categories such as hot water, heating/cooling, ventilation, lighting and lifts. These estimates were correlated, as accurately as possible, to energy billing data obtained from EnergyAustralia's customer information system. Power loggers were installed at 25 of the sample sites to record the summer peak whole-of-building load profile for the month of February 2004. The loggers were three-phase and recorded five-minute average interval data including volts, amps, kW, kVA, kVAr and power factor. One logger failed during the monitoring period, reducing the logged sample size to 24.

## ENERGY ANALYSIS RESULTS

Electricity and gas billing data for the most recent available 12 month billing period was used as the primary source of information for the total energy consumption of common areas and apartments. Common area end-uses comprised lighting, lifts, centralised hot water systems, centralised components of space heating and cooling systems (eg cooling towers), car park ventilation, common exhaust fans, pools, spas and saunas. Breakdown of the common area energy consumptions was based on data from the walk-through audits. Consequently, this particular data has not been substantiated with actual metered consumption data.

Individual apartment end uses comprised hot water heating, space cooling and heating, lighting, cooking (electric only), exhaust fans, appliances and other standby power. Not all of these end-uses were able to be audited for the individual apartments. They are collectively reported as 'other internal' in the building audit breakdowns.

As an example of the variability within the actual site energy data, the total metered energy consumption for two representative sites (Site A and Site B) is presented in Table 2 below. It is interesting to note that the audit estimates for these sites were 86% and 101% respectively of the EnergyAustralia meter readings. Such outcomes from the energy audits highlighted the challenge of accurately predicting energy consumption from a walk-through audit. Discrepancies are more likely to be the result of missing loads, under- or over-estimation of usage hours, miscalculations, etc, rather than errors in utility billing data.

TABLE 2: COMPARISON OF ANNUAL ENERGY CONSUMPTION AND ANNUAL PER CAPITA GREENHOUSE GAS EMISSIONS FOR TWO HIGH-RISE APARTMENT SITES, SYDNEY.

| Site | Number of dwellings | Annual site total energy consumption (MJ/year) | Annual per capita greenhouse gas (tonnes $CO_2$/ person/-year) |
|---|---|---|---|
| Site A | ~ 175 | 11,215,214 | 6.5 |
| Site B | ~ 158 | 5,853,856 | 3.5 |

It is clear that the housing represented in Site A generated nearly twice the per-capita quantity of greenhouse emissions than that of Site B. The actual consumption data has been broken down according to the audit estimates into major end-use categories for each building. An example of this is displayed in Figure 1 for Site A and Site B.

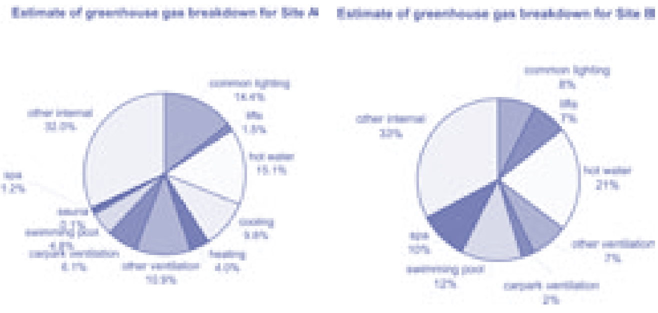

*Figure 1: Estimated breakdown into greenhouse gas sources for Site A (left) and Site B (right).*

It is interesting to note that, although Table 2 indicates that the per-capita greenhouse emissions of Site A and Site B are very different, Figure 1 shows that the breakdown between common area energy usage and apartment energy usage is not that dissimilar. A key difference in the greenhouse breakdown is that Site B does not have a central heating/ cooling system, has lower common area lighting loads and car park ventilation requirements, but nonetheless has an electrically heated swimming pool and spa.

## VARIATION ACROSS HOUSING TYPES

Variation in per-capita greenhouse emissions across the housing spectrum from single, detached dwellings to high-density, multi-unit apartment blocks is of considerable importance in establishing the practicality of applying energy benchmarks in the BASIX for Multi-Units tool.

In seeking to determine housing type dependencies, the analysis initially considered all 45 sites that received energy audits in the greenhouse gas component of the study. Some sites were then eliminated from the study where their total per-dwelling energy use was greater than 1.5 standard deviations from the sample mean. This elimination of strongly atypical data effectively decreased the sample size from 45 to 41, and reduced the number of apartments from 3,854 to 3,670. A summary of the per-dwelling greenhouse characteristics of this selected sub-sample is presented in Table 3.

TABLE 3: TOTAL ANNUAL GREENHOUSE GAS EMISSIONS BY DWELLING TYPE.

| **Building type** | **ANNUAL GREENHOUSE EMISSIONS** | |
|---|---|---|
| | **per dwelling (tonnes $CO_2$/ dwelling/year)** | **per person (tonnes $CO_2$/ person/year)** |
| High-Rise | 10.4 | 5.4 |
| Mid-Rise | 7.3 | 3.8 |
| Low-Rise | 6.5 | 3.4 |
| Townhouse + Villas | 5.1 | 2.1 |
| Detached | 9.0 | 2.9 |
| AVERAGE | 8.0 | 4.1 |

The per-dwelling greenhouse emissions findings in Column 2 of Table 3 have been reduced to per-occupant emissions by dividing the per-dwelling emissions by Australian Bureau of Statistics (ABS) 2001 Census occupancy rates for each housing type. This measure of the emissions, provided in Column 3 of Table 3, is charted in Figure 2, where it can be seen that the differences between dwelling types becomes somewhat more pronounced than the per-dwelling metric would suggest.

Here, the generally lower occupancy rates (1.92 persons per dwelling) of high-rise, mid-rise and low-rise apartments leads to per-capita greenhouse emissions that exceed those of detached dwellings (3.05 persons per dwelling). Indeed, when viewed on the per-occupant basis, only townhouse and villa housing forms are seen to be less greenhouse-intensive than detached.

In Figure 2, the NSW average residential greenhouse gas emissions adopted by BASIX has been marked as 3,392 kg $CO_2$/person/year. The BASIX target, also shown on the chart, requires a 25% reduction in greenhouse gas emissions compared to the NSW average.

The range in the derived per-occupant greenhouse emissions from the multi-unit study is shown by the variance bars displayed in Figure 2 for each of the audited building forms.

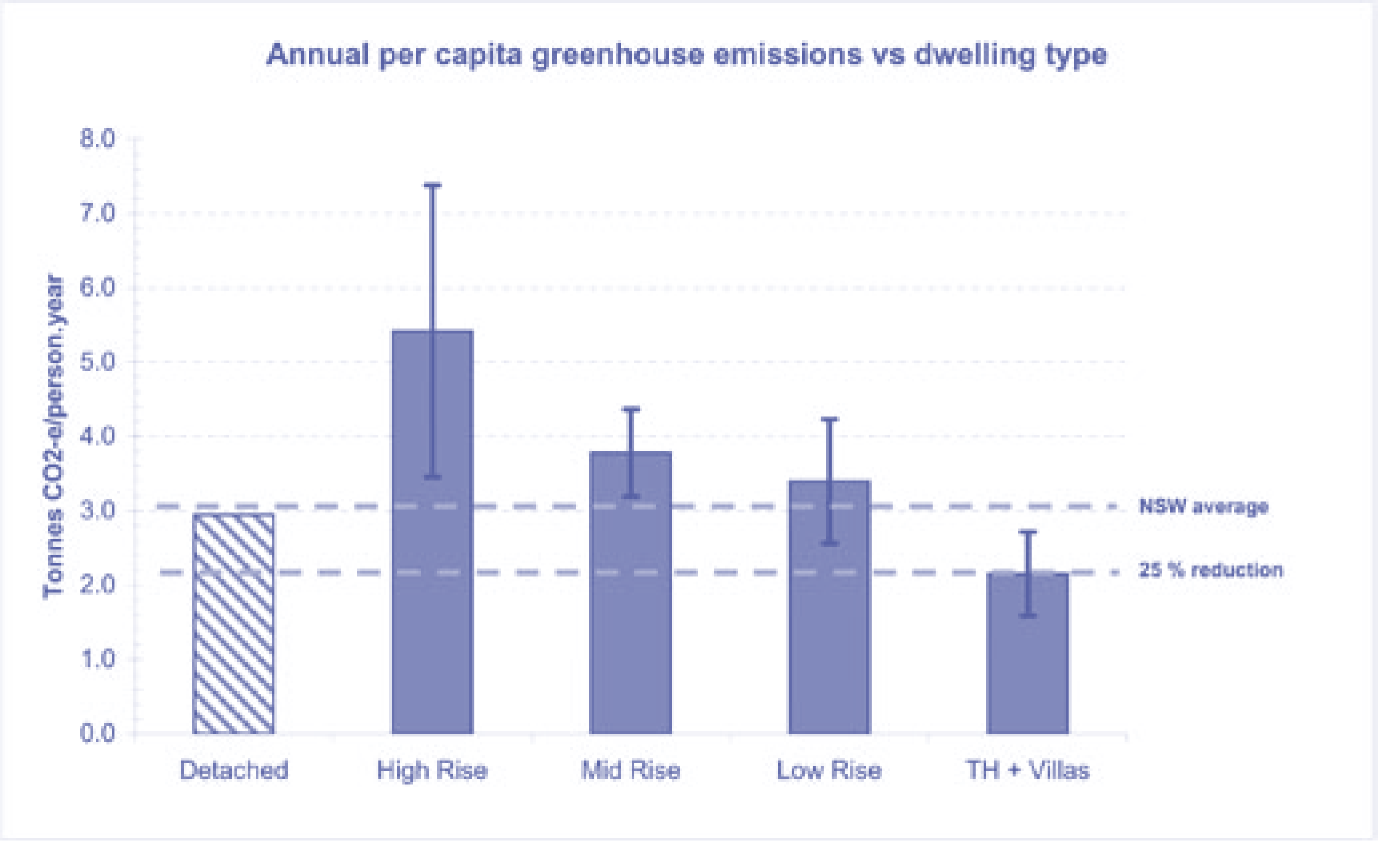

*Figure 2: Annual per-capita greenhouse gas emissions for each dwelling type.*

Substantial greenhouse inefficiencies, such as electrically-heated swimming pools and uncontrolled and inefficient lighting and ventilation systems, were commonly identified in the energy audits. With more thoughtful selection of common area technologies, many high-rise buildings could enjoy large energy and greenhouse savings. In fact, as none of the audited buildings boasted energy-efficient design. It is likely that even those that are represented by the lower variance markers in Figure 2 could achieve substantial greenhouse savings with quite modest changes to common plant, systems and apartment design.

## PEAK DEMAND ANALYSIS RESULTS

Three-phase power loggers were installed at 25 of the audited sites. These instruments recorded the whole-of-building load profiles over February 2004, thereby providing accurate quantification of RMS line voltage, current, kW, kVA, kVAr and power factor over an important summer peak period. In most cases the demand profile had the expected characteristic shape with peak demand occurring between 5 pm and 9 pm, and a smaller morning peak between 7 am and 9 am. The overall monthly peak demand was identified for each site. Any demand spikes outside of the hours of 12 pm to 9 pm (generally associated with off-peak hot water systems turning on) were excluded from the analysis. Across all sites, the average summer peak demand was 2.6 kVA per apartment, ranging from 0.4 kVA up to 7.9 kVA per apartment.

No clear relationship between building category and peak demand could be discerned in the logged data. Of the 24 power-monitored sites, nine were provided with air-conditioning systems. Analysis of the peak load information from the air-conditioned and non air-conditioned site data sets shows a strong relationship exists between the use of air-conditioning systems and building peak demand. The average peak demand for the 15 sites with no air-conditioning was 1.8 kVA per apartment over the month of February. In contrast, the average peak demand for the remaining nine sites with air-conditioning was 3.8 kVA per apartment. Attributed to air-conditioning, this 111% increase of two kVA more than doubled the average peak demand.

Sydney weather data for the study period was obtained from the Bureau of Meteorology. Four high temperature days with maximum temperatures of greater than 32°C were encountered during the logging period (9, 11, 21 and 29 February 2004). Not surprisingly, the peak demand at sites with air-conditioners increased significantly as ambient temperature rose towards those peaks. For example, in Figure 3, the monitored peak demand at Site No. 2 (coastal Sydney, low-rise, 34 luxury dwellings) for a mild day (23°C) and for a hot day (37°C) was seen to almost double from 79 kVA to 155 kVA (an increase of 76 kVA or more than 2.2 kVA per apartment) where the peak occurred around 6.30 pm.

Mon 23/2/04 – Max Temp 23°C

Mon 9/2/04 – Max Temp 37°C

Mon 23/2/04 – Max Temp 23°C

Mon 9/2/04 – Max Temp 37°C

Mon 9/2/04 – Max Temp 37°C

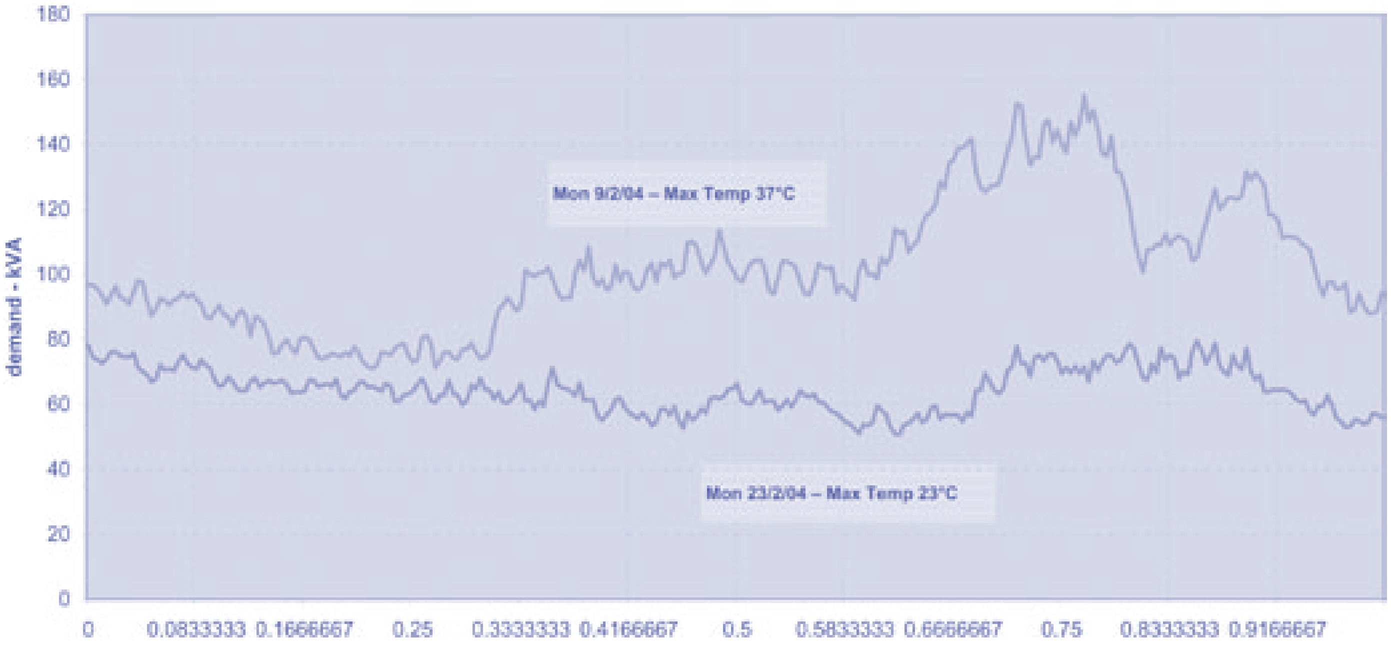

*Figure 3: Daily peak demand versus maximum ambient temperature.*

## FUTURE STUDIES

In taking this research further, it is suggested that future studies should aim to increase the sample size (total number of sites) as well as properly randomise the samples in terms of billing addresses. Furthermore, the number of sites audited in each housing type should ideally reflect the local occupancy rates for each dwelling type. According to ABS Census 2001, in NSW, 2% of people live in high-rise apartments compared to 10.3% of people who live in low-rise apartments. Hence, as is not the case with the present study where the sample size was particularly small for townhouses and villas, audited low-rise apartments should outnumber their high-rise counterparts by approximately five to one. Because of different responses to climate, future studies should also ensure greater involvement of western Sydney dwellings, as these were under-represented in this study. The accuracy of the study might also be improved if the actual occupancy rates of each building were assessed in the study. This method of assessing the occupancy would, however, need to be coordinated with the billing period and, because it must involve a survey of all building inhabitants, would be resource intensive. Some of the challenges faced in this study included: identifying and making contact with an enthusiastic and responsible site representative; gaining permission from the wider body corporate; strata managers unwilling to become involved; and the energy auditors gaining access to certain common areas. Useful strategies included offering to return the results of their energy audit, thus indicating potential energy saving opportunities, as well as identifying a helpful strata manager that had access to a number of multi-unit sites. Future studies could publicly advertise for participants. By getting building owners who are proactively seeking to be part of the study, this method should ensure that there is an adequate level of cooperation and enthusiasm for the study. However, this method would introduce its own set of sample biases. It is critical that future studies continue to look at the whole building consumption, including internal apartment consumption and common areas, to fully understand the energy needs of multi-unit dwellings.

## CONCLUSIONS

The results of this multi-unit residential energy study point to general trends and instances of great variability in multi-unit residential buildings. When expressed as annual greenhouse emissions per occupant, the study results reflect that people living in apartment buildings produce more greenhouse gas emissions than people living in detached houses. This is a result of energy consumption in common areas as well as lower occupancy rates of apartments compared to detached houses. Townhouses and villas appear to be the most efficient dwelling form on a per capita greenhouse gas basis. It is also clear that the provision of air-conditioning has much impact on peak energy demand. Indeed, if air-conditioner installation can be avoided through better thermal performance of dwellings, then considerable demand can be avoided not only in peak summer demand periods but even in mild weather when active cooling would not normally be required. However, while better building design and selection of efficient technologies are an essential means of minimising the peak demand of residential building stock, other mechanisms, such as pricing, are also important. It must be noted that these multi-unit dwellings were only assessed on stationary energy consumption, and that there are other advantages to high-density housing located near public transport, such as lower transport emissions. These could be investigated in future studies.