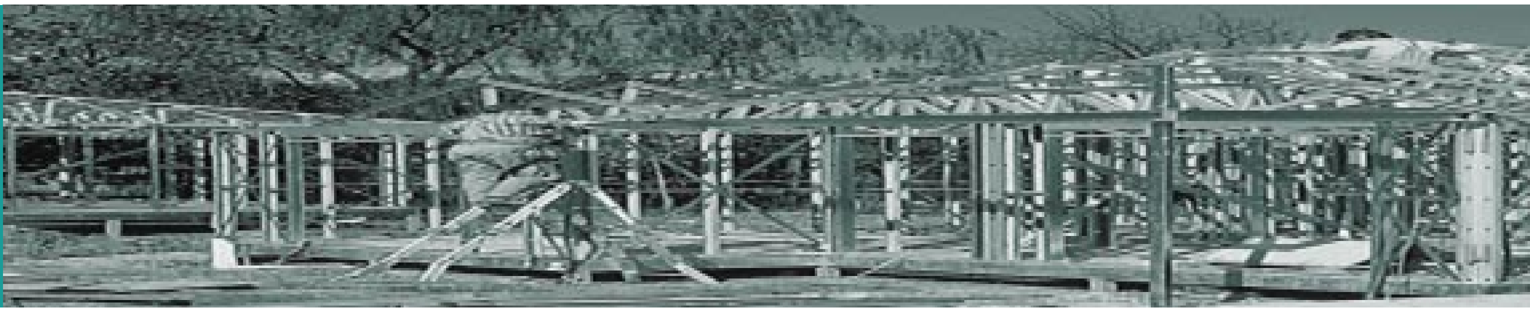
Australian Residential Building Sector Greenhouse Gas Emissions 1990–2010

AUSTRALIAN
Greenhouse
Office

final
report
1999

A PROJECT FOR THE AUSTRALIAN GREENHOUSE OFFICE



ISBN 1876536 25 X

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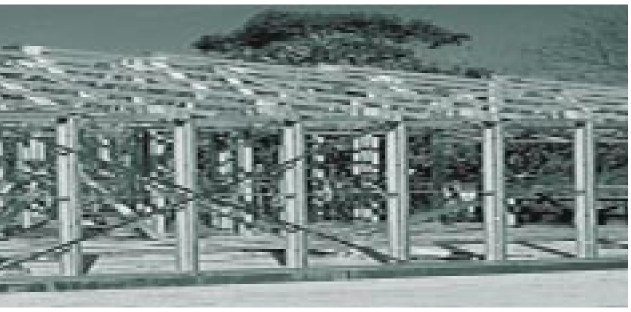
The Executive Summary, Final Report and the Appendices to the Final Report are available on CD-ROM inserted inside the back cover of this publication.

Design Wingrove Wingrove Design
Photos Courtesy of the Housing Industry Association
Printed on Australian 100% recycled paper

FOREWORD



Though the full effects of emissions of greenhouse gases on the Earth's atmosphere are not yet completely understood, the scientific evidence points to a discernible human influence on global climate change.

The residential building sector has recognised the need to address greenhouse concerns, and not just from the perspective of climate change, but also to improve the comfort of the built environment for all Australians.

The Australian Greenhouse Office is pleased to present this study as a valuable sectoral contribution to the broader greenhouse debate.

Importantly, it provides the most up to date and comprehensive baseline data of greenhouse gas emissions for the residential building sector.

I hope that members of the building industry will find this study stimulates not only further discussion on the greenhouse problem, but supports the development of initiatives designed to address these concerns.

Without doubt the building industry has the challenge of becoming more environmentally sensitive while remaining economically efficient. It is a difficult challenge, for the issues are diverse and complex.

I would like to commend the authors of the study, Energy Efficient Strategies, as well as acknowledge the contribution of the Steering Committee representing industry and government organisations.

Gwenyth Andrews

Gwen Andrews
Chief Executive
Australian Greenhouse Office

July 1999

Acknowledgements

The study was produced for the Australian Greenhouse Office by Lloyd Harrington and Robert Foster of Energy Efficient Strategies

with assistance from

Energy Partners
George Wilkenfeld and Associates

and additional contributions from

Graham Treloar, Deakin University
Mark Ellis and Associates

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1 INTRODUCTION

1.1 Review of the brief

1.1.1 Background

In his Statement of 20 November 1997, “Safeguarding the Future: Australia’s Response to Climate Change”, the Prime Minister announced a package of measures to reduce Australia’s greenhouse gas emissions. He noted that this package of measures was designed both to ensure that Australia plays its part in the global effort required to reduce greenhouse gas emissions and to protect Australian jobs and industry. The Government is therefore seeking “realistic, cost-effective reductions in key sectors where emissions are high or growing strongly, while also fairly spreading the burden of action across the economy”. The Prime Minister also noted that “[The Government is] prepared to ask industry to do more than they may otherwise be prepared to do, that is, to go beyond a “no regrets”, minimal cost approach where this is sensible in order to achieve effective and meaningful outcomes”.

Subsequent negotiations resulted in an international agreement to the Kyoto Protocol to the Framework Convention on Climate Change, under which Australia will have an obligation, inter alia, to reduce its rate of greenhouse gas emissions to 108 per cent of its 1990 level by 2008–2012. This compares with a business-as-usual scenario prior to the Prime Minister’s Statement of 28 per cent emissions growth for the economy as a whole, and around 40 per cent for energy-related emissions.

For the building sector, the Prime Minister’s Statement specified:

“The Commonwealth will work with the States, Territories and key industry stakeholders to develop voluntary minimum energy performance standards for new and substantially refurbished commercial buildings on the basis of energy efficiency benchmarks. If after 12 months, the Government assesses that the voluntary approach is not achieving acceptable progress towards higher standards of energy efficiency for housing and commercial buildings, we will work with the States and industry to implement mandatory standards through amendment of the Building Code of Australia.”

Following consultation with the building industry, the Australian Greenhouse Office (AGO) decided to conduct a baseline study on the greenhouse gas emissions attributable to the residential building sector of the economy.

Accordingly, this project is to provide a firm, quantitative basis for the subsequent development of specific greenhouse response measures by industry and government. The Commonwealth Government (AGO) will consider the impact of these measures in the context of its overall greenhouse strategy.

1.1.2 Project aims and objectives

The study is designed to articulate, concisely and quantitatively, the following key elements:

- 1990 greenhouse gas emissions attributable to the residential buildings sector;
- business-as-usual emission growth projections, 1990–2010, with and without emissions-reduction measures implemented or announced to date, taking into account changes in consumer behaviour;
- a quantitative assessment of an equitable greenhouse emission reduction commitment for the building sector, taking into account baseline and projected emissions growth to 2010 and the Kyoto Protocol commitment for Australia as a whole; and,
- a quantitative assessment of any “gap” between the proposed emissions reduction commitment to 2010 for the building sector and the projected emissions growth with measures implemented or announced to date.

1.1.3 Project scope and related issues

As set out in the project proposal, this report covers energy consumption and greenhouse emissions from the following building classifications of the Building Code of Australia:

- Class 1a (i) — detached houses
- Class 1a (ii) — attached dwellings (including town houses, terrace houses and villas)
- Class 2 — buildings containing two or more sole occupancy units (flats)

These building types constitute the vast majority of residential building types in Australia.

The following dwellings (sometimes also called "residential" buildings) as defined under the Building Code of Australia are not covered by this study:

- Class 3a — boarding houses, guest houses and hostels
- Class 3b — residential parts of motels or hotels
- Class 3c — residential parts of schools
- Class 3d — accommodation for the aged or disabled
- Class 3e — staff accommodation in health care buildings (eg hospitals)
- Class 3f — residential parts of a detention centre
- Class 4 — dwellings in a non-residential building

These are generally classified as non-private households under the Australian Census and are covered in the commercial sector.

Greenhouse gas emissions embodied in construction materials and emissions associated with the construction or demolition process will not be covered in detail in this study. However, the study identifies the level of information relating to emissions and/or energy embodied in the fabric of buildings or associated with the construction/demolition process. This could form the basis of a future quantitative and qualitative study. The report also sets out some example calculations for embodied energy and discusses issues related to embodied energy.

The quantification of baselines and projection of emissions follows, as close as possible, the relevant Australian Methodologies for the Estimation of Greenhouse Gas Emissions and Sinks, as published by the National Greenhouse Gas Inventory Committee.

1.2 Approach to the project

We developed a two-phase approach to the project:

1. a research and information gathering stage during which all of the relevant data for the project was collected from existing sources; and

2. an analysis and modelling stage, which synthesised the data into energy and greenhouse gas emission forecasts for a base case and various pre-defined scenarios.

1.2.1 Data sources

Primary data sources used for the project are listed below. References are included throughout the main body of the text.

Population and households: Household numbers were obtained from the Census of Population and Housing (ABS 2015.0). Population data was obtained from a number of ABS demographic publications (ABS 3222.0, ABS 3102.0). Households numbers were estimated on the basis of household size trends at the state level.

Appliance ownership and housing stock data: National data sets for ownership and penetration of appliances and housing stock in Australia were derived from ABS national energy surveys conducted in November 1980, June 1983 and (nominally January) 1986 (ABS 8212.0 and 8213.0) and an environmental issues survey ABS 4602.0 in June 1994. Additional data sources were the 1976 Census and more recent household surveys undertaken by BIS Schrapnel (1998b) and Test Research (1995), as well as ABS 4172.0.

End use energy consumption: Estimates of in-use energy consumption by equipment type were obtained from a wide range of sources including Pacific Power (1996), with additional end-use information from analysis of retail sales data and energy labelling data by EES (1997). Other data sources included ACA (1990), Bartels (1985 and 1988), Bartels et al (1988), Fiebig and Woodland (1991 and 1993) and SECWA (1991). The Pacific Power study is the result of appliance monitoring in about 300 NSW households during 1993–1994. Data in Bartels and Fiebig and Woodland is based on a conditional demand analysis of NSW households where ABS ownership data is matched to utility billing data (samples sizes are generally 5,000+). Some electricity data was also available from Queensland (EES 1995). Other sources included engineering estimates and measurements published in Choice magazine.

Building shell performance: Data on the building shell stock attributes was derived from the ABS national energy surveys conducted January 1986 (ABS 8212.0 and 8213.0). Details on the building construction types and levels of insulation in floors and walls were also derived from this source. The survey by ABS (4602.0) in June 1994 provided data on insulation levels but not by construction type, so this was source was used to verify insulation trends at state level to 1994. National data on stock floor area was obtained from NIEIR (1997). Data on new dwelling construction (including shell type and floor area by state) from 1987 to 1997 was obtained from the Australian Bureau of Statistics (Building Research and Outputs Group in Adelaide). Building insulation data was also obtained from FARIMA (Fibreglass and Rockwool Insulation Manufacturer's Association). Demolition data came from the Building Control Commission in Victoria. Floor area additions (extensions) and retrofit insulation data were derived from BIS Schrapnel (1994). Requirements for existing energy efficiency programs for buildings came from the Building Code of Australia. Building shell performance of a range of building shells was modelled using Nationwide House Energy Rating Scheme (NatHERS) software on a number of standardised "generic" house designs. A total of 15 construction types were modelled under 5 climate zones and 4 orientations. See the section on the Building Shell for more details.

Climate data: EES had access to daily temperature data for 8 capital cities from 1970 to 1997 (ABM 1997). The project team also had access to climate data built into the HERS modelling system as well as data from the revised third edition of the *"Australian Solar Radiation Data Handbook"* published by the Australian and New Zealand Solar Energy Society and the Energy Research and Development Corporation. The Handbook, including a full set of tab delimited data files on disk, was published by ERDC in April 1995.

Greenhouse gas emissions: George Wilkenfeld (GWA) provided estimated greenhouse gas emissions from the National Greenhouse Gas Inventory and projected state level intensities using the Australian Methodologies for the Estimation of Greenhouse Gas Emissions and Sinks. Cross sectoral analysis of emissions was derived from GWA (1998).

1.2.2 Modelling

During the second phase of the project, the data was synthesised by means of an end use model to benchmark actual energy consumption and greenhouse emissions in 1990 and these were projected forward to 2010 under a base case scenario (Business as Usual *with* measures or BAU+). The BAU+ scenario incorporated the impact of energy policy programs which were already in place between 1990 and November 1997 (eg HERS, minimum insulation requirements in Victoria and Minimum Energy Performance Standrds (MEPS) in the ACT) or which are finalised and scheduled to be introduced over the forecast period (eg MEPS for electric storage water heaters and refrigerators and freezers in 1999). Energy labelling of appliances is included in all scenarios.

The main parts to the building shell energy end use model developed for this project were as follows:

- characterisation of the building stock in terms of construction type and insulation levels by state and climate region;
- determination of the characteristics of additions to the building stock (new dwellings), demolitions (retirements), extensions and retrofit insulation, with projections of trends and program options to 2010;
- modelling of the unconstrained heating and cooling requirements by building shell/climate/orientation using the NatHERS model;
- constraining of the heating and cooling requirements back to known levels of use in each state.

The main parts to the appliance and equipment energy end use model developed for this project were as follows:

- determination of the ownership and penetration by state of all major appliances (including heating and cooling equipment) in households from 1966 to date with projections to 2010.
- Determination of the appliance and equipment characteristics (capacity, energy consumption and energy efficiency) from 1966 to date with projections to 2010;
- Determination of energy service trends in recent years (eg frequency and duration of use, climate impacts etc) with projections to 2010;

The end use model developed for this project explicitly models the stock characteristics of the following major end uses:

- refrigerators
- freezers
- clothes washers (including frequency of use and wash temperature trends)
- clothes dryers (including frequency of use)
- dishwashers (including frequency of use, water connection modes)
- water heaters (all major fuels including electric peak, electric off peak, natural gas and LPG (storage and instantaneous), solar/electric boost (based on projected hot water delivery profiles)

- space heaters by fuel type (gas, LPG, solid fuel) with climate zone and building shell impacts
- various air conditioner types with climate zone and building shell impacts
- cooktops and ovens by fuel type
- TV and VCR (including standby losses)
- other standby losses
- miscellaneous energy consumption

Modelling was at the state level for all of the above appliances, but at a regional climatic level for building shells and heating and cooling equipment (which was then reaggregated to state level for stock modelling purposes).

The end use or "bottom up" model is based on a stock model which takes into account the average technical characteristics of both new appliances and buildings entering the stock and old ones leaving the stock to provide a stock weighted average for each year during the modelling period. The model has the capability of estimating the impact of selected end use behavioural changes which applies to all stock, such as the tendency towards the use of cold water washing or hours of operation/frequency of use. The model also has the capability to quantify the impact of various alternative penetration scenarios (eg high level of natural gas penetration) although this was not undertaken for this project, as it was beyond the scope of work.

The above "bottom up" energy end use estimates were reconciled with the known "top down" energy supply envelopes obtained from ABARE (1998) up to the point where historical records were available (1986 to 1997). Beyond 1997, the model projects energy consumption at the end use level with adjustments as necessary to the relevant projected state greenhouse gas intensity indices for major fuels such as electricity, gas and solid fuels.

1.3 Project team and acknowledgments

This study was undertaken by Energy Efficient Strategies (Victoria), with Assistance from Energy Partners (ACT) and George Wilkenfeld and Associates (NSW), for the Australian Greenhouse Office.

A number of organisations were contacted during the project and their cooperation and assistance is gratefully acknowledged. We would like to particularly thank staff of ABARE, the Australian Gas Association, FARIMA and the Australian Bureau of Statistics for information provided specifically for this project. The assistance of the Australasian Window Council (AWC) in allowing the results of its 1995 simulations to be reused to define the Climate Types for this project is gratefully acknowledged. The Assistance of John Ballinger through the provision of NatHERS input files and data is also gratefully acknowledged.

The study was carried out primarily by Lloyd Harrington and Robert Foster of Energy Efficient Strategies. Lloyd Harrington was responsible for collection and collation of all appliance data, ownership data, developing the stock models for all equipment types and reconciling top down energy data. Robert Foster undertook research into building shell configurations and developed the building shell stock model for heating and cooling loads. Trevor Lee and Dr Peter Lyons of Energy Partners undertook a large number of runs on the Nationwide House Energy Rating Scheme (NatHERS) Model to determine the unconstrained heating and cooling requirements.

A total of 2000+ runs were required to cover all climate regions, orientations and building shell configurations. Dr George Wilkenfeld of George Wilkenfeld and Associates provided data on greenhouse gas emission factors by state (historical and forecast) in line with the Australian Methodologies for the Estimation of Greenhouse Gas Emissions and Sinks. Mark Ellis of Mark Ellis and Associates provided a review of third party end use measurement and estimate projects within Australia over the past 10 years. Graham Treloar provided numerous references on embodied energy and contributed the majority of text to the section on embodied energy. All team members contributed documentation for the report.

Notwithstanding the many individuals and organisations that have assisted during this project, the content and form of this report, and all of the views, conclusions and recommendations expressed in it, are those of Energy Efficient Strategies.

2 PROJECT RESULTS

2.1 Approach to modelling for this project

There is a degree of certainty regarding the energy consumption of major appliances in the residential sector. Water heaters and refrigerators, for example, operate continuously, and if their key characteristics are known then their annual energy consumption can be estimated with reasonable confidence. This is helped by the fact that a large proportion of electric water heaters are off-peak, and so are separately metered. There is a large amount of survey data on the penetration and frequency of use of major appliances (eg dishwashers, clothes washers) and preferred user settings (eg hot versus cold wash). Again, this allows annual energy consumption to be estimated with reasonable confidence.

By contrast most households have several space heating devices of various energy types, and use them interchangeably and/or simultaneously. It is therefore difficult to model heating demand (and cooling demand) directly. Although there is some ABS survey data on the fuel and technology type used for “main” and for “secondary” heating, and on reported hours of heating and cooling, there is little data on the number of heaters in use during heating hours, or their average output.

The mildness of the climate in most parts of Australia means that the parameters of the heating season are less well defined than in North America or in northern Europe, where whole-house heating (and, in the USA, whole-house cooling) is relatively common, and most of the heating and cooling load can be correlated with heating and cooling degree days and the thermal characteristics of dwellings. In Australia, the more usual pattern is intermittent heating of part of the dwelling, and the number of dwellings with no fixed heating or cooling devices at all exceed the number with whole-house heating.

It is possible to calculate theoretical heating and cooling energy demand required to maintain any Australian dwelling at standard comfort conditions, given its location, size, orientation, insulation and construction materials. Indeed, this is the basis of the Nationwide House Energy Rating Scheme (NatHERS) and other building shell thermal performance modelling software. It is also possible to use the same approach to calculate an aggregated heating and cooling demand for all dwellings, and to estimate the energy consumption that would result if the existing stock of heating and cooling appliances were used to meet the demand. However, the energy consumption estimated in this way is typically several times the actual energy used for heating and cooling. For example, in 1990 the unconstrained[5] heating and cooling demand (before conversion efficiency of end use devices) approximately equalled the total residential energy consumption for Australia for all end uses and fuels (ie around 300 PJ — ie about 2.5 times greater than actual energy consumption for that end use).

For this study, the baseline energy consumption of households has been modelled using the following iterative approach:

1. For each energy form, consumption for purposes other than heating (and, in the case of electricity, cooling) was modelled first, as there is a reasonable degree of certainty regarding the magnitude of these end uses. This is called the Business as Usual with measures (BAU+) Scenario. This scenario includes those program measures introduced or finalised for introduction during the period from 1990 to November 1997 (the time of the Prime Minister’s statement). These include MEPS for refrigerators, freezers and electric storage water heaters, as well as minimum insulation standards for dwellings in Victoria and a minimum 4 star ACTHERS rating in the ACT. An intermediate population and household forecast has been used for the BAU+ projections (ABS Series II);

2. The building stock from 1986 was characterised into 15 main categories of construction (lightweight/brick veneer/double brick with timber/concrete slab floor combinations and no insulation/roof only/roof and wall insulation combinations) within each state. Separate and attached dwellings were separately modelled by construction type. Data was based on household surveys by ABS and data on the characteristics of new dwellings by state from 1986 and other sources.

3. The aggregate heating and cooling demand (unconstrained) was then calculated using the NatHERS building shell modelling program. Generic designs for both detached and non detached housing types were used. These were modelled through the range of construction types, insulation levels, possible orientations and climate regions. For each variant the performance characteristics were combined with the estimated penetration levels and floor areas to determine total demand. The program accounted for existing

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[5] “Unconstrained” refers to the energy demand required to maintain an entire dwelling at a high level of human comfort continuously during normal waking hours 365 days a year. In reality such demand is usually “constrained” by various user behaviours including, reducing the hours of heating and or cooling operation (occupancy levels), conditioning of only part of their homes (zoning) and acceptance of lower comfort levels (thermostat settings).

stock, new stock added each year, retirements of stock through demolition and alterations to stock through additions and insulation retrofitting.

4. The heating (and cooling) demand was adjusted to be a proportion of the unconstrained demand for each state, on the basis of reduced hours of occupancy (in comparison with the HERS model) and zoned heating and cooling within a household (only part of the house is typically climate controlled). Occupancy was generally set assuming that the house was only heated or cooled for 50 per cent of total hours for all technologies and all states in all years. Zoning factors were adjusted by energy type to ensure that the total consumption of each energy form, as recorded by the Australian Bureau of Agricultural and Resource Economics (ABARE), were broadly consistent for the period 1987 to 1997. Where possible, a constant zoning factor was used for all states. Whilst the development of this process involved a number of checks and balances it is recognised that data relating to user behaviour as it affects the use of heating and cooling appliances is very limited. Post occupancy studies aimed at quantifying better some of these factors would be a most useful follow up and refining tool for this study.

5. The heating and cooling energy was checked for fit with the stock of heating and cooling equipment, and information about hours of use and direct metering data by end use where this was available. Third party sources such as this were used to check all end use energy estimates wherever possible, or to calibrate end use energy consumption at the state level where this is known with some certainty.

The approach is simplest for wood, for which it has been assumed that all consumption is for space heating (the small amount of wood use for cooking and water heating (ie 0.4 per cent and 1.9 per cent respectively of households in 1998) has been ignored for this study). The ABARE estimates of wood consumption have been examined, although these are subject to considerable uncertainty since wood use is not metered, and a part of it is self-gathered rather than supplied by merchants. Wood consumption estimated by this study are somewhat less than that estimated by ABARE. Two classes of wood heating technology — open and closed combustion — have been modelled separately, since they have quite different efficiency and greenhouse emissions characteristics. However, little firm data on the market share for these types is available at this stage (Mogg 1999). The average energy efficiency of each equipment class has been varied over time.

At the other extreme is electricity, where total consumption is accurately recorded, but a relatively small share of it is used for heating or cooling. Electricity is the preferred form of heating energy in the parts of Australia where the climate is mildest (eg Queensland), so dwelling thermal characteristics are often of limited use in predicting consumption. Furthermore, the heating energy share needs to be further divided between two main classes of heating technology — heat pump and resistance — and two classes of cooling technology — heat pump and evaporative. Again, the average energy efficiency of each equipment class has been varied over time.

Natural gas and LPG are used almost entirely for water heating, space heating and cooking (there is a small amount of gas used for purposes such as pool heating, clothes drying and novelty lighting, and LPG is used for recreational purposes and some portable appliances (eg BBQs), but these uses have been ignored for this study). There is a high degree of correlation between space heating demand and gas consumption. Space heating accounts for the majority of natural gas use in most states, and most of the space heating demand in Australia is met by natural gas.

The consumption of the minor fuels — briquettes, coal, kerosene, heating oil, automotive diesel oil and town gas — has not been explicitly modelled for this project. Together these accounted for 11.2 PJ of ABARE's estimate of total household energy use in 1990 of 322.3 PJ (3.5 per cent) and accounted for 1.7 per cent of greenhouse gas emissions in that year. ABARE project the market share of these fuels to fall to 4.9 PJ (just 1.2 per cent) of ABARE's forecast residential energy consumption of 411.8 PJ in 2010. Where it was necessary to account for energy and greenhouse gas emissions from these minor fuels, historical and forecast values as provided by ABARE have been used.

ABARE calculates the contribution of solar energy to the household sector in terms of equivalent fossil energy displaced. The appliance model developed for this project also explicitly estimates solar contribution of installed solar water heaters, but this is treated as a negative heat loss for the electric water heating load (as almost all installed solar water heaters are electric boosted). The solar contribution estimated by the end use model correlates reasonably closely with the ABARE estimates.

The contribution of passive solar energy to space heating via optimally designed orientation and glazing is captured by the decrease in the heating required to maintain standard heating comfort conditions. This contribution is not counted explicitly by ABARE or for this project.

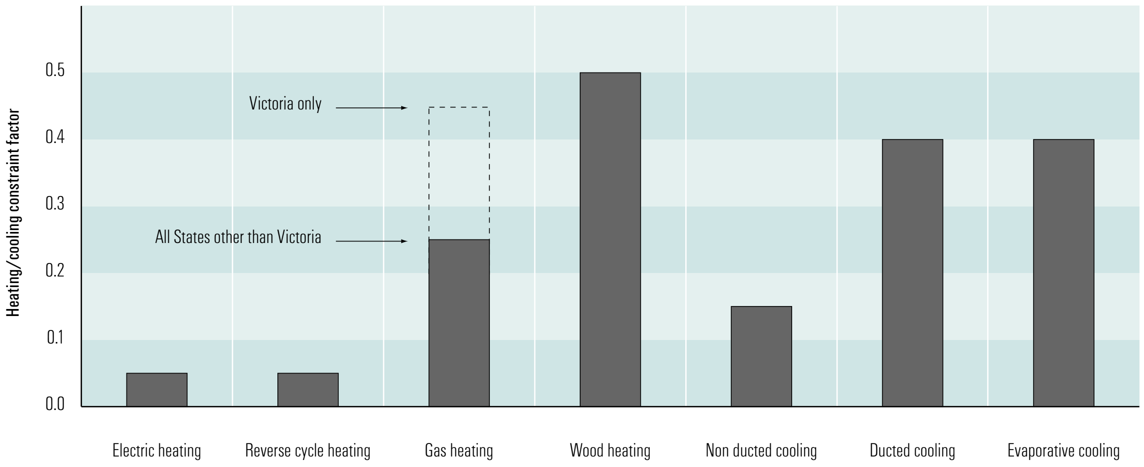
2.2 Energy by end use

The first task was to develop a model of appliance stock and use within each energy form that matched the residential sector energy use reported by ABARE over the period 1987 to 1997.

Wood accounts for a large share of the energy used in space heating, but a far smaller share of the greenhouse gas emissions. The greenhouse intensity of wood use is low, because unlike coal, gas and petroleum, wood is a renewable fuel. For national greenhouse accounting purposes, it is considered that the CO_2 produced from the combustion of wood and other biofuels is exactly balanced by the takeup of carbon from the atmosphere when the biomass regrows. Therefore the greenhouse-intensity of wood use comprises only the effect of the CH_4 and N_2O produced during its combustion (expressed as equivalent CO_2). Wood burned in closed combustion heaters has a low greenhouse gas intensity (about 4 kT CO_2-e/PJ), but when wood is burned in an open fire under poorly controlled conditions, the greenhouse impact is about 58 kT CO_2-e/PJ, comparable to burning natural gas (which varies from 56 kT CO_2-e/PJ in the NT to 65 kT CO_2-e/PJ in NSW and ACT). Electricity has by far the highest greenhouse gas intensity, ranging from about 214 kT CO_2-e/PJ in the NT to 382 kT CO_2-e/PJ in Victoria (not counting Tasmania, where nearly all generation is hydro and the intensity is nearly zero in most years).

An “unconstrained heating/cooling” model was developed to calculate what the heating and cooling demand would be in each State given the distribution of housing types and climatic zones, if all dwellings maintained the standard comfort conditions embodied in the NatHERS program in terms of continuity of heating/cooling, target internal temperatures, proportion of dwelling heated/cooled and a high level of occupancy. In all States but Victoria, where whole-house gas heating is relatively common, the actual estimated energy consumption for heating was significantly lower than the unconstrained demand would suggest. Figure 1 shows the “constraint ratio” adopted for each heating technology. Constraint factors in the model are broken into two parts: the first being on average houses are occupied less than assumed in the NatHERS model (called occupancy level) (eg heating is turned down/off when at work or when away) and second, that typically only part of the house is thermally controlled (called zoning). The overall constraint factors are shown in Figure 1. Note that the constraint factor for Victorian Gas heating was 0.45, whereas it was 0.25 for all other states.

Figure 1: Constraint factors for heating and cooling by technology



2.2.1 Results for 1998

Electricity is the major energy source for residential buildings, accounting for about 48 per cent of all energy in 1998. Natural gas is the next biggest fuel, accounting for 35 per cent of energy while wood accounts for about 14 per cent. All other fuels had either a small share or were insignificant.

In terms of greenhouse gas emissions from residential buildings, electricity dominates accounting for 84 per cent of emissions. The only other significant fuel in terms of emissions is natural gas at 13.4 per cent.

Space heating and cooling is responsible for 39 per cent of energy consumption in residential buildings, but accounts for about 15 per cent of greenhouse gas emissions.

Figure 2 presents the energy trend for 1986 to 1998 broken down by energy form;

Figure 3 presents the greenhouse gas emissions trend from 1986 to 1998 broken down by energy form;

Figure 4 presents the energy trend for 1986 to 1998 broken down by end use;

Figure 5 presents the greenhouse gas emissions trend from 1986 to 1998 broken down by end use.

Figure 2: Residential energy consumption by fuel 1986–1998

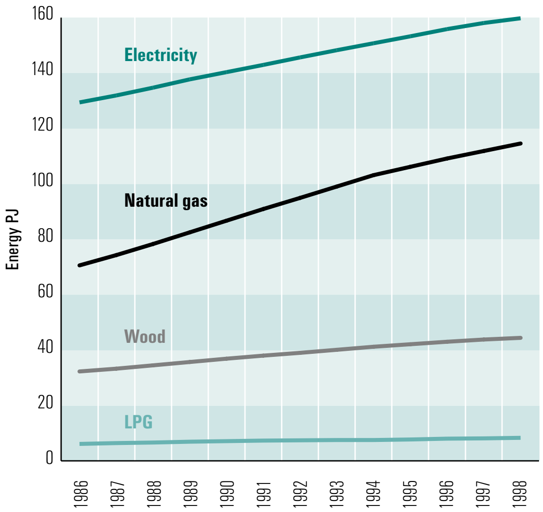


Figure 4: Residential energy consumption by end use 1986–1998

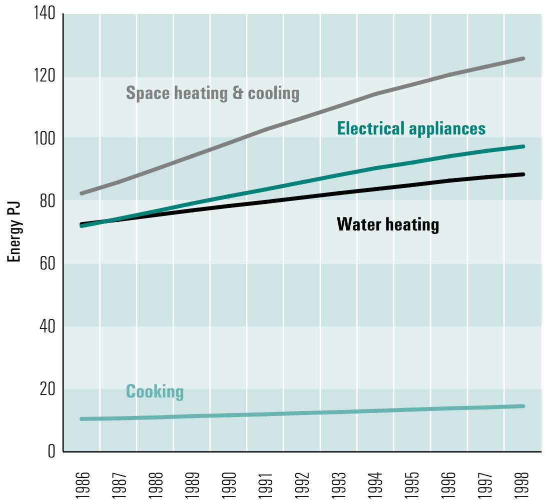


Figure 3: Residential greenhouse emissions by fuel 1986–1998

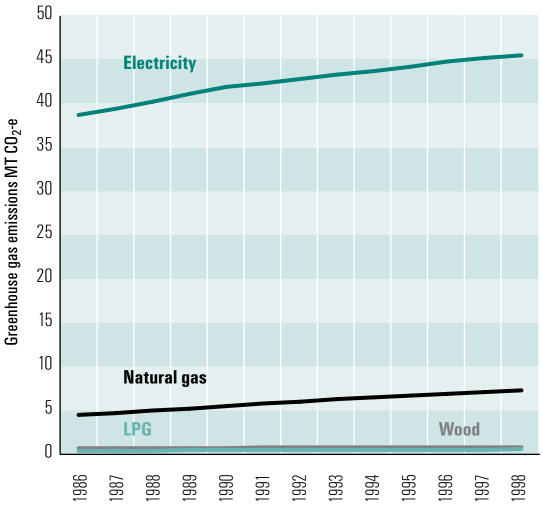
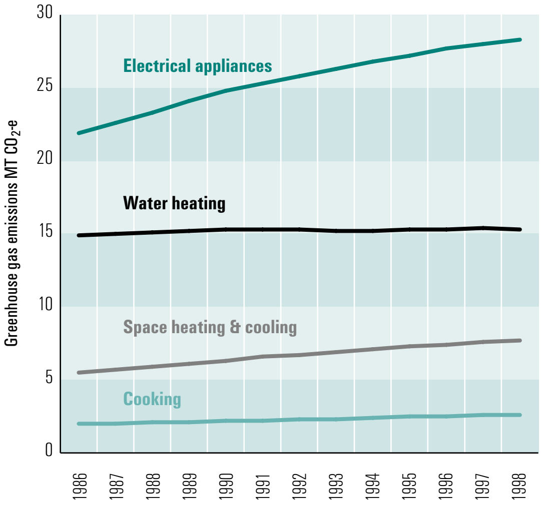


Figure 5: Residential greenhouse emissions by end use 1986–1998



2.2.2 Trends 1987 to 1998

Total electricity and natural gas energy consumption appear to be growing strongly in the residential sector, with some moderate growth in wood consumption. LPG consumption is stable.

There is strong growth in greenhouse gas emissions from electricity in the residential sector. There is also some growth in emissions from natural gas, but total emissions are much smaller in magnitude when compared to emissions from electricity. There is little change in the emissions from wood or LPG — these are very small in comparison.

Space heating is the single biggest energy end use in the residential sector and the total energy consumed is continuing to grow strongly. Electricity consumption for appliances and equipment and water heating is also growing strongly. Energy consumption for cooking is growing slowly.

Greenhouse gas emissions from electrical appliances and equipment are growing rapidly and is the major driver for the increase in greenhouse gas emissions from residential buildings. Emissions from space heating are also growing, but at a slow rate. Emissions for water heating are stable as a result of fuel changes from electricity to natural gas. Emissions from cooking are small and growing slowly.

2.3 Top down energy data

ABARE supplied data on energy consumption by fuel and by state for the years 1972 to 1997 (ABARE 1998). The ACT has been included within NSW data for all years. This was the primary data source used to calibrate the model outputs. In the financial year 1989–90, ABARE estimate that the residential sector in Australia consumed at total of 322.3 PJ of energy. The end use model developed for this project accounts some 270.4PJ of energy. The main difference in the total energy is for wood and woodwaste. The ABARE estimates of wood consumption were examined for 1990 (74.1 PJ) and are considerably higher than predicted by our model (36.8 PJ). We could have artificially boosted wood consumption by assuming increased levels of zoning and occupancy for wood heating households (or reduced efficiency), but this would be inconsistent with the approach used for other fuels. Wood consumption is subject to considerable uncertainty since wood use is not metered, and a part of it is self-gathered rather than supplied by merchants. This difference, however, is not overly significant, as wood generally only contributes a very small amount of greenhouse gas emissions per PJ delivered. So this discrepancy has been ignored. All values quoted in this report are EES estimates except where otherwise noted.

Differences between ABARE estimates and EES estimates for other fuels modelled by EES (electricity, natural gas and LPG) were generally very small and totalled less than 1 PJ in 1990.

Consumption of fuels not specifically covered by this study are shown in Table 1. They account only for 3.4 per cent of residential energy consumption in 1990 (although some of these, such as coal, are rather greenhouse intensive) and are projected by ABARE to decline to negligible levels by 2010. Greenhouse gas emissions associated with these fuels are estimated to be 0.85 MT CO_2-e in 1990 and 0.38 MT CO_2-e in 2010.

Table 1: ABARE residential energy sundry fuels 1990 and 2010

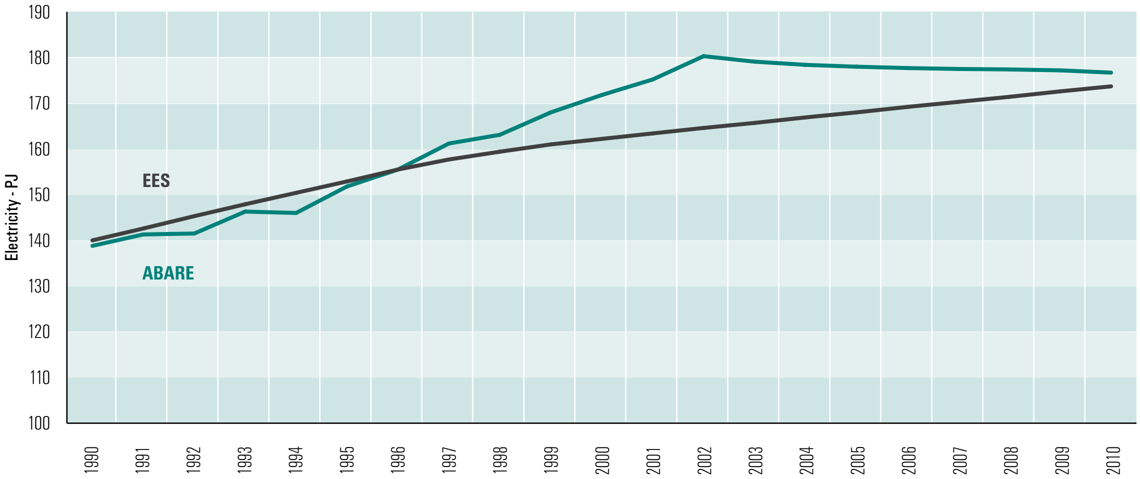
Fuel	1990 PJ	2010 PJ
Black coal	0.30	0.00
Brown coal briquettes	0.27	0.20
Lighting kerosene	2.20	0.33
Heating oil	4.00	2.20
ADO	2.37	1.61
Town gas	2.07	0.59
Total PJ	11.21	4.93

Source: ABARE 1998

EES model outputs and ABARE actual and forecast values from 1990 to 2010 for electricity and natural gas are shown in Figure 6 and Figure 7.

The EES estimates of electricity consumption are a reasonable fit to the ABARE actual data from 1990 to 1997. Note that actual electricity consumption can be very sensitive to weather conditions in any particular year. ABARE projections from 1998 to 2010 are generally somewhat higher than the BAU+ scenario (particularly from 2000 to 2008), although by 2010 the values are converging. No data on the forecasting methodology used by ABARE has been obtained for this project.

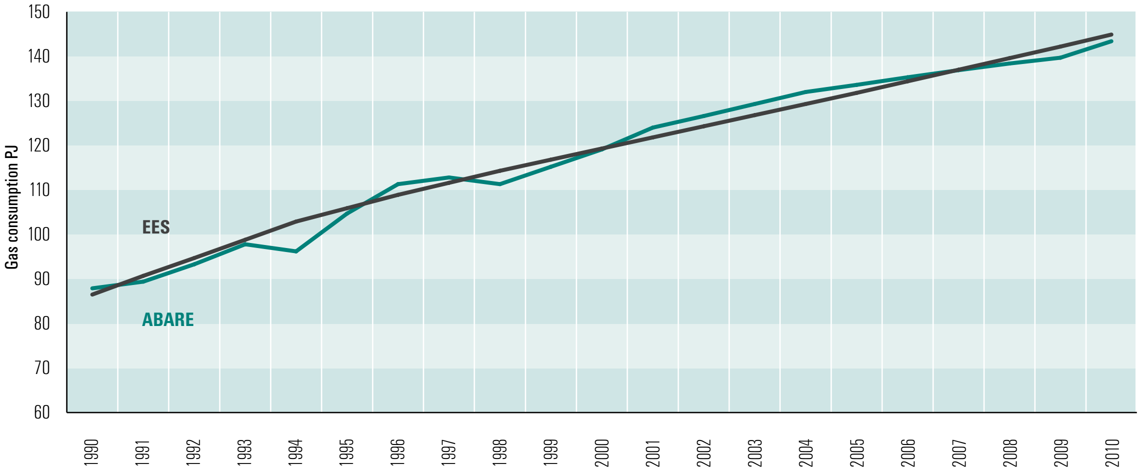
Figure 6: EES and ABARE electricity projections 1990–2010



The EES gas projections could be improved with better data from Australian Gas Association regarding forecast expansions in the supply system by state and saturation levels of gas appliance ownership. Unfortunately, this data was not available during the analysis for the project and we have had to rely on state based trend data on penetration. Note that the ABARE gas forecast is the one published in ABARE (1997). The EES projections and the ABARE forecasts are extremely close right through the period 1990 to 2010. It is unclear why actual natural gas consumption was low in 1994. Victorian gas penetration is now close to saturation, except perhaps for some water heating. Actual consumption of gas, and to a lesser extent, electricity is subject to considerable year to year variation from the trend line due to variations in actual heating requirements which are weather dependent.

Model projections for LPG are slightly below ABARE estimates for all states, but there are likely to be other end uses for LPG which are not tracked by the EES model (eg camping equipment, absorption refrigeration, limited lighting, barbques etc.).

Figure 7: EES and ABARE natural gas projections 1990–2010



2.4 Business as usual projections

Note that the energy and emission values quoted in the following tables and figures include only EES estimates and projections for the 4 main residential fuels: electricity, natural gas, LPG and wood.

2.4.1 BAU+ residential totals by state

Total business as usual *with* measures (BAU+) energy projections by state from 1990 to 2010 are shown in Table 2.

Total business as usual *with* measures (BAU+) greenhouse gas emissions by state from 1990 to 2010 are shown in Table 3 and for 2010 in Figure 8.

NSW and Victoria are expected to dominate greenhouse gas emissions in 2010, accounting for some 64 per cent of the national residential total. Queensland is the next most significant with 17 per cent.

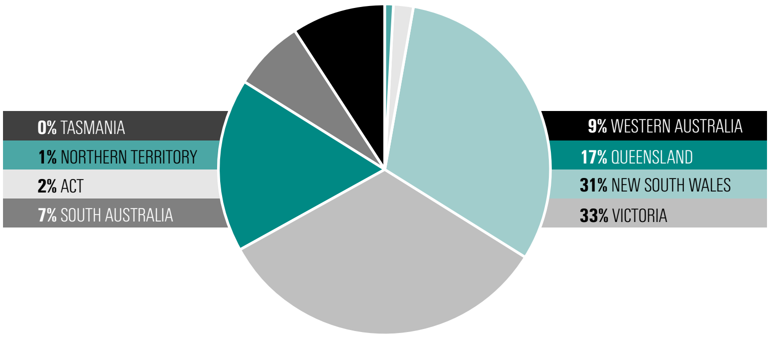
Table 2: BAU+ total residential energy consumption by state 1990–2010

Year	Total energy PJ NSW	Total energy PJ VIC	Total energy PJ QLD	Total energy PJ SA	Total energy PJ WA	Total energy PJ TAS	Total energy PJ NT	Total energy PJ ACT	Total energy PJ Australia
1990	75.8	107.8	27.0	20.9	20.1	12.7	1.4	4.8	270.4
1991	77.4	111.3	27.9	21.3	21.0	13.1	1.4	5.1	278.5
1992	79.3	114.4	28.9	21.7	21.9	13.4	1.5	5.4	286.3
1993	81.1	117.4	29.9	22.1	22.8	13.7	1.5	5.6	294.1
1994	83.0	120.4	30.9	22.4	23.8	14.0	1.5	5.9	301.9
1995	84.9	122.5	31.9	22.8	24.6	14.2	1.6	6.1	308.5
1996	86.8	124.6	33.0	23.1	25.5	14.5	1.6	6.2	315.3
1997	88.5	126.3	33.9	23.4	26.2	14.6	1.7	6.4	321.0
1998	89.9	128.2	34.6	23.6	27.0	14.7	1.7	6.5	326.2
1999	91.3	129.8	35.3	23.8	27.7	14.7	1.8	6.6	331.2
2000	92.6	131.2	36.0	24.0	28.4	14.8	1.8	6.7	335.6
2001	93.8	132.6	36.7	24.2	29.1	14.8	1.9	6.9	339.9
2002	95.0	133.9	37.3	24.4	29.8	14.9	1.9	7.0	344.2
2003	96.2	135.3	38.0	24.6	30.6	14.9	2.0	7.1	348.6
2004	97.4	136.6	38.6	24.7	31.3	15.0	2.0	7.2	352.9
2005	98.7	138.0	39.3	24.9	32.0	15.0	2.0	7.3	357.3
2006	99.9	139.3	40.0	25.1	32.8	15.1	2.1	7.5	361.7
2007	101.1	140.6	40.6	25.2	33.6	15.1	2.1	7.6	366.0
2008	102.4	141.9	41.3	25.4	34.3	15.1	2.2	7.7	370.5
2009	103.6	143.3	42.0	25.6	35.1	15.2	2.2	7.9	374.9
2010	104.9	144.6	42.7	25.7	35.9	15.2	2.3	8.0	379.3

Table 3: BAU+ total residential greenhouse gas emissions by state 1990–2010

Year	Total MTCO$_2$-e NSW	Total MTCO$_2$-e VIC	Total MTCO$_2$-e QLD	Total MTCO$_2$-e SA	Total MTCO$_2$-e WA	Total MTCO$_2$-e TAS	Total MTCO$_2$-e NT	Total MTCO$_2$-e ACT	Total MTCO$_2$-e Australia
1990	16.8	16.5	6.9	3.5	3.6	0.3	0.3	0.9	48.6
1991	16.8	16.8	7.1	3.6	3.7	0.2	0.3	0.9	49.3
1992	16.8	17.1	7.3	3.7	8	0.2	0.3	0.9	50.1
1993	16.8	17.3	7.5	3.8	3.9	0.2	0.3	0.9	50.8
1994	16.8	17.6	7.8	3.9	4.0	0.2	0.3	1.0	51.6
1995	16.8	17.8	8.0	4.0	4.1	0.2	0.3	1.0	52.2
1996	17.0	18.0	8.2	4.1	4.2	0.2	0.3	1.0	53.0
1997	17.2	18.1	8.4	4.1	4.2	0.2	0.4	1.0	53.6
1998	17.3	18.3	8.6	4.1	4.3	0.2	0.4	1.0	54.0
1999	17.4	18.4	8.7	4.1	4.4	0.2	0.4	1.0	54.5
2000	17.4	18.5	8.8	4.1	4.4	0.2	0.4	1.0	54.8
2001	17.4	18.6	8.9	4.1	4.5	0.2	0.4	1.0	55.0
2002	17.4	18.7	9.0	4.1	4.5	0.2	0.4	1.0	55.3
2003	17.5	18.7	9.0	4.1	4.6	0.2	0.4	1.0	55.5
2004	17.5	18.8	9.1	4.1	4.6	0.2	0.4	1.0	55.7
2005	17.5	18.9	9.2	4.1	4.6	0.2	0.4	1.0	55.9
2006	17.5	18.9	9.3	4.1	4.7	0.2	0.4	1.0	56.1
2007	17.5	19.0	9.4	4.1	4.7	0.2	0.4	1.0	56.2
2008	17.5	19.0	9.5	4.1	4.8	0.2	0.4	1.0	56.4
2009	17.4	19.0	9.5	4.1	4.8	0.2	0.5	1.0	56.5
2010	17.4	19.1	9.6	4.1	4.9	0.1	0.5	1.0	56.7

Figure 8: BAU+ greenhouse emissions by state in 2010



2.4.2 BAU+ residential totals by fuel

Total business as usual *with* measures (BAU+) energy consumption by fuel from 1990 to 2010 is shown in Table 4.

Table 4: BAU+ total residential energy consumption by fuel 1990–2010

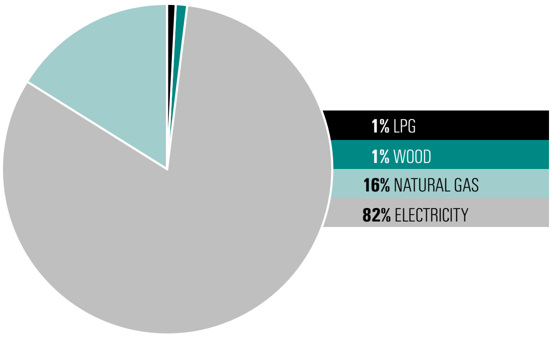
Year	Electricity PJ	Natural gas PJ	LPG PJ	Wood PJ
1990	140.0	86.5	7.1	36.8
1991	142.6	90.7	7.3	37.9
1992	145.3	94.7	7.4	38.9
1993	147.9	98.8	7.5	40.0
1994	150.4	102.9	7.5	41.1
1995	152.9	105.9	7.7	42.0
1996	155.5	108.9	8.0	42.9
1997	157.7	111.6	8.1	43.7
1998	159.4	114.3	8.3	44.3
1999	161.0	116.8	8.4	45.0
2000	162.2	119.3	8.5	45.5
2001	163.4	121.8	8.6	46.1
2002	164.6	124.3	8.7	46.6
2003	165.7	126.8	8.9	47.2
2004	166.9	129.3	9.0	47.8
2005	168.0	131.8	9.1	48.4
2006	169.2	134.4	9.2	49.0
2007	170.3	137.0	9.2	49.5
2008	171.4	139.6	9.3	50.1
2009	172.6	142.2	9.4	50.6
2010	173.7	144.9	9.5	51.2

Total business as usual *with* measures (BAU+) greenhouse gas emissions by fuel from 1990 to 2010 are shown in Table 5 and for 2010 in Figure 9.

Table 5: BAU+ total residential greenhouse gas emissions by fuel 1990–2010

Year	Electricity MT CO_2-e	Natural gas MT CO_2-e	LPG MT CO_2-e	Wood MT CO_2-e
1990	41.9	5.5	0.5	0.7
1991	42.3	5.8	0.5	0.8
1992	42.8	6.0	0.5	0.8
1993	43.3	6.3	0.5	0.8
1994	43.7	6.5	0.5	0.8
1995	44.2	6.7	0.5	0.8
1996	44.8	6.9	0.5	0.8
1997	45.2	7.1	0.5	0.8
1998	45.5	7.3	0.6	0.8
1999	45.7	7.4	0.6	0.7
2000	45.9	7.6	0.6	0.7
2001	46.0	7.7	0.6	0.7
2002	46.0	7.9	0.6	0.7
2003	46.1	8.1	0.6	0.7
2004	46.2	8.2	0.6	0.7
2005	46.3	8.4	0.6	0.7
2006	46.3	8.5	0.6	0.7
2007	46.3	8.7	0.6	0.7
2008	46.2	8.9	0.6	0.6
2009	46.2	9.0	0.6	0.6
2010	46.2	9.2	0.6	0.6

Figure 9: BAU+ greenhouse gas emissions by fuel in 2010



Electricity is expected to dominate greenhouse gas emissions in the residential sector in 2010.

2.4.3 BAU+ residential totals by end use

Total business as usual *with* measures (BAU+) energy consumption by major end use from 1990 to 2010 is shown in Table 6.

Table 6: BAU+ total residential energy consumption by end use 1990–2010

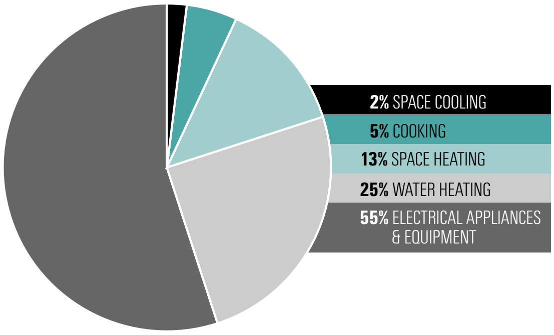
Year	Electricial appliances PJ	Water heating PJ	Cooking PJ	Space heating and cooling PJ
1990	81.6	78.5	11.7	98.6
1991	83.8	79.8	12.0	102.9
1992	86.1	81.2	12.4	106.6
1993	88.4	82.6	12.7	110.4
1994	90.6	83.9	13.1	114.3
1995	92.4	85.2	13.5	117.3
1996	94.4	86.6	13.9	120.4
1997	96.1	87.7	14.2	123.0
1998	97.5	88.6	14.6	125.6
1999	98.8	89.5	14.9	128.0
2000	100.0	90.1	15.2	130.2
2001	101.2	90.7	15.5	132.4
2002	102.4	91.3	15.8	134.6
2003	103.6	91.9	16.1	136.9
2004	104.8	92.5	16.4	139.1
2005	106.1	93.2	16.7	141.3
2006	107.3	93.9	17.0	143.5
2007	108.5	94.6	17.3	145.7
2008	109.7	95.3	17.5	148.0
2009	110.9	96.0	17.8	150.2
2010	112.2	96.7	18.0	152.4

Total business as usual *with* measures (BAU+) greenhouse gas emissions by major end use from 1990 to 2010 are shown in Table 7.

Table 7: BAU+ total residential greenhouse gas emissions by end use 1990–2010

Year	Electricial appliances MT CO_2-e	Water heating MT CO_2-e	Cooking MT CO_2-e	Space heating MT CO_2-e
1990	81.6	78.5	11.7	98.6
1990	24.8	15.3	2.2	6.3
1991	25.3	15.3	2.2	6.6
1992	25.8	15.3	2.3	6.7
1993	26.3	15.2	2.3	6.9
1994	26.8	15.2	2.4	7.1
1995	27.2	15.3	2.5	7.3
1996	27.7	15.3	2.5	7.4
1997	28.0	15.4	2.6	7.6
1998	28.3	15.3	2.6	7.7
1999	28.6	15.3	2.7	7.8
2000	28.8	15.2	2.7	7.9
2001	29.0	15.1	2.8	8.1
2002	29.2	15.0	2.8	8.2
2003	29.4	14.9	2.9	8.3
2004	29.6	14.8	2.9	8.3
2005	29.8	14.8	3.0	8.4
2006	29.9	14.7	3.0	8.5
2007	30.1	14.6	3.0	8.6
2008	30.2	14.5	3.0	8.7
2009	30.3	14.4	3.1	8.8
2010	30.5	14.3	3.1	8.9

Figure 10: BAU+ greenhouse gas emissions by end use 2010



Electrical appliances and equipment are expected to dominate greenhouse gas emissions in 2010, accounting for some 55 per cent of the national residential total. Water heating and space heating are the next most significant with 25 per cent and 13 per cent respectively. Cooking and space cooling account for only 5 per cent and 2 per cent respectively.

2.4.4 BAU+ space heating and cooling by state

Business as usual *with* measures (BAU+) greenhouse gas emissions for electric heating and electric cooling by state are shown in Table 8 and Table 9.

Table 8: BAU+ electric space heating greenhouse gas emissions by state 1990–2010

Year	Total MTCO$_2$-e NSW	Total MTCO$_2$-e VIC	Total MTCO$_2$-e QLD	Total MTCO$_2$-e SA	Total MTCO$_2$-e WA	Total MTCO$_2$-e TAS	Total MTCO$_2$-e NT	Total MTCO$_2$-e ACT	Total MTCO$_2$-e Australia
1990	0.5	0.5	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1991	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1992	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1993	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1994	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
1995	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
1996	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
1997	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1998	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.2
1999	0.5	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
2000	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
2001	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
2002	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	1.1
2003	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.1
2004	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.1
2005	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.1
2006	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.1
2007	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.0
2008	0.4	0.3	0.1	0.1	0.0	0.0	0.0	0.0	1.0
2009	0.4	0.3	0.1	0.1	0.0	0.0	0.0	0.0	1.0
2010	0.4	0.3	0.1	0.1	0.0	0.0	0.0	0.0	1.0

Table 9: BAU+ electric space cooling greenhouse gas emissions by state 1990–2010

Year	Total MTCO$_2$-e NSW	Total MTCO$_2$-e VIC	Total MTCO$_2$-e QLD	Total MTCO$_2$-e SA	Total MTCO$_2$-e WA	Total MTCO$_2$-e TAS	Total MTCO$_2$-e NT	Total MTCO$_2$-e ACT	Total MTCO$_2$-e Australia
1990	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.0	0.9
1991	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.0	0.9
1992	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.0	0.9
1993	0.3	0.2	0.2	0.1	0.1	0.0	0.1	0.0	1.0
1994	0.3	0.2	0.2	0.1	0.1	0.0	0.1	0.0	1.0
1995	0.3	0.2	0.3	0.1	0.1	0.0	0.1	0.0	1.0
1996	0.3	0.2	0.3	0.1	0.1	0.0	0.1	0.0	1.1
1997	0.3	0.2	0.3	0.1	0.2	0.0	0.1	0.0	1.1
1998	0.3	0.2	0.3	0.1	0.2	0.0	0.1	0.0	1.1
1999	0.3	0.2	0.3	0.1	0.2	0.0	0.1	0.0	1.2
2000	0.3	0.2	0.3	0.2	0.2	0.0	0.1	0.0	1.2
2001	0.3	0.2	0.3	0.2	0.2	0.0	0.1	0.0	1.2
2002	0.3	0.2	0.3	0.2	0.2	0.0	0.1	0.0	1.2
2003	0.3	0.2	0.3	0.2	0.2	0.0	0.1	0.0	1.3
2004	0.3	0.2	0.3	0.2	0.2	0.0	0.1	0.0	1.3
2005	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.3
2006	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.3
2007	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.3
2008	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.4
2009	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.4
2010	0.3	0.2	0.4	0.2	0.2	0.0	0.1	0.0	1.4

Business as usual *with* measures (BAU+) greenhouse gas emissions for natural gas space heating by state are shown in Table 10.

Table 10: BAU+ natural gas space heating greenhouse gas emissions by state 1990–2010

Year	Total MTCO$_2$-e NSW	Total MTCO$_2$-e VIC	Total MTCO$_2$-e QLD	Total MTCO$_2$-e SA	Total MTCO$_2$-e WA	Total MTCO$_2$-e TAS	Total MTCO$_2$-e NT	Total MTCO$_2$-e ACT	Total MTCO$_2$-e Australia
1990	0.2	2.8	0.0	0.1	0.1	0.0	0.0	0.0	3.3
1991	0.2	3.0	0.0	0.1	0.1	0.0	0.0	0.1	3.4
1992	0.2	3.1	0.0	0.1	0.1	0.0	0.0	0.1	3.6
1993	0.2	3.2	0.0	0.1	0.1	0.0	0.0	0.1	3.8
1994	0.3	3.3	0.0	0.1	0.1	0.0	0.0	0.1	4.0
1995	0.3	3.4	0.0	0.1	0.1	0.0	0.0	0.1	4.1
1996	0.3	3.5	0.0	0.1	0.1	0.0	0.0	0.1	4.2
1997	0.3	3.5	0.0	0.1	0.2	0.0	0.0	0.1	4.3
1998	0.3	3.6	0.0	0.1	0.2	0.0	0.0	0.1	4.4
1999	0.4	3.7	0.0	0.1	0.2	0.0	0.0	0.1	4.5
2000	0.4	3.7	0.0	0.2	0.2	0.0	0.0	0.1	4.6
2001	0.4	3.8	0.0	0.2	0.2	0.0	.0	0.1	4.7
2002	0.4	3.8	0.0	0.2	0.2	0.0	0.0	0.1	4.8
2003	0.4	3.9	0.0	0.2	0.2	0.0	0.0	0.2	4.8
2004	0.5	3.9	0.0	0.2	0.2	0.0	0.0	0.2	4.9
2005	0.5	4.0	0.0	0.2	0.3	0.0	0.0	0.2	5.0
2006	0.5	4.0	0.0	0.2	0.3	0.0	0.0	0.2	5.1
2007	0.5	4.1	0.0	0.2	0.3	0.0	0.0	0.2	5.2
2008	0.5	4.1	0.0	0.2	0.3	0.0	0.0	0.2	5.3
2009	0.6	4.2	0.0	0.2	0.3	0.0	0.0	0.2	5.4
2010	0.6	4.2	0.0	0.2	0.3	0.0	0.0	0.2	5.5

2.4.5 BAU+ space heating and cooling by fuel

Total business as usual *with* measures (BAU+) energy consumption for space heating and cooling by fuel 1990 to 2010 is shown in Table 11.

Table 11: BAU+ space heating and cooling energy consumption by fuel 1990–2010

Year	Electricity PJ	Natural gas PJ	LPG PJ	Wood PJ
1990	7.1	51.2	3.6	36.8
1991	7.1	54.1	3.7	37.9
1992	7.2	56.7	3.8	38.9
1993	7.3	59.3	3.8	40.0
1994	7.3	62.1	3.8	41.1
1995	7.5	63.9	4.0	42.0
199	7.7	65.6	4.1	42.9
1997	7.9	67.2	4.2	43.7
1998	8.1	68.8	4.3	44.3
1999	8.2	70.4	4.4	45.0
2000	8.4	71.8	4.5	45.5
2001	8.5	73.3	4.6	46.1
2002	8.6	74.7	4.7	46.6
2003	8.7	76.2	4.8	47.2
2004	8.8	77.6	4.9	47.8
2005	8.9	79.1	5.0	48.4
2006	8.9	80.6	5.0	49.0
2007	9.0	82.1	5.1	49.5
2008	9.0	83.6	5.2	50.1
2009	9.1	85.2	5.3	50.6
2010	9.1	86.8	5.4	51.2

Heating and cooling business as usual *with* measures (BAU+) greenhouse gas emissions by fuel from 1990 to 2010 are shown in Table 12. Emissions from electricity are about 60 per cent to 80 per cent of those from natural gas emissions, even though the primary energy for gas is a factor of 6 times higher. This is because greenhouse gas intensities for electricity production based on coal are very high relative to natural gas.

Table 12: BAU+ space heating and cooling greenhouse gas emissions by fuel 1990–2010

Year	Electricity MT CO_2-e	Natural gas MT CO_2-e	LPG MT CO_2-e	Wood MT CO_2-e
1990	2.1	3.3	0.2	0.7
1991	2.1	3.4	0.3	0.8
1992	2.1	3.6	0.3	0.8
1993	2.1	3.8	0.3	0.8
1994	2.1	4.0	0.3	0.8
1995	2.2	4.1	0.3	0.8
1996	2.2	4.2	0.3	0.8
1997	2.2	4.3	0.3	0.8
1998	2.3	4.4	0.3	0.8
1999	2.3	4.5	0.3	0.7
2000	2.3	4.6	0.3	0.7
2001	2.4	4.7	0.3	0.7
2002	2.4	4.8	0.3	0.7
2003	2.4	4.8	0.3	0.7
2004	2.4	4.9	0.3	0.7
2005	2.4	5.0	0.3	0.7
2006	2.4	5.1	0.3	0.7
2007	2.4	5.2	0.3	0.7
2008	2.4	5.3	0.3	0.6
2009	2.4	5.4	0.4	0.6
2010	2.4	5.5	0.4	0.6

2.5 Building shell scenarios

Four building shell projection scenarios were modelled to estimate the impact on changes in building shell thermal performance on residential energy consumption.

The population, household size and non-heating/cooling energy use assumptions (ie BAU+ for appliance characteristics and performance) were common to all four — the differences lie in the assumptions about change in the thermal performance of the dwelling stock, and the consequent impacts on heating and cooling energy requirements. An additional hypothetical scenario (BAU-) has been developed to estimate the impact of those residential programs introduced from 1990 to 1997.

As discussed above, BAU+ and BAU- both include energy labelling for appliances.

The projection scenarios are:

1. BAU+ (business-as-usual *with* measures) — this assumes that dwellings continue to be constructed to the standards prevailing today, including existing or agreed minimum standards where applicable: eg minimum building insulation standards in Victoria and 4 star ACTHERS energy rating in ACT. MEPS for refrigerators, freezers and electric storage water heaters are also included in this scenario;

2. BAU- (business-as-usual *without* measures) — as for BAU+, but excluding those program measures that were introduced or announced during the period 1990 to November 1997;

3. ME (Medium Efficiency) — as for BAU+ with the addition of a 3.5 star effective minimum building shell requirement (as defined in the NatHERS model) for all new dwellings in all states (similar to the SEDA “Smart Homes” program) from 2000;

4. HE (High Efficiency) — as for BAU+ with the addition of a 5 star effective minimum building shell requirement (as defined in the NatHERS model) for all new dwellings in all states from 2000;

5. HE+ (High Efficiency Plus) — as for HE for new dwellings, but also assumes that the thermal performance of *existing* dwellings is improved by an aggressive ceiling insulation retrofit program.

The heating and cooling energy required under each scenario is calculated as follows:

- the unconstrained[6] heating/cooling demand is calculated from the characteristics of the building stock using the NatHERS model for the known range of construction types and climate types.
- it is assumed that the constraint ratios calculated for the years 1990 to 1997 persist: ie if the unconstrained heating demand in a State doubles, the constrained heating/cooling demand also doubles.
- the constrained demand must then be met by a combination of energy forms and system types that is common to all scenarios given projected penetrations or main heating types at the state level.

It would appear from the modelling undertaken for this study that many householders are accepting standards of thermal comfort that are significantly lower than those used in NatHERS. This may be because the dwellings are simply too difficult and/or expensive to heat or cool adequately, but it should be recognised that thermal comfort requirements and occupancy levels can vary considerably. As the thermal performance of the building stock improves, householders in more efficient homes may decide to take some of the potential energy savings as increased thermal comfort rather than as reduced energy consumption. This is quite difficult to model and there is little data to confirm or otherwise the extent of this effect in Australia. There is some documentation regarding this effect in Europe and the United States within particular segments (typically for low income households), but this data is unlikely to translate to Australia given the different climatic and cultural aspects.

However, given the high level of constraint of both heating and cooling demands in Australia, small changes in user behaviour would have a large impact on heating and cooling energy. Benefits still accrue from improvements in the building shell, but these may not occur in the form directly intended (eg in the form of improved comfort instead of greenhouse gas emission reductions). Conversely, there is some evidence that improvements in building shell thermal performance may result in the occupants avoiding the installation of space conditioning equipment (typically cooling equipment) which they may have otherwise chosen to install in a building with poorer thermal performance. These possibilities need to be considered when assessing the quantitative data in this report.

Energy consumption under all 5 scenarios from 1990 to 2010 is shown in Table 13.

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[6] The term “unconstrained” refers to the theoretical energy consumption required to maintain a house at comfortable conditions all year (assuming space heating and cooling equipment is installed). This “unconstrained” energy then has to be “constrained” to more accurately reflect actual energy used by typical households for heating and cooling. These terms are explained in more detail in the chapter on building shells.

Table 13: Total energy consumption 1990–2010 — 5 building shell scenarios

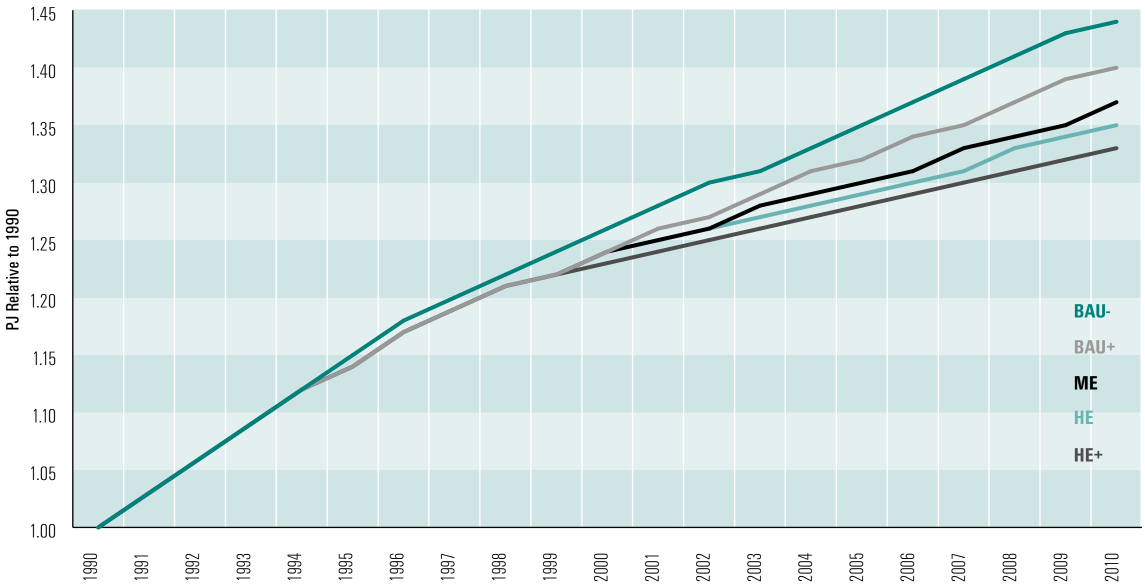
Year	BAU- PJ	BAU+ PJ	ME PJ	HE PJ	HE+ PJ
1990	270.4	270.4	270.4	270.4	270.4
1991	278.5	278.5	278.5	278.5	278.5
1992	286.8	286.3	286.3	286.3	286.3
1993	295.0	294.1	294.1	294.1	294.1
1994	303.3	301.9	301.9	301.9	301.9
1995	310.4	308.5	308.5	308.5	308.5
1996	317.8	315.3	315.3	315.3	315.3
1997	323.9	321.0	321.0	321.0	321.0
1998	329.6	326.2	326.2	326.2	326.2
1999	335.0	331.2	331.2	331.2	331.2
2000	340.2	335.6	334.6	334.2	333.3
2001	345.3	339.9	338.0	337.2	335.4
2002	350.4	344.2	341.4	340.1	337.7
2003	355.5	348.6	344.8	343.1	340.0
2004	360.6	352.9	348.3	346.1	342.4
2005	365.6	357.3	351.7	349.2	345.0
2006	370.7	361.7	355.2	352.2	347.6
2007	375.7	366.0	358.7	355.3	350.2
2008	380.7	370.5	362.2	358.4	353.0
2009	385.7	374.9	365.8	361.5	355.8
2010	390.7	379.3	369.3	364.6	358.6

Table 14: Energy consumption relative to 1990 — 5 building shell scenarios

Year	BAU-	BAU+	ME	HE	HE+
1990	1.00	1.00	1.00	1.00	1.00
1991	1.03	1.03	1.03	1.03	1.03
1992	1.06	1.06	1.06	1.06	1.06
1993	1.09	1.09	1.09	1.09	1.09
1994	1.12	1.12	1.12	1.12	1.12
1995	1.15	1.14	1.14	1.14	1.14
1996	1.18	1.17	1.17	1.17	1.17
1997	1.20	1.19	1.19	1.19	1.19
1998	1.22	1.21	1.21	1.21	1.21
1999	1.24	1.22	1.22	1.22	1.22
2000	1.26	1.24	1.24	1.24	1.23
2001	1.28	1.26	1.25	1.25	1.24
2002	1.30	1.27	1.26	1.26	1.25
2003	1.31	1.29	1.28	1.27	1.26
2004	1.33	1.31	1.29	1.28	1.27
2005	1.35	1.32	1.30	1.29	1.28
2006	1.37	1.34	1.31	1.30	1.29
2007	1.39	1.35	1.33	1.31	1.30
2008	1.41	1.37	1.34	1.33	1.31
2009	1.43	1.39	1.35	1.34	1.32
2010	1.44	1.40	1.37	1.35	1.33

Energy consumption for each of the five scenarios relative to 1990 is shown in Table 14 and Figure 11.

Figure 11: Energy consumption relative to 1990 — 5 building shell scenarios



Greenhouse gas emissions under all 5 scenarios from 1990 to 2010 are shown in Table 15 and emissions relative to 1990 levels are shown in Table 16 and Figure 12.

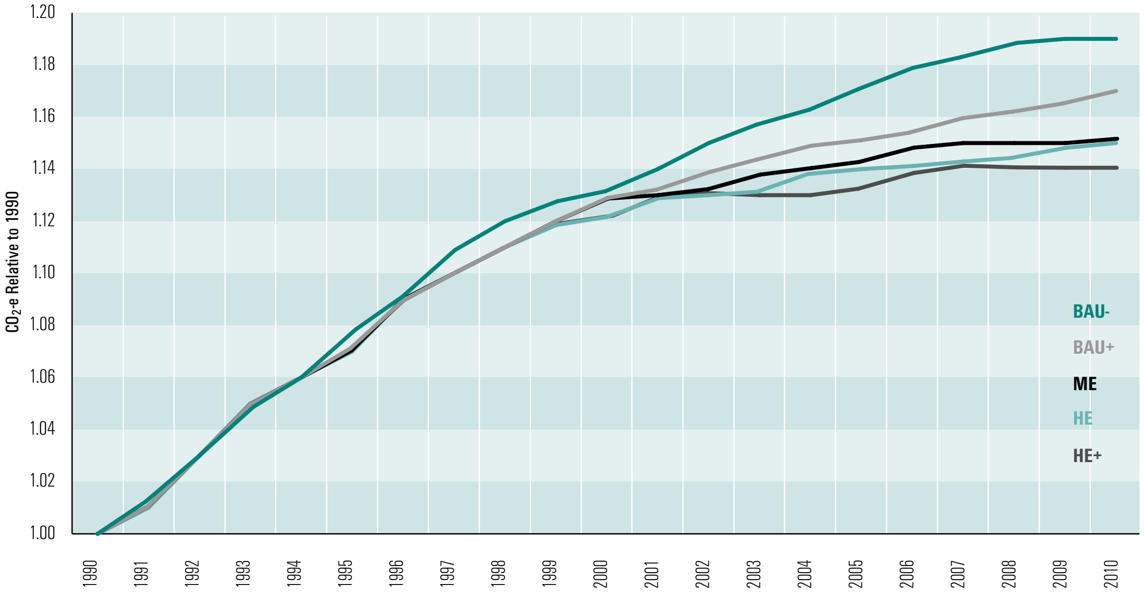
Table 15: Total greenhouse gas emissions 1990–2010 — 5 building shell scenarios

Year	BAU- MTCO$_2$-e	BAU+ MTCO$_2$-e	ME MTCO$_2$-e	HE MTCO$_2$-e	HE+ MTCO$_2$-e
1990	48.6	48.6	48.6	48.6	48.6
1991	49.3	49.3	49.3	49.3	49.3
1992	50.1	50.1	50.1	50.1	50.1
1993	50.9	50.8	50.8	50.8	50.8
1994	51.6	51.6	51.6	51.6	51.6
1995	52.3	52.2	52.2	52.2	52.2
1996	53.1	53.0	53.0	53.0	53.0
1997	53.7	53.6	53.6	53.6	53.6
1998	54.2	54.0	54.0	54.0	54.0
1999	54.7	54.5	54.5	54.5	54.5
2000	55.1	54.8	54.7	54.7	54.6
2001	55.5	55.0	54.9	54.8	54.7
2002	55.9	55.3	55.1	55.0	54.8
2003	56.2	55.5	55.2	55.1	54.9
2004	56.6	55.7	55.4	55.3	55.1
2005	56.9	55.9	55.6	55.4	55.2
2006	57.2	56.1	55.7	55.5	55.2
2007	57.4	56.2	55.8	55.6	55.3
2008	57.6	56.4	55.9	55.7	55.3
2009	57.9	56.5	56.0	55.7	55.4
2010	58.1	56.7	56.1	55.8	55.4

Table 16: Total greenhouse gas emissions relative to 1990 — 5 building shell scenarios

Year	BAU-	BAU+	ME	HE	HE+
1990	1.00	1.00	1.00	1.00	1.00
1991	1.01	1.01	1.01	1.01	1.01
1992	1.03	1.03	1.03	1.03	1.03
1993	1.05	1.05	1.05	1.05	1.05
1994	1.06	1.06	1.06	1.06	1.06
1995	1.08	1.07	1.07	1.07	1.07
1996	1.09	1.09	1.09	1.09	1.09
1997	1.11	1.10	1.10	1.10	1.10
1998	1.12	1.11	1.11	1.11	1.11
1999	1.13	1.12	1.12	1.12	1.12
2000	1.13	1.13	1.13	1.12	1.12
2001	1.14	1.13	1.13	1.13	1.13
2002	1.15	1.14	1.13	1.13	1.13
2003	1.16	1.14	1.14	1.13	1.13
2004	1.16	1.15	1.14	1.14	1.13
2005	1.17	1.15	1.14	1.14	1.13
2006	1.18	1.15	1.15	1.14	1.14
2007	1.18	1.16	1.15	1.14	1.14
2008	1.19	1.16	1.15	1.14	1.14
2009	1.19	1.16	1.15	1.15	1.14
2010	1.19	1.17	1.15	1.15	1.14

Figure 12: Total greenhouse gas emissions relative to 1990 – 5 building shell scenarios



Heating and cooling energy and greenhouse gas emissions are shown in Table 17 to Table 20.

Table 17: Heating and cooling energy consumption 1990–2010 — 5 building shell scenarios

Year	BAU- PJ	BAU+ PJ	ME PJ	HE PJ	HE+ PJ
1990	98.6	98.6	98.6	98.6	98.6
1991	102.9	102.9	102.9	102.9	102.9
1992	107.1	106.6	106.6	106.6	106.6
1993	111.3	110.4	110.4	110.4	110.4
1994	115.7	114.3	114.3	114.3	114.3
1995	119.2	117.3	117.3	117.3	117.3
1996	122.8	120.4	120.4	120.4	120.4
1997	125.9	123.0	123.0	123.0	123.0
1998	129.0	125.6	125.6	125.6	125.6
1999	131.8	128.0	128.0	128.0	128.0
2000	134.5	130.2	129.3	128.9	128.0
2001	137.1	132.4	130.5	129.7	128.0
2002	139.7	134.6	131.8	130.5	128.1
2003	142.3	136.9	133.1	131.4	128.3
2004	144.9	139.1	134.4	132.3	128.6
2005	147.4	141.3	135.7	133.2	129.0
2006	150.0	143.5	137.1	134.1	129.4
2007	152.6	145.7	138.4	135.0	129.9
2008	155.2	148.0	139.7	135.9	130.5
2009	157.7	150.2	141.1	136.8	131.1
2010	160.3	152.4	142.4	137.7	131.7

Table 18: Heating and cooling energy relative to 1990 — 5 building shell scenarios

Year	BAU-	BAU+	ME	HE	HE+
1990	1.00	1.00	1.00	1.00	1.00
1991	1.04	1.04	1.04	1.04	1.04
1992	1.09	1.08	1.08	1.08	1.08
1993	1.13	1.12	1.12	1.12	1.12
1994	1.17	1.16	1.16	1.16	1.16
1995	1.21	1.19	1.19	1.19	1.19
1996	1.25	1.22	1.22	1.22	1.22
1997	1.28	1.25	1.25	1.25	1.25
1998	1.31	1.27	1.27	1.27	1.27
1999	1.34	1.30	1.30	1.30	1.30
2000	1.36	1.32	1.31	1.31	1.30
2001	1.39	1.34	1.32	1.31	1.30
2002	1.42	1.36	1.34	1.32	1.30
2003	1.44	1.39	1.35	1.33	1.30
2004	1.47	1.41	1.36	1.34	1.30
2005	1.49	1.43	1.38	1.35	1.31
2006	1.52	1.45	1.39	1.36	1.31
2007	1.55	1.48	1.40	1.37	1.32
2008	1.57	1.50	1.42	1.38	1.32
2009	1.60	1.52	1.43	1.39	1.33
2010	1.62	1.55	1.44	1.40	1.34

Table 19: Heating and cooling greenhouse emissions 1990–2010 — 5 building shell scenarios

Year	BAU- MTCO$_2$-e	BAU+ MTCO$_2$-e	ME MTCO$_2$-e	HE MTCO$_2$-e	HE+ MTCO$_2$-e
1990	48.6	48.6	48.6	48.6	48.6
1990	6.35	6.35	6.35	6.35	6.35
1991	6.55	6.55	6.55	6.55	6.55
1992	6.75	6.73	6.73	6.73	6.73
1993	6.96	6.91	6.91	6.91	6.91
1994	7.17	7.09	7.09	7.09	7.09
1995	7.37	7.25	7.25	7.25	7.25
1996	7.58	7.42	7.42	7.42	7.42
1997	7.75	7.57	7.57	7.57	7.57
1998	7.91	7.70	7.70	7.70	7.70
1999	8.07	7.83	7.83	7.83	7.83
2000	8.21	7.95	7.88	7.86	7.80
2001	8.34	8.05	7.93	7.88	7.77
2002	8.46	8.15	7.97	7.90	7.74
2003	8.58	8.25	8.01	7.91	7.72
2004	8.70	8.35	8.05	7.93	7.70
2005	8.81	8.44	8.08	7.94	7.68
2006	8.92	8.52	8.11	7.94	7.66
2007	9.02	8.61	8.14	7.95	7.64
2008	9.12	8.69	8.17	7.96	7.63
2009	9.22	8.77	8.20	7.96	7.62
2010	9.32	8.85	8.23	7.97	7.61

Table 20: Heating and cooling emissions relative to 1990 — 5 building shell scenarios

Year	BAU-	BAU+	ME	HE	HE+
1990	1.00	1.00	1.00	1.00	1.00
1991	1.03	1.03	1.03	1.03	1.03
1992	1.06	1.06	1.06	1.06	1.06
1993	1.10	1.09	1.09	1.09	1.09
1994	1.13	1.12	1.12	1.12	1.12
1995	1.16	1.14	1.14	1.14	1.14
1996	1.19	1.17	1.17	1.17	1.17
1997	1.22	1.19	1.19	1.19	1.19
1998	1.25	1.21	1.21	1.21	1.21
1999	1.27	1.23	1.23	1.23	1.23
2000	1.29	1.25	1.24	1.24	1.23
2001	1.31	1.27	1.25	1.24	1.22
2002	1.33	1.28	1.26	1.24	1.22
2003	1.35	1.30	1.26	1.25	1.22
2004	1.37	1.31	1.27	1.25	1.21
2005	1.39	1.33	1.27	1.25	1.21
2006	1.40	1.34	1.28	1.25	1.21
2007	1.42	1.36	1.28	1.25	1.20
2008	1.44	1.37	1.29	1.25	1.20
2009	1.45	1.38	1.29	1.25	1.20
2010	1.47	1.39	1.30	1.26	1.20

2.6 Cooking energy

Cooking energy is supplied roughly equally by gas and electric, although gas cooktops and electric ovens are both increasing in penetration, while gas ovens and electric cooktops are falling from favour. Ovens probably use a little more than half of the energy required for cooking in Australia. In 2010, electricity is expected to dominate greenhouse gas emissions from cooking appliances with over 80 per cent. Overall cooking energy use is small in comparison with other end uses and is shown by fuel in Table 21. Emissions by fuel for cooking are shown in Table 22.

Table 21: BAU+ cooking energy by fuel 1990–2010

Year	Electricity PJ	Natural gas PJ	LPG PJ
1990	6.3	4.6	0.9
1991	6.5	4.7	0.8
1992	6.7	4.9	0.8
1993	6.9	5.0	0.8
1994	7.1	5.2	0.8
1995	7.3	5.3	0.8
1996	7.6	5.5	0.8
1997	7.8	5.6	0.8
1998	8.0	5.7	0.9
1999	8.2	5.8	0.9
2000	8.4	6.0	0.9
2001	8.6	6.1	0.9
2002	8.7	6.2	0.9
2003	8.9	6.3	0.9
2004	9.1	6.5	0.9
2005	9.2	6.6	0.9
2006	9.4	6.7	0.9
2007	9.5	6.8	0.9
2008	9.6	7.0	1.0
2009	9.7	7.1	1.0
2010	9.8	7.2	1.0

Table 22: BAU+ cooking greenhouse gas emissions by fuel 1990–2010

Year	Electricity MT CO_2-e	Natural gas MT CO_2-e	LPG MT CO_2-e
1990	1.8	0.3	0.1
1991	1.9	0.3	0.1
1992	1.9	0.3	0.1
1993	2.0	0.3	0.1
1994	2.0	0.3	0.1
1995	2.1	0.3	0.1
1996	2.1	0.3	0.1
1997	2.2	0.4	0.1
1998	2.2	0.4	0.1
1999	2.3	0.4	0.1
2000	2.3	0.4	0.1
2001	2.4	0.4	0.1
2002	2.4	0.4	0.1
2003	2.4	0.4	0.1
2004	2.4	0.4	0.1
2005	2.5	0.4	0.1
2006	2.5	0.4	0.1
2007	2.5	0.4	0.1
2008	2.5	0.4	0.1
2009	2.5	0.4	0.1
2010	2.5	0.5	0.1

2.7 Water heating energy

Water heater energy in 1990 is dominated by electricity, although electric penetration is forecast to slowly decline with increasing gas penetration to 2010. In 2010, electricity is still expected to dominate greenhouse gas emissions from water heaters, totalling about 76 per cent. Energy by fuel for water heating is shown in Table 23. In 1990, electric water heaters accounted for about 27 per cent of all residential greenhouse gas emissions. Greenhouse gas emissions by fuel for water heating are shown in Table 24.

Table 23: BAU+ water heater energy by fuel 1990–2010

Year	Electricity PJ	Natural gas PJ	LPG PJ
1990	45.1	30.8	2.6
1991	45.2	32.0	2.7
1992	45.3	33.2	2.8
1993	45.3	34.4	2.8
1994	45.4	35.6	2.9
1995	45.6	36.7	3.0
1996	45.8	37.8	3.0
1997	45.9	38.8	3.1
1998	45.9	39.7	3.1
1999	45.8	40.6	3.1
2000	45.5	41.5	3.1
2001	45.1	42.4	3.1
2002	44.8	43.4	3.1
2003	44.5	44.3	3.2
2004	44.2	45.2	3.2
2005	43.9	46.1	3.2
2006	43.6	47.1	3.2
2007	43.4	48.0	3.2
2008	43.1	49.0	3.2
2009	42.9	50.0	3.2
2010	42.6	50.9	3.2

Table 24: BAU+ water heater greenhouse gas emissions by fuel 1990–2010

Year	Electricity MT CO_2-e	Natural gas MT CO_2-e	LPG MT CO_2-e
1990	13.2	2.0	0.2
1991	13.1	2.0	0.2
1992	13.0	2.1	0.2
1993	12.9	2.2	0.2
1994	12.8	2.3	0.2
1995	12.7	2.3	0.2
1996	12.7	2.4	0.2
1997	12.7	2.5	0.2
1998	12.6	2.5	0.2
1999	12.5	2.6	0.2
2000	12.4	2.6	0.2
2001	12.2	2.7	0.2
2002	12.1	2.8	0.2
2003	11.9	2.8	0.2
2004	11.8	2.9	0.2
2005	11.6	2.9	0.2
2006	11.5	3.0	0.2
2007	11.3	3.1	0.2
2008	11.2	3.1	0.2
2009	11.0	3.2	0.2
2010	10.9	3.2	0.2

2.8 Electrical appliances and equipment

Refrigerators were the largest single end use in 1990, although miscellaneous electricity appears to be growing rapidly (this end use requires further investigation). Miscellaneous electricity could include a large component of standby energy not explicitly included in the model. Lighting and standby electricity consumption (included for all appliances and equipment) are both significant.

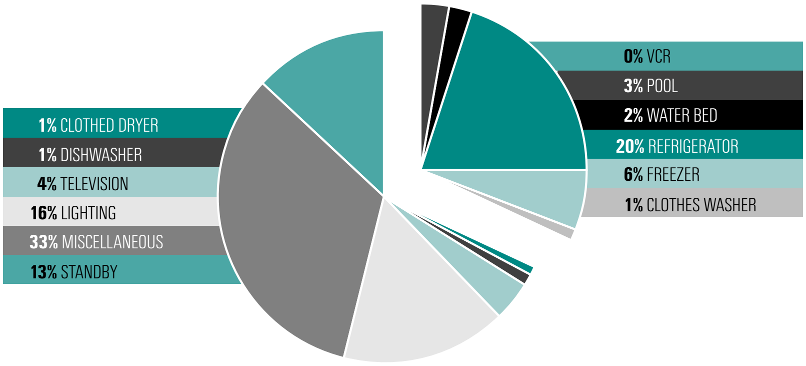
Energy consumption for pools and water beds have been estimated on the basis of constant ownership from 1986 at state level (about 10 per cent and 7 per cent respectively) and constant energy consumption per unit as based on the Pacific Power (1996) measurements for these end uses (1350 and 750 kWh per year respectively). Water bed energy consumption has been adjusted according to the average ambient temperature in each state relative to the estimated thermostat set point of 34°C.

Miscellaneous electricity consumption is also likely to include standby electricity not estimated directly, secondary lighting sources (especially plug based lighting which is difficult to meter), other water pumps (such as pressure pumps) and secondary electric heating (mainly portable units), which is known to be significant in some states. Electricity consumption by year and end use for appliances and equipment is shown in Table 25 and in 2010 in Figure 13.

Table 25: BAU+ appliances and equipment — Electricity by end use1990–2010

Year	Refrigerator PJ	Freezer PJ	Clothes washer PJ	Clothes dryer PJ	Dishwasher PJ	TV PJ	VCR PJ	Lighting PJ	Miscellaneous PJ	Standby PJ
1990	22.6	6.7	1.0	1.5	1.1	1.6	0.0	13.4	19.9	7.4
1991	22.8	6.8	1.0	1.6	1.1	1.7	0.0	13.6	20.6	8.2
1992	22.9	6.8	1.1	1.6	1.2	1.8	0.0	13.8	21.3	9.1
1993	23.0	6.9	1.1	1.6	1.2	2.0	0.0	14.0	22.0	10.0
1994	23.1	6.9	1.1	1.6	1.3	2.2	0.0	14.2	22.8	10.8
1995	23.2	7.0	1.1	1.6	1.3	2.3	0.0	14.3	23.6	11.7
1996	23.3	7.0	1.1	1.6	1.3	2.5	0.0	14.6	24.4	11.9
1997	23.4	7.1	1.2	1.6	1.3	2.7	0.1	14.9	25.3	12.3
1998	23.5	7.1	1.2	1.6	1.4	2.9	0.1	15.1	26.0	12.6
1999	23.4	7.1	1.2	1.5	1.4	3.1	0.1	15.3	26.8	12.8
2000	23.3	7.1	1.2	1.5	1.4	3.3	0.1	15.6	27.5	13.0
2001	23.2	7.1	1.2	1.5	1.4	3.4	0.1	15.8	28.3	13.1
2002	23.1	7.1	1.2	1.4	1.4	3.6	0.1	16.0	29.0	13.2
2003	23.1	7.0	1.3	1.4	1.4	3.8	0.1	16.3	29.8	13.4
2004	23.0	7.0	1.3	1.4	1.4	3.9	0.1	16.5	30.5	13.5
2005	22.9	7.0	1.3	1.3	1.4	4.1	0.1	16.7	31.3	13.6
2006	22.8	7.0	1.3	1.3	1.4	4.3	0.1	16.9	32.1	13.7
2007	22.7	6.9	1.3	1.3	1.4	4.4	0.1	17.1	32.9	13.8
2008	22.6	6.9	1.3	1.3	1.4	4.6	0.1	17.3	33.7	13.9
2009	22.5	6.9	1.3	1.3	1.4	4.8	0.1	17.5	34.5	14.0
2010	22.4	6.9	1.4	1.2	1.4	4.9	0.1	17.7	35.3	14.1

Figure 13: BAU+ appliance and equipment electricity share 2010



2.9 Greenhouse gas emissions in 1990

Total greenhouse gas emissions from residential buildings in 1990 are estimated to be 48.6 MT CO_2-e.[7] This includes emissions from electricity, natural gas, wood and LPG as estimated by the model developed by EES for this project. In addition, there were emissions from other fuels such as solid fuels (coal, briquettes), various oil products, town gas and so on. The energy values recorded by ABARE for these additional fuels (11.2 PJ) have been used to calculate greenhouse gas emissions in 1990. These accounted for an extra 0.9 MT CO_2-e in 1990, totalling 49.5 MT CO_2-e .

2.10 Business as usual projections to 2010

Under the business-as-usual scenario *with* measures, the total greenhouse emissions from residential buildings in 2010 are projected to be 56.7 MT CO_2-e. This includes emissions from electricity, natural gas, wood and LPG. In addition, ABARE forecast that a small amount of other fuels such as solid fuels (eg coal, briquettes), various oil products, town gas and so on will be used in 2010. The energy values projected by ABARE for these additional fuels (4.9 PJ) have been used to calculate greenhouse gas emissions in 2010. These account for an extra 0.4 MT CO_2-e in 2010, totalling 57.1 MT CO_2-e.

Under the business-as-usual scenario *without* measures, the total greenhouse emissions from residential buildings in 2010 are projected to be 58.1 MT CO_2-e. Emissions from other fuels are assumed to be the same as the business-as-usual scenario *with* measures scenario above. Therefore the impact of program measures implemented from 1990 to November 1997 is 1.4 MT CO_2-e in 2010 (7.9 PJ), or 2.8 per cent of the 1990 residential sector emissions.

These projections include expected changes in consumer behaviour, where these are known.

2.11 Assessment of an equitable commitment for the building sector

Greenhouse gas emissions from the residential sector which are attributable to the building sector are assumed to relate only to space heating and cooling. Estimated greenhouse emissions for space heating and cooling in 1990 were estimated to be 6.3 MT CO_2-e. This includes emissions from electricity, natural gas, wood and LPG. Emissions from other fuels have been ignored (even though many of these are likely to be related to space heating).

Australia's commitment under the Kyoto Protocol to the Framework Convention on Climate Change is to limit its total greenhouse gas emissions to 108 per cent of the 1990 value by 2010. Therefore an equitable contribution by the building sector could be 108 per cent of the 1990 emission levels for space heating and cooling, or some 6.9 MT CO_2-e.

We are not suggesting that "equitable" in this context means fair or reasonable with respect to the building sector. This is merely the share of the national emission reduction target assuming that a uniform contribution is made by all sectors. Ultimately, governments will have to consider a range of factors such as feasibility and cost effectiveness of measures within each of the major sectors before settling on specific programs.

2.12 Quantification of the emission gap

As discussed above, for the purposes of this study, if an equitable contribution by the building sector is assumed to be 108 per cent of the 1990 emission levels attributable to space heating and cooling, or some 6.9 MT CO_2-e in 2010, the business-as-usual *with* measures scenario projects that greenhouse emissions will be somewhat higher at 8.9 MT CO_2-e in 2010, which is +39.4 per cent of the 1990 levels. The emission gap in 2010 is therefore some 2.1 MT CO_2-e in 2010, or 23.6 per cent of BAU+ projected heating and cooling emissions in that year.

A range of scenarios have been quantified as part of this project to obtain an assessment of possible program measures which could be used to meet an "equitable" commitment by the building industry to meeting the emission targets. The emission gap for each of these main scenarios is outlined below.

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[7] The term CO_2–e refers to the net carbon dioxide from combustion of the specified fuel(s) plus the equivalent global warming potential of associated emissions (methane and nitrous oxide). The CO_2–equivalent values are slightly higher than the CO_2 value because of the global warming impact of the small amounts of CH_4 and N_2O emitted during combustion.

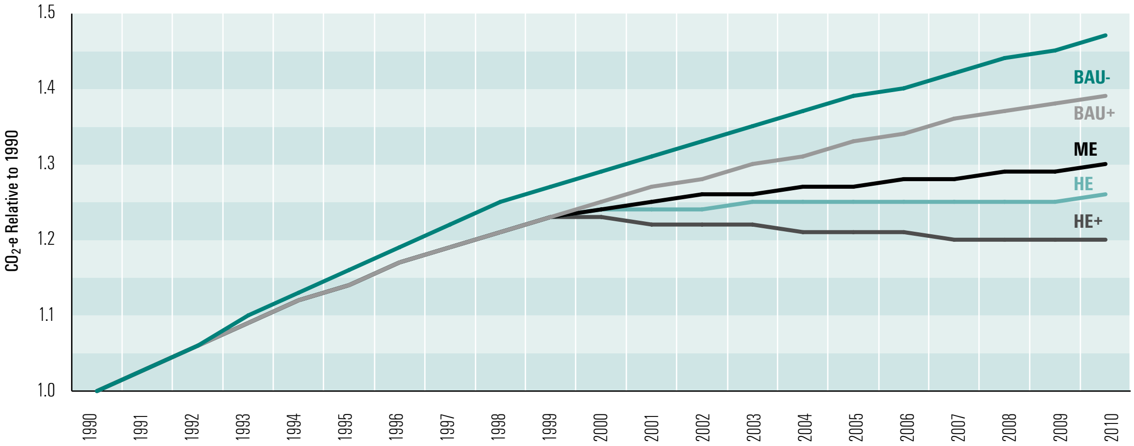
Medium Efficiency (ME) — The projected greenhouse gas emissions in 2010 attributable to space heating and cooling from electricity, natural gas, wood and LPG under this scenario is 8.2 MT CO_2-e in 2010, which is +29.6 per cent of the 1990 levels. The emission gap in 2010 for this scenario is therefore some 1.4 MT CO_2-e in 2010, or 16.7 per cent of heating and cooling emissions in that year.

High Efficiency (HE) — The projected greenhouse gas emissions in 2010 attributable to space heating and cooling from electricity, natural gas, wood and LPG under this scenario is 8.0 MT CO_2-e n 2010, which is +25.5 per cent of the 1990 levels. The emission gap in 2010 for this scenario is therefore some 1.1 MT CO_2-e in 2010, or 13.9 per cent of heating and cooling emissions in that year.

High Efficiency Plus (HE+) — The projected greenhouse gas emissions in 2010 attributable to space heating and cooling from electricity, natural gas, wood and LPG under this scenario is 7.6 MT CO_2-e in 2010, which is 19.9 per cent of the 1990 levels. The emission gap in 2010 for this scenario is therefore some 0.8 MT CO_2-e in 2010, or 9.9 per cent of heating and cooling emissions in that year.

Greenhouse gas emissions for the five scenarios relative to 1990 are also depicted in Figure 14, together with the Kyoto target (+8 per cent relative to 1990 emissions).

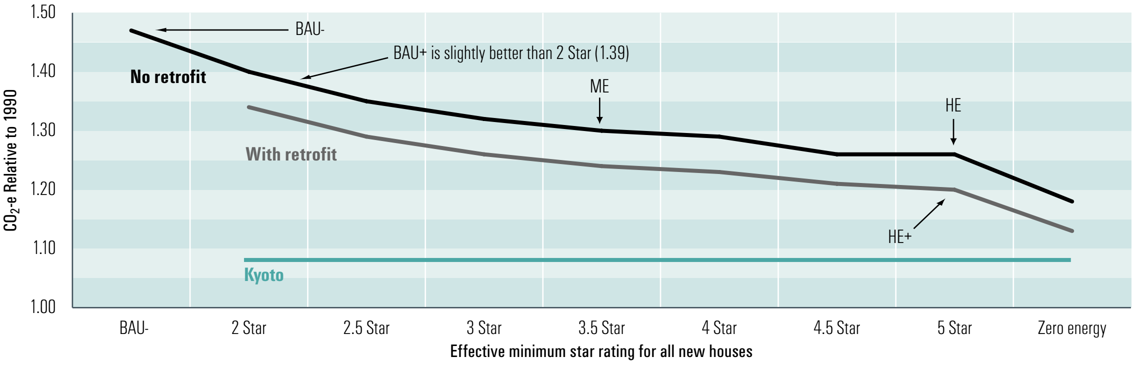
Figure 14: Projected heating and cooling greenhouse gas emissions relative to 1990



The results of a range of building shell simulations are summarised in Figure 15 which indicates the impact of improvements in the thermal performance of building shells on the greenhouse gas emissions for space heating and cooling in 2010. The "with retrofit" option assumes an aggressive ceiling insulation program within existing houses currently without ceiling insulation as per the HE+ scenario.

The "zero energy" option plotted on the horizontal axis is a hypothetical case where all new houses from 2000 use zero net energy for space heating and cooling. Even this "optimistic" scenario is unable to achieve the Kyoto commitment for Australia, mainly because of the limited proportion of the housing stock that is affected in the period from 2000 to 2010.

Figure 15: Impact of building shell energy efficiency on greenhouse gas emissions in 2010



Note: The star rating bands are non linear and the rate of change varies with climate zone.

3 BUILDING SHELL MODELLING

3.1 Overview of process

Energy use and greenhouse gas emissions resulting from space heating and cooling end uses are dependent not only on the relative efficiencies of the appliances themselves, but also on the thermal performance characteristics of the building shell in which they operate.

Improvements in the thermal performance characteristics of the building stock will result in a reduced demand for both heating and cooling. The relationship, however, is not necessarily a direct one. In some circumstances, especially in the case of renovations, improvements in building shell thermal performance may be partly taken in the form of improved comfort levels. In other circumstances, improvements in building shell thermal performance may result in the occupants avoiding the installation of space conditioning equipment (typically cooling equipment) which they may have otherwise chosen to install in a building with poorer thermal performance. The lack of hard data in this area precludes any meaningful assessment of its potential effect.

Thermal performance of the building shell is governed by a number of major factors namely:

- Insulation levels for ceilings, walls and to a minor degree, floors.
- Thermal mass — primarily affected through choice of floor and internal wall construction materials.
- Orientation, to the extent that it affects exposure to incident solar radiation, especially upon windows.
- Glazing area, type and shading.
- Infiltration (air leakage).

Modelling of the building stock was based upon the categorisation of the stock into various “construction types” made up of combinations of the most common variants of each of the above factors. Stock was then further divided into two broad types known to exhibit differing performance characteristics and differing trends in terms of stock numbers. These two main types are:

- Detached Houses
- Non Detached Houses ie houses that share either common walls or floors or both.

Historical data was used to establish the relative penetration levels for each of the identified construction types within the existing stock at the selected base point of 1986 (ABS household survey ABS8212.0). This base point was chosen on the basis that only from 1987 onwards has detailed data been kept by the ABS on the characteristics of practically all new dwellings constructed (ABS 1998).

From this base point in 1986 the relative penetration levels of each construction type in the years subsequent to this point are then determined by inputting the following factors for each year from the base point to the present:

- Additions of new stock by construction type and floor area.
- Retirements of existing stock (demolitions) by construction type and floor area.

Note: Other forms of building alterations likely to affect thermal performance such as retrofitting of double glazing, fitting of draft seals and erection of shading devices were believed to be either insignificant or overly difficult to quantify from the available data. In the case of shading devices, some adjustment for the known tendency to provide shading to west facing windows was consciously adopted in the simulation studies (see below).

Trends in penetration levels for each of the construction types are then mapped and projected forward to 2010. These are converted to actual numbers of dwellings by multiplying them by the known number of dwellings up until 1997 then by the projected number of dwellings up until 2010. Projections for dwelling numbers are done for the ABS population projection series number II. Note that the model can also project for ABS series I and III if required.

Stock numbers for particular construction types are then adjusted to account for the retrofitting of insulation to their roof spaces. This process in effect shifts a proportion of the stock each year from one set of construction types (uninsulated) to another set of construction types (ceiling insulated), however it does not affect the total number or floor area of the stock.

Using information regarding the average floor area of existing stock, average floor area of new stock being added and average floor area of stock being retired, gross floor areas can then be calculated for each year for each construction type.

This floor area is then further adjusted to account for alterations to existing stock through building additions to floor area (extensions). This process does not affect the total number of the stock but does affect its floor area.

Using this gross floor area for each construction type for each year and for each state, a climate zone weighted heating and cooling performance level in terms of annual MJ/m^2 is then calculated to give a total “unconstrained” heating and cooling load for each state and for each year. Here, “unconstrained load” is used to mean the energy demanded to keep most of the dwelling comfortable to current middle class standards for the periods specified in the NatHERS program without regard for the occupants often adopting lower comfort standards and/or shorter durations and/or heating or cooling only parts of the house. The concepts of “unconstrained and constrained load” are more fully explained later in this chapter.

The heating and cooling performance levels are determined for representative generic detached and non detached housing formats using the NatHERS thermal performance modelling program developed by CSIRO for the Nationwide House Energy Rating Scheme. Within each generic housing type, performance levels are determined for each construction type and for a range of representative climate zones throughout Australia.

Data regarding proportions of stock found in each climate zone within each state is then used to derive the weighted heating and cooling performance levels for each state.

Finally the output in terms of unconstrained heating and cooling loads by year by state are fed into the heating and cooling appliance stock models to firstly give constrained levels of heating and cooling and finally greenhouse gas emission levels. Total end use energy consumption thus estimated has been reconciled with metered top down energy data as recorded by ABARE (see Chapter 2 — Project results).

The whole process involved in the modelling of the building shell stock is described in Figure 16.

3.2 Existing energy programs and scenarios examined

Five main scenarios were analysed with respect to building shells. These were:

- Business as usual *with* measures (BAU+): includes efficiency measures introduced between 1990 and November 1997;
- Business as usual *without* measures (BAU-): excluding building shell efficiency measures }introduced between 1990 and November 1997;
- Medium efficiency case (ME);
- High efficiency case (HE);
- High efficiency plus retrofitting case (HE+)

These are described in more detail in the following section.

The various scenarios impact differently on projected heating and cooling demands. For details of the construction types referred to in the following sections refer the section entitled “Defining the Stock Characteristics”.

3.2.1 Business as usual *with* measures (BAU+)

The Business as usual *with* measures (BAU+) scenario projects current trends in construction types to the year 2010. Penetration rates for each of the construction types are mapped from available ABS data for new housing stock constructed between 1987 and 1997 for each state. Projections are then made based upon this historical data as to likely penetration levels for the various construction types to be found in the new housing stock to be built from 1998 to 2010. These projected penetration rates are then fed into the new housing section of the stock model where they are multiplied by the projected household numbers to give stock numbers for each type of construction for each State for each year.

The BAU+ model accounts for building shell energy efficiency programs implemented in each state up to November 1997. These programs are:

- Victoria — mandatory wall and ceiling insulation requirements since 1992. An alternative compliance method available in Victoria is a requirement to meet a 3 star rating[8] using the VicHERS modelling tool; however this method has only been adopted in a very small number of cases.
- ACT — mandatory compliance with ACTHERS 4 star performance requirements since 1996; mandatory insulation of walls and inaccessible ceilings and suspended floors since December 1992 and now including all ceilings.

Note that the Energy Smart Homes Program that commenced in NSW in 1998 requiring a minimum NatHERS 3.5 Star rating has not been included in this scenario. The program is in its infancy and its predicted rate of adoption by councils is not certain. This scenario is however covered in the Medium Efficiency Scenario where an effective minimum 3.5 star rating for all new housing would be applied from the year 2000 (for all states, not just NSW).

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[8] Until 1996, Victorian regulations required a 4 star minimum for compliance.

The BAU+ scenario also includes minimum energy performance standards for refrigerators, freezers and electric storage water heaters which are due to come into effect in 1999 (these were announced 1995). These are discussed in more detail in the chapter which covers appliances.

The impacts of these programs are included in the stock model in two ways:

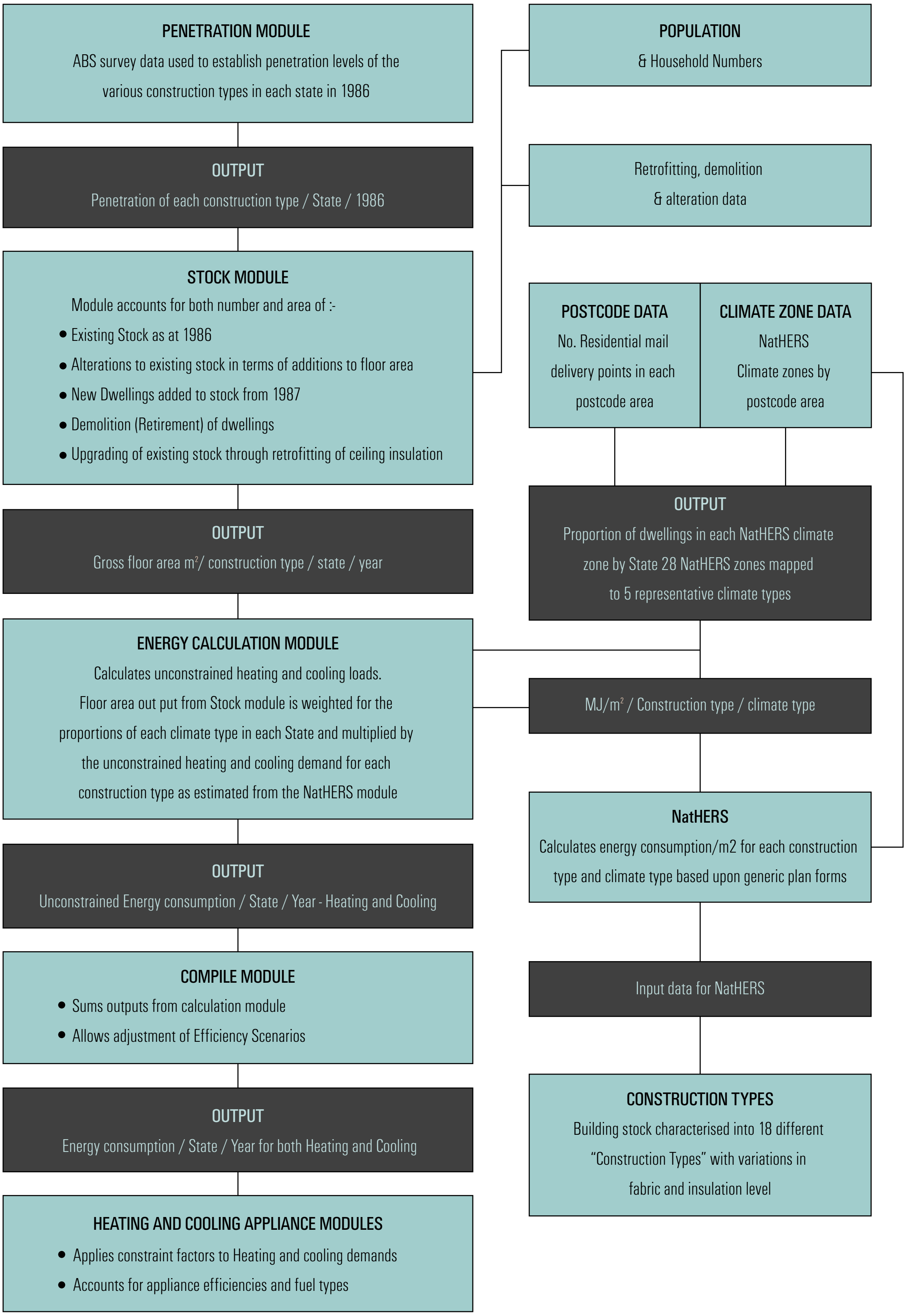
1. In the case of the mandatory insulation requirements of Victoria and ACT, all new dwellings constructed during the mandated period are deemed to be confined to those construction types with both wall and ceiling insulation.
2. In the case of ACTHERS, a separate construction type category has been provided especially to cover this type. This construction type category assumes an energy performance standard as derived from the NatHERS data base rather than a set of construction characteristics. In the case of ACTHERS a performance standard of 4 stars is assumed, that is, the minimum prescribed energy performance required for compliance. The NatHERS star rating system is similar to that used with appliances such as refrigerators, whereby the higher the star rating achieved the greater the energy efficiency of the product (in this case the building shell). The various star ratings for the range of climate types adopted for use in this study equate to energy consumption levels per m^2 of floor area per year for heating and cooling in the NatHERS model as follows:

Table 26: NatHERS star rating bands

	Climate Type				
Star rating	**Townsville**	**Brisbane**	**Western Sydney**	**Melbourne**	**Canberra**
0.5	470	290	600	430	1100
1	470	290	600	430	1100
1.5	300	160	503	310	921
2	300	160	405	310	743
2.5	250	120	308	250	564
3	250	120	210	250	385
3.5	200	90	180	210	330
4	200	90	150	210	275
4.5	170	60	120	170	220
5	170	60	90	170	165

Note: Values shown are equivalent combined heating and cooling energy consumption (MJ/m^2/yr).

Figure 16: Building shell stock model flow chart



A 100 per cent compliance in the ACT has been assumed since the mandatory 4-star level was introduced in May 1996. (It should be noted, however, that the 4-star rating allows for carpet, weather stripping and insulating window furnishings, which may not all be implemented. A review of ACTHERS currently under way is planned to establish the frequency of energy conserving interior decoration but the results will not be available in time for this study).

3.2.2 Business as usual *without* measures

The Business as usual *without* measures (BAU-) scenario is identical to the BAU+ scenario except that the building shell efficiency programs introduced since 1990 in the BAU+ scenario are assumed to be absent. This scenario predicts then the energy consumption and greenhouse gas emissions that would have resulted assuming the same user behaviour patterns. The results of the BAU- case when compared to the BAU+ case will thus reflect the energy and emission impacts of those programs.

3.2.3 Medium efficiency

The Medium Efficiency (ME) scenario assumes that in the year 2000 a national effective minimum energy performance requirement for all new housing building shells is introduced at 3.5 stars, as defined in NatHERS. This means that up until the year 2000 this scenario is the same as BAU+. Following the year 2000 it is then assumed that all new stock will meet the minimum performance requirement of 3.5 stars, except for the ACT, which is assumed to maintain its current 4 star requirement.

To achieve this in terms of the stock model, a separate construction type category has been provided. This construction type category assumes an energy performance standard of 3.5 stars rather than a set of construction characteristics. In this scenario the stock model assumes a 100 per cent penetration of this construction type for all new housing built post 1999.

3.2.4 High efficiency

The High Efficiency (HE) scenario is identical to the medium efficiency scenario except that the national effective minimum energy performance requirement for new buildings is raised from 3.5 stars to 5 stars.[9] As with the ME scenario a separate construction type category is provided to cover the 5 star house type.

3.2.5 High efficiency plus

The High Efficiency Plus (HE+) scenario is similar to the HE scenario, except that in addition to the measures adopted in the HE scenario, it is assumed that from the year 2000 there will be an aggressive program set in place to accelerate the rate of retrofitting of ceiling insulation to existing uninsulated building stock. Retrofitting currently occurs at a rate of approximately 1 per cent of stock numbers per annum (BIS Shrapnel 1994). The proposed level of increase has been set so as to achieve a 60 per cent-70 per cent saturation by the year 2010 (approximately 3.5 per cent per annum). This is considered to be a practical limit given that such a scheme would need to be voluntary and that retrofitting would be impractical in certain circumstances such as in the case of houses with skillion type roofs (ie no roof space).

Retrofitting of ceiling insulation was chosen as an option for this study for a number of reasons. Firstly, it is known from previous studies (eg Coldicutt et al 1977; FARIMA 1983; Williamson 1991, Knowles 1997) that ceiling insulation retrofitting is one of the most cost effective energy efficiency strategies. Secondly, at least in the case of houses with accessible roof spaces, it is a practical, non-invasive treatment that requires no other concurrent building works to be undertaken to effect its installation.

3.2.6 Discussion regarding scenarios

Whilst there are many single methods available for improving the thermal performance of the building shell, the modelling of a performance based efficiency scenario, such as a requirement for 5 star rated homes, rather than a limited prescriptive set of measures such as improved ceiling insulation levels or double glazing, permits the greatest flexibility for designers and builders alike. In reality, an approach similar to that adopted for Victoria could be used where both a performance specification and a deemed to comply set of measures are mandated.

For the purposes of this study the focus was placed on two effective minimum performance levels. Firstly, the 3.5 star (ME scenario) which equates roughly to the median level of performance adopted or proposed to be adopted in the near future by; Victoria (mandated insulation levels, adopted), ACT (ACTHERS 4.0 star, adopted) and NSW (Smart Homes program = 3.5 Star, proposed). Secondly, a 5 star rating which is the current maximum rating available

[9] The building shell model developed is able to model any performance based requirement.

in the NatHERS system was examined. Whilst this may be the current maximum rating available, higher efficiencies would be possible. By some European standards our 5 star level would be considered to represent only a very mediocre level of thermal performance. Performance standards could in theory be set up to a maximum as noted earlier whereby the dwelling has no net energy demand for either heating or cooling.

3.3 Defining the stock characteristics

To model the thermal performance characteristics of the stock, it was first necessary to define the stock in terms of its construction characteristics. These characteristics then formed part of the input for the NatHERS program used to predict unconstrained heating and cooling demands for each construction type.

The major stock related inputs required for NatHERS that affect performance are as follows:

1. Spatial details — floor plan data, ceiling heights etc.
2. Orientation
3. Basic construction types — floor, wall and roof construction combinations
4. Insulation
5. Glazing — area, type, shading
6. Level of infiltration (air leakage)

Clearly there would be, within the existing stock, an almost infinite number of variations and combinations of the above factors. It was therefore necessary to select a range of combinations and variations that could adequately represent the actual range of combinations and variations known to be in existence. In carrying out this process regard was given only to those factors that were likely to significantly affect thermal performance.

The selection rationale is defined in the following sections.

3.3.1 Spatial details

Floor plan

The problem in determining floor plan details is that there are almost an infinite number of variations within the existing stock. Clearly it is impractical to either determine the full range of variations or to model them. Instead a pragmatic approach was adopted. A "Generic" plan was used, one for detached dwellings and one for non detached dwellings. (Floor plans are shown in the Australian Residential Building Sector Greenhouse Gas Emissions Appendices).

The differentiation between detached and non detached plan types is important for two reasons. Firstly, the presence of shared walls and or floors/ceilings in the non detached type effectively reduces the heat transfer through the shared surfaces resulting in significant efficiency improvements as compared to non detached housing of otherwise similar construction. Secondly, from the available ABS data, it is known that there is an increasing proportion of non detached type housing produced each year. This trend should translate into an overall improvement in shell thermal performance over time.

The Non detached dwelling type is subject to an additional set of complicating factors not relevant to detached dwelling types. As noted previously, non detached dwellings by definition share a common wall and or floor/ceiling with an adjoining dwelling. In general terms (discounting the potential effects relating to altered levels of solar gain) the greater the number of shared surfaces, the lower the potential energy demand for heating and cooling. If we consider a dwelling as a basic 6 sided box then a non detached dwelling could have anywhere between one and five shared external surfaces. There is unfortunately no data available regarding the actual penetration levels of the various configurations in terms of number of shared surfaces of constructed units. What is known however is that non detached dwellings can be either Class 1b or Class 2 buildings as defined in the Building Code of Australia. Class 1b buildings typically share between 1 and 3 external surfaces (average = 2) and Class 2 buildings would typically share between 2 and 5 external surfaces (average = 3.5). ABS statistics for the past 10 years suggest that each of these types is produced in similar numbers at a National level. In terms of defining a representative non detached house type it would therefore seem reasonable, given the limitations of available data, to adopt a plan form with its number of shared external surfaces somewhere between these two averages. The plan selected has a shared wall on each side and is two storeys high (effectively an additional half a shared surface in the form of half of its floor area — 1st storey roof and 2nd storey floor) thus giving a total of approximately 2.5 shared surfaces.

Whilst the plans are generic, they are modelled through a representative range of construction types, insulation options and for each of four orientations (North, South, East and West). Furthermore, the floor area is adjusted to match the average floor area for each year studied. These particular variables, along with the ability to effectively zone a dwelling, are known to be by far the most significant factors in determining thermal performance.

It is worthwhile noting that even by restricting the floor plan types to this degree, the modelling through each of the 5 climate types still required several thousand NatHERS simulation runs (not counting those to test the sensitivity of the results to the vagaries of suburban solar obstruction).

Orientation

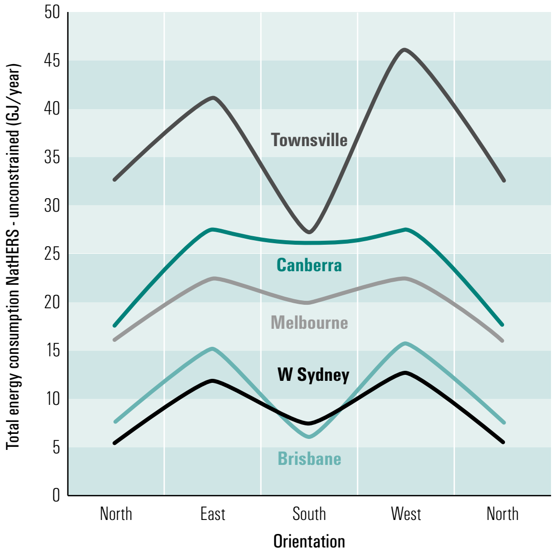
Orientation of the generic houses will affect the level of exposure to incident solar radiation, most importantly on windows. From experience it is known that orientation of houses is almost entirely random, that is, favourable orientation in terms of passive solar design principles is rarely a consideration. Decisions regarding orientation are typically made based upon the shape and topography of the block and the position of the road, ie naturally random variables.

It can therefore be assumed that our generic house plans will be found to be evenly distributed around the range of possible orientations. To model this, NatHERS runs were done for each of the 4 cardinal orientations and the results averaged. The study revealed that the NatHERS runs for various orientations of the generic detached house showed little sensitivity to orientation with on average less than 5 per cent variation in performance between the most and least favourable orientations. This is to be expected given that the generic detached house is not a passive solar designed house and it has a reasonably even distribution of glazing around its perimeter. The non detached house type demonstrated a greater sensitivity to orientation with variation in performance of up to 20 per cent with respect to orientation. This too is to be expected given that the non detached house plan has glazing only on two opposite walls.

A Study by Energy Efficiency Victoria in their “Energy Efficiency Housing Manual” found that a detached house designed along passive solar design principles exhibited a far greater sensitivity to orientation compared to our generic plan. Energy consumption (based upon VicHERS analysis) was found to be 40 per cent greater for the least favourable orientation (living areas to West) as compared to the most favourable orientation (living areas to North). The significance of this finding is that should a policy embrace the concept of passive solar design principles as a means of improving shell performance, then the issue of providing opportunities for favourable orientations in terms of land subdivision practices would also need to be addressed especially in southern states where passive solar design is most relevant.

Similar results for NatHERS simulations for all climate zones are shown in Figure 17 on a passive solar design house (brick veneer, concrete slab, single glazed, insulated, predominantly north glazing). It should be noted that the passive solar design house used for this simulation is one designed for heating dominated climates such as Melbourne and Canberra and hence results for cooling dominated climates such as Townsville and Brisbane are not particularly indicative.

Figure 17: Effect of orientation on a passive solar design house by climate zone



Note: East and west glazing performs poorly in all climate zones.

In recent times a number of schemes such as the ACTHERS program in the ACT, and to a lesser extent the Energy Smart Homes scheme in NSW, have been adopted. These schemes would tend to increase the number of houses having more favourable (northerly) orientations. In these cases, a level of performance rather than a set of design characteristics is assumed for houses built under these schemes (eg 4 star rated in ACTHERS). This is dealt with in more detail in the section below on Basic Construction Types.

Ceiling heights

The minimum ceiling height permitted in new dwellings is now 2.4 metres. Historically, greater ceiling heights have been the norm ranging from about 2.7- 3.0 metres in the mid part of the century up to 3.6 metres for older stock.

A stock weighted average of 2.6 metres has been adopted. Although this average will be higher than that expected for new stock, experience with NatHERS modelling suggests that even moderate changes in ceiling height will not significantly affect thermal performance.

3.3.2 Basic construction types

The construction type of the floor, walls and to a lesser degree the roof affects both the insulating characteristics and the thermal mass of the shell. For the purposes of modelling, a set of the most common floor/wall combinations were selected to represent the full range of major construction types. In addition, a number of performance based types were included to represent particular programs either currently in operation or possible in terms of a “higher efficiency” projection scenarios.

3.3.3 Insulation

The extent to which insulation is added to ceilings walls and floor affects the thermal performance of the shell by limiting heat flow into and out of the shell. For the purposes of modelling, a set of the most common floor and ceiling insulation combinations were selected to represent the range of major insulation installation types.

The combinations are as follows:

- None
- Ceiling Only
- Walls and Ceiling

Combinations including floor insulation options were not considered as, generally speaking, floor insulation is uncommon and has the least effect upon thermal performance as compared to ceiling and wall insulation.

R values for wall and ceiling insulation were selected on the following basis:

- Walls — R=1.5 was selected as being the most common value in framed construction (eg it is the mandated level under the ACT Addendum of the BCA) and represents a compromise between the practical maximum of R=2.5 with fibreglass batts and 90mm timber studs and the low first cost option of R=1.0 as the approximate long term value of reflective foil mounted on the outside face of the studs.

Table 27: Housing construction types

Basic construction type*	Description
Lightweight	Timber or metal framed walls with sheet cladding and suspended timber floor**
Brick veneer/Timber floor	Brick or block veneer walls, internal timber or metal wall frame and a suspended timber floor. Category also Includes precast concrete walls with internal framing
Brick veneer/Concrete floor	Brick or block veneer walls, internal timber or metal wall frame and a concrete raft slab floor. Category also includes precast concrete walls with internal framing
Cavity brick/Timber floor	Cavity brick or block and suspended timber floor
Cavity brick/Concrete floor	Cavity brick or block and a concrete raft slab floor
(ME) 3.5 STAR	Medium efficiency scenario: effective minimum 3.5 star. This also equates to the NSW energy smart homes program performance level
ACT HERS (4 Star)	ACT performance based effective minimum 4 star
(HE) 5 STAR	High efficiency scenario effective minimum 5 star

Notes: Variations in roof types were not considered as generally speaking roof type (as distinct from roof insulation) has a comparatively small effect upon thermal performance. ** Combinations of lightweight structure with concrete floor were found to be relatively uncommon and so did not warrant being included as a separate type. Instead stock numbers for these types were aggregated with BV/Concrete floor, given its similar thermal performance characteristics.*

- Ceilings — A climate-responsive value was selected as being 75 per cent of the level recommended by Standards Australia (AS2627.1, 1993) for each Climate Type: for example for Canberra (Climate Type V, NatHERS Climate Zone 24) this would be R=3.0 (75 per cent of R=4.0) — the discounting allows for the market tendency to install less than the recommended financial optimum due to the law of diminishing returns and, in the case of the blow-in materials, for the tendency for the long term value to be rather less than the initially installed value due to settling.

Note that both these values are indicative of the insulation levels actually installed. The average insulation level for all dwellings would be rather lower as it would include all the dwellings which have no insulation at all.

By combining the various "Basic construction types" with the various insulation options, a set of construction type/insulation options designed to represent the bulk of known combinations were created. These have been called the "Construction Types" and are shown in Table 28.

Construction types that might fall outside this range (others) have been considered to be evenly distributed in terms of performance characteristics amongst these existing types.

3.3.4 Glazing — area, type and shading

No double glazing — Double glazing currently has an insignificant market share except in the Alpine climate zone (NatHERS ALP25), which has a small population — overall for Australia it would be much less than 1 per cent (eg a survey of 150 dwellings commenced or under construction in Canberra in the winter of 1998 found none with double glazing). High efficiency houses such as those that may use double glazing are accounted for separately in HE scenario 5 star homes construction types.

At the request of the coordinating committee, a separate limited study was conducted to gauge the impact of clear double glazing on the generic detached house. The most typical case was selected: viz. brick veneer and concrete floor. The results indicate that double glazing on average in the above case will result in a 20–25 per cent reduction in unconstrained energy demand for heating and 10–15 per cent reduction in unconstrained energy demand for cooling.

Window area — 20 per cent of GFA (gross floor area) for the detached house type which is somewhat low relative to current design of detached dwellings, but is thought to be

Table 28: Construction types modelled

Construction type	Basic construction	Insulation	Code adopted in figures
1	Lightweight	None	(LW/N)
2	Lightweight	Ceiling only	(LW/C)
3	Lightweight	Walls and ceiling	(LW/W+C)
4	Brick veneer/Timber floor	None	(BV/T/N)
5	Brick veneer/Timber floor	Ceiling only	(BV/T/C)
6	Brick veneer/Timber floor	Walls and ceiling	(BV/T/W+C)
7	Brick veneer/Concrete floor	None	(BV/C/N)
8	Brick veneer/Concrete floor	Ceiling only	(BV/C/C)
9	Brick veneer/Concrete floor	Walls and ceiling	(BV/C/W+C)
10	Cavity brick/Timber floor	None	(CB/T/N)
11	Cavity brick/Timber floor	Ceiling only	(CB/T/C)
12	Cavity brick/Timber floor	Walls and ceiling	(CB/T/W+C)
13	Cavity brick/Concrete floor	None	(CB/C/N)
14	Cavity brick/Concrete floor	Ceiling only	(CB/C/C)
15	Cavity brick/Concrete floor	Walls and ceiling	(CB/C/W+C)
16	(ME) – 3.5 STAR	Performance based	(ME -3.5Star)
17	ACT HERS (4 Star)	Performance based	(ACTHERS)
18	(HE) – 5 STAR	Performance based	(HE -5 Star)

indicative for the housing stock as a whole. The fraction in non detached housing is more constant over the years due to its constraint by the limited area of exposed wall into which windows can be let. A GFA of 19 per cent was used in the non detached house type.

Window frame type — Aluminium is dominant in the housing market now (although timber frames are not insignificant) and its performance is similar to the steel frames which were dominant several decades ago and as such this is considered the most thermally indicative option.

Orientation — Each of the cardinal orientations is modelled the results are representative of the gamut of sitings. It was noted that the energy consumption of the generic detached house is fairly insensitive to orientation due to its fairly even spread of glass areas while the non detached dwelling (a two storey row house) has glazing only on two walls and as such has a performance which is more highly orientation dependent.

Shading — The detached house is modelled with 450mm wide eaves plus awnings on west and a solar discount (suburbia factor) to allow for the inadvertent and planned shading of windows by planting, pergolas etc. and neighbouring buildings. Solar irradiation of windows is discounted to 60 per cent of the unobstructed value in winter and 80 per cent in summer. This “suburbia factor” is a professional judgment as no objective research in this field is known. Full sun values have also been modelled to gauge the sensitivity to shading in different climate types. Nationally, shading has the effect of increasing unconstrained heating requirements by about 10 per cent and reducing unconstrained cooling demand by about 30 per cent. The net effect of shading is a 3 per cent reduction of total heating and cooling for unconstrained demand. However, given the domination of heating loads and the high level of constraint for cooling demand nationally, shading is likely to have no net effect on total heating and cooling energy consumption (or perhaps result in a small increase). As expected, the sensitivity analysis shows that shading is highly beneficial in cooling dominated climates while solar access is important for heating dominated climates (especially for passive solar designs which utilise solar gain in winter).

Additionally, the medium density dwelling is modelled with actual solar obstruction for a townhouse development. Further it is recognised that west facing windows tend to more commonly receive solar reduction treatments such as awnings or reflective films. To account for this, west facing windows are modelled with a 0.5 Shading Coefficient when irradiated in hot conditions.

3.3.5 Level of infiltration

The level of infiltration is measured by the number of air changes per hour. This is mainly affected by the following factors:

- How well windows and doors are sealed.
- Whether or not wall vents are present.
- Whether or not there are vented skylights or ceiling fans present.

There is no available data on any of these factors, hence some informed guesses need to be made. Generally speaking, it is known that the older a house, the less well it is sealed. Older houses tend to have poorer fitting windows and doors and are more likely to have wall vents. Lightweight construction forms would be the most typical examples. A further factor is that concrete slab floors provide better sealing than suspended timber floors, especially the older tongue and groove boards (the difference is much less with the common practice of using the large particle board sheets with rubber/plastic connecting tongues). On this basis we can order our construction types from worst to best and have assumed indicative air change rates shown in Table 29.

Table 29: Assumed air change rates by construction type

Construction	Indicative air change rate*
Lightweight	1.5
Brick veneer/Timber floor	1.0
Double brick/Timber floor	1.0
Brick veneer/Concrete floor	0.5
Double brick/Concrete floor	0.5

** Note: NatHERS models infiltration as being responsive to wind speed on an hour by hour basis using the formula Air Change = 0.45 + 0.39 (Velocity and in accordance with the construction type selected. Age factors and specific air leakage weak points need to be manually input.*

3.4 Existing stock

3.4.1 Penetration levels of construction types

Penetration levels for the various construction types in the existing stock were determined through reference to the ABS National Energy Surveys for 1980, 1983, 1986 and 1994 (see the bibliography on data sources for more details). The surveys provided information on wall and ceiling insulation levels by type of wall construction. Wall constructions in the ABS studies were categorised as follows:

- Brick veneer
- Double brick
- Stone
- Weatherboard
- Fibro cement
- Other

The process of converting this data into our selected construction types required a number of assumptions. These were as follows:

1. As only the presence of either wall insulation **or** ceiling insulation were recorded it was assumed that those dwellings with wall insulation were a subset of those dwellings with ceiling insulation. This assumption is based upon the knowledge that wall insulation is relatively uncommon and tends to be used only in better quality housing or by energy conscious builders/owners. In these circumstances ceiling insulation is also likely to have been installed.

2. A small proportion of the respondents to the survey indicated that they did not know whether the walls or roof were insulated (about 10 per cent for roof insulation and 16 per cent for wall insulation) — it has been assumed that these houses were not insulated (conservative).

3. No data is provided as to the floor construction in this survey. It is known that only two main types of floor construction exist. These types are suspended timber floors and concrete floors. Concrete floors can be further divided into slab on ground type and suspended type with the former being by far the more dominant type. Advice received from the Cement and Concrete Association of Australia was that concrete slab on ground construction in residential buildings was unknown prior to 1970, since that time it has continued to gain an increasing share of the new housing market until the present where concrete floor slabs are now used in approximately 80 per cent of all houses built nationally. On this basis it has been estimated that at our base point of 1986 the penetration of concrete flooring was approximately 15 per cent of all stock. This proportion of 15 per cent concrete floors and 85 per cent suspended timber floors was then applied across the range of construction types with the exception of lightweight construction where the use of concrete floors is uncommon.

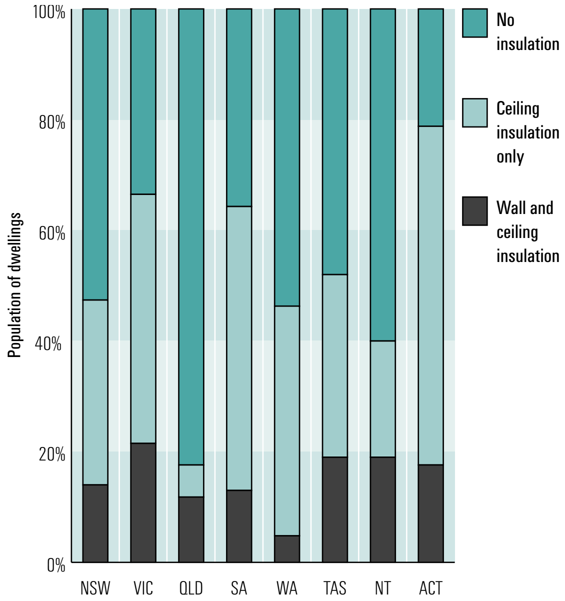
4. Construction noted as “stone” has been aggregated with double brick construction and constructions noted as “weatherboard”, “fibro cement” and “other” have all been classified as lightweight under our construction types.

5. State levels for saturation rates of insulation have been applied equally across the range of construction types in that state (which will result in only a modest overestimate of the insulation of cavity brick and stone walls).

6. No separate data was available for non detached construction type penetrations as distinct from detached. An assumption was made that the profile for non detached housing would be similar to that for detached housing except that the penetration of lightweight construction types would be significantly lower. For non detached penetrations of construction types, levels for lightweight construction were reduced to 10 per cent of their value associated with detached housing. The other 90 per cent was then evenly distributed between the remaining construction types.

From this data penetration levels at 1986 were estimated for each construction type for each state. These are summarised in Figure 18 and Figure 19.

Figure 18: Penetration of building insulation by state – Existing stock 1986



3.4.2 Floor area

Average floor areas for dwellings as at 1986 were determined from NIEIR data which provides national average floor areas for both detached and non detached dwellings (NIEIR 1997). NIEIR provides data up to 1996. These values were used to check and calibrate the stock models output.

From the 1986 start point, data from the ABS on floor areas for new construction in the housing sector was added each year from 1987 to 1997. Available ABS data only included floor area data on detached dwellings. Floor areas for non detached dwellings were estimated on the basis of the historical proportion of non detached floor area to detached floor area (derived from NIEIR 1997 data). Projections for average floor areas for dwellings built after 1997 were then made and added into the existing stock. The results of this analysis of trends in new dwelling floor areas and total stock floor areas are shown in Figure 20 to Figure 22.

Figure 19: Penetration of construction types for detached housing – Stock 1986 and 1997

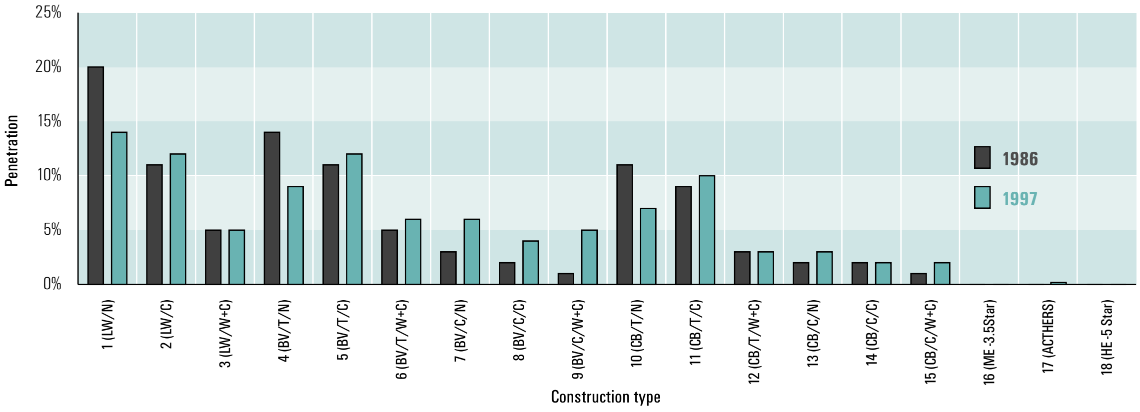
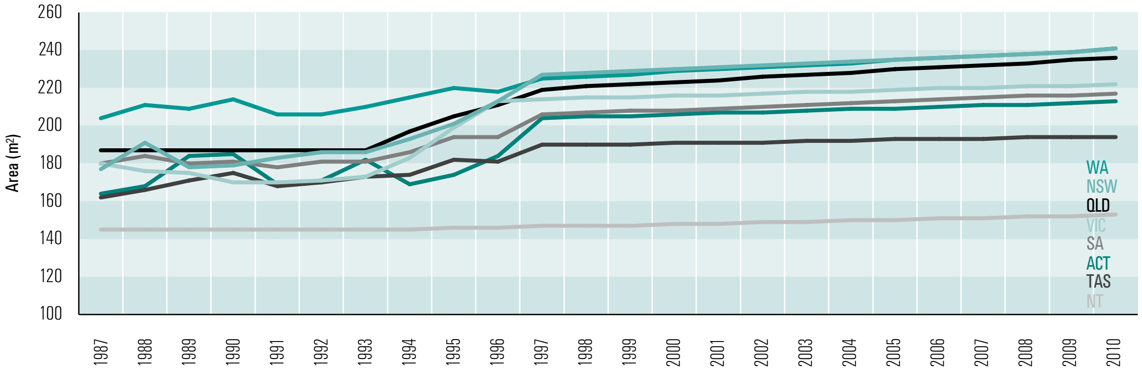


Figure 20: State trends in floor areas of new detached dwellings 1987–2010



Note: Data for QLD and NT in the 1980s and early 1990s was not available and some interpolation was required. Years 1998 to 2010 are projections.

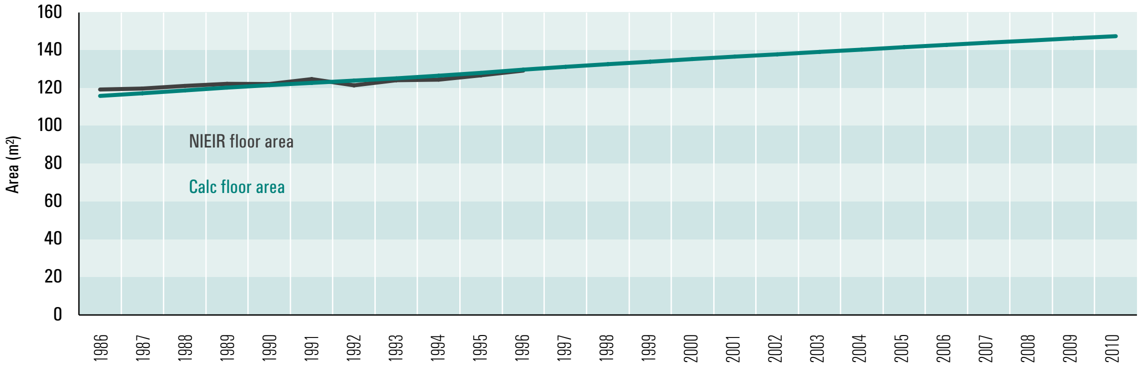
3.5 Additions of new stock

Data available from both NIEIR and ABS indicate that additions of new stock is currently occurring at a rate of around 2 per cent of existing stock per annum. In round figures this means that the current stock of about 6 million houses is increasing at a rate of approximately 130,000 per year. This increase is not static and varies as a result of a number of factors, the most significant one being the state of the economy. The growth in household numbers is projected to decrease towards 2010.

The projected growth of households to 2010 indicates an approximate increase in stock of 38 per cent over the study period of 1990 to 2010, with 17 per cent (or practically half) of this increase already having occurred by 1998. In policy terms this means that any initiative directed at improving the thermal performance of new building stock is likely to affect only a maximum of 20 per cent of the total stock at 2010 if commenced in 2000.

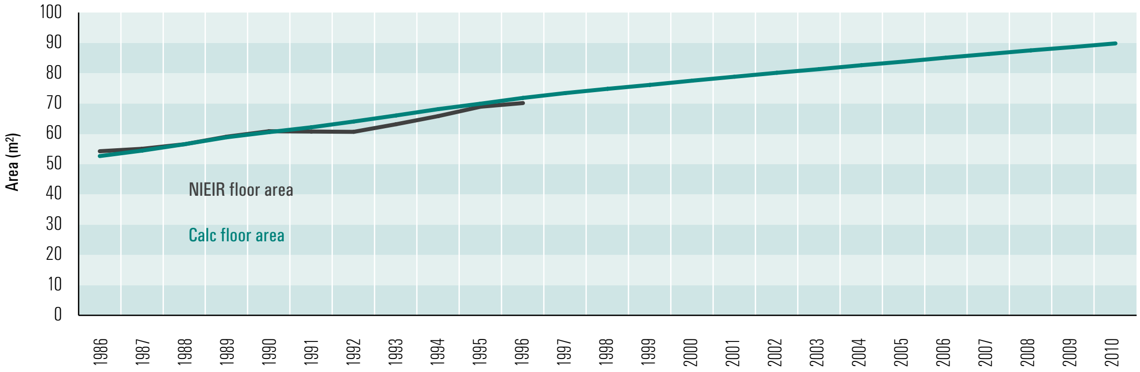
Whilst the rate of addition of new stock is relatively steady over time, a steady trend towards the non detached type has been observed over the past 10 years. In national terms the proportion of non detached type housing has increased from approximately 22 per cent of all new housing in 1987 to about 30 per cent in 1997. This increase has not been uniform on a state by state basis. Some states, such as NSW, have shown a strong increase (24 per cent to 43 per cent), whereas other states such as Tasmania have gone against the national trend with non detached housing decreasing (24 per cent to 13 per cent). These trends are illustrated in the following figures:

Figure 21: Stock average floor area – Detached housing 1986–2010



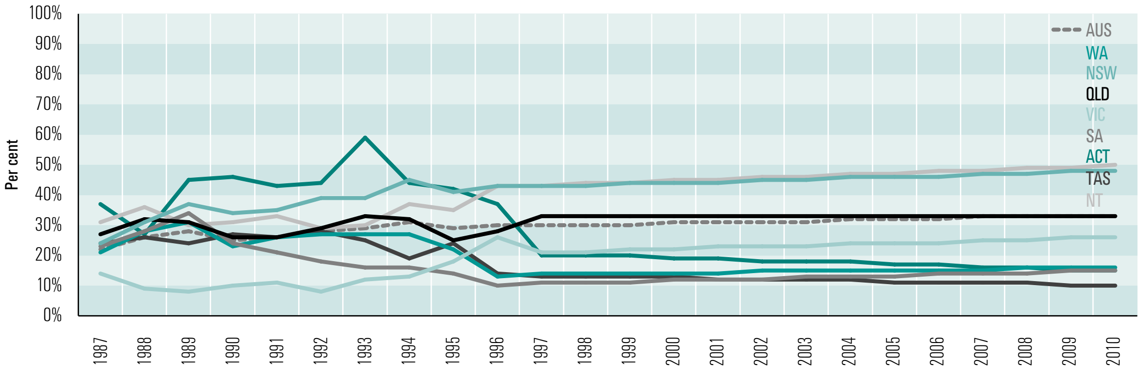
Note: Calculated figures exclude increase in stock average floor area through renovation additions.

Figure 22: Stock average floor area – Non detached housing 1986–2010



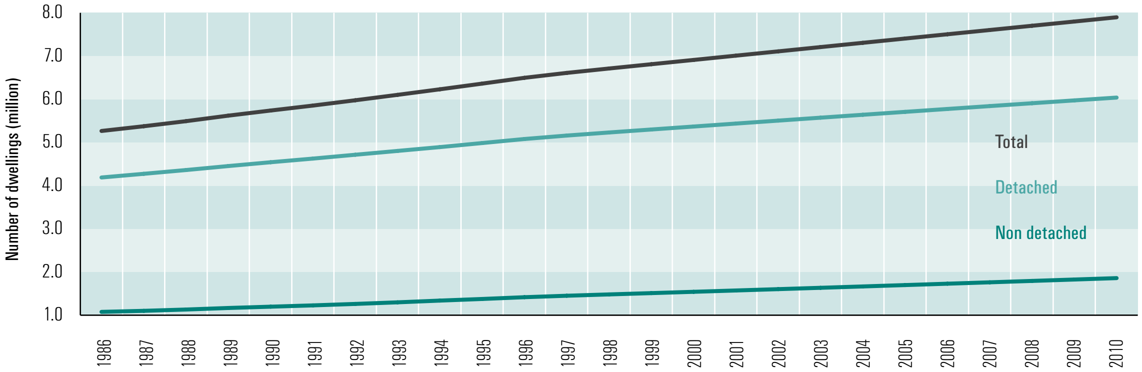
Note: Calculated figures exclude increase in stock average floor area through renovation additions.

Figure 23: Proportion of non detached housing by state 1987–2010



Note: Years 1998 to 2010 are projections.

Figure 24: National housing stock, detached, non detached and total 1986–2010



Since 1987, the ABS in South Australia has been collecting data from building permit approval notices obtained from councils around Australia (ABS 1998a). Data sets for wall construction types by floor types were obtained along with floor area data. This data was reconciled into our various construction types by using the following assumptions:

1. Construction noted as “stone” has been aggregated with double brick construction and constructions noted as “weatherboard”, “fibro cement” and “other” have all been classified as lightweight under construction types 1 to 3.

2. No information was available regarding insulation levels for construction during the period 1987 to 1997. Levels in Victoria post 1992 were assumed to be 100 per cent following mandating in the BCA. Wall insulation in ACT post 1992 was also assumed to be 100 per cent post 1992 following mandating in the BCA. For other states an average national figure of 40 per cent ceiling and 20 per cent walls (walls assumed to be walls and ceilings) was adopted following advice from FARIMA (1998). These levels were roughly adjusted at a state level according to the historic levels found in each state. State levels for saturation rates of insulation have been applied equally across the range of construction types in that state. (Note: this assumption is likely to lead to an overestimation of wall insulation levels for cavity brick construction which tends to have relatively low levels of insulation. This form of construction is uncommon in all states except WA, and as such is not likely to significantly affect the final result).

3. As with floor areas, no separate data was available for non detached construction type penetrations as distinct from detached. An assumption was made that the profile for new non detached housing would be similar to that for detached housing except that the penetration

of lightweight construction types would be significantly lower. For non detached penetrations of construction types, levels for lightweight construction were reduced to 10 per cent of their value associated with detached housing. The other 90 per cent was then evenly distributed between the remaining construction types.

Actual numbers of the various construction types built in each year from 1987–1997 were fed into the stock model which then calculated penetration rates in a time series from our start point in 1986 to the end of the available data set in 1997. The penetration rate trends were then projected forward until 2010 to provide a BAU+ scenario for each state. By contrast, the ME and HE scenarios assumed a penetration rate for type 16 (3.5 star) and type 18 (5 Star) construction respectively of 100 per cent post 1999.

3.6 Retirement of existing stock (demolitions)

Retirements of existing stock (demolitions) affect both the relative penetrations of various construction types and the gross floor area of the entire stock. Unfortunately, no data regarding demolitions is available in any state except Victoria where only numbers of demolitions since the start of 1998 have been recorded by the State office of the Building Control Commission in their BASIS publication. From this very limited data base a National rate of demolition was calculated to be occurring at a rate of approximately 0.2 per cent of the total stock per annum.

Demolitions are expected to mainly affect the older stock. As older stock construction types are more prevalent than more recent construction types the application of this demolition rate equally over the existing stock numbers will tend to result in the deletion of a higher proportion of the older stock construction types. This methodology is relatively unsophisticated but given the very small proportion of demolitions each year, is considered adequate, especially given that no data is available on the profile of demolished stock.

With respect to the floor area lost through demolitions, no data whatsoever is available. As stated previously, demolitions are most likely to affect older stock. On this basis a nominal area of 100m^2 (detached) and 50m^2 (non detached) was chosen as representative of the average area for this older stock as at 1986. This average area was progressively increased by 1m^2 per annum to reflect the trend towards demolition of progressively newer stock (in absolute terms) over time.

3.7 Alterations to existing stock

3.7.1. Added floor area

Gross floor areas are adjusted each year to allow for additions to floor area through renovation work that affects approximately 2.5 per cent of the existing stock each year by adding approx. 40–50m^2 of floor area to those houses (BIS Schrapnel 1994).

Although the average rate of addition to floor area is 2.5 per cent, the rates for detached and non detached are quite different. Detached houses are added to at a rate of almost 3 per cent whereas non detached is around 1 per cent (BIS Schrapnel 1994). This is to be expected given the higher degree of site restrictions imposed upon non detached types — the number and average floor area added is expected to be less in comparison with detached dwellings. There is however no data available on the actual average floor area added to non detached house types so an assumption has had to be made. Considering the significant level of site restriction on most non detached housing it is unlikely that on average more than one room is added. On this basis an average addition area for non detached housing of 15m^2 has been assumed.

Whilst this process does not affect the actual stock numbers, it does affect the gross floor areas by adding almost 1 per cent to the total stock floor area per annum.

There was no data on the construction types used for the purposes of house additions. An assumption therefore had to be made that the added floor area was of a construction type that matched the existing construction type. Professional experience suggests that this assumption will be true in the majority of cases.

3.7.2 Added insulation

As stated previously, stock numbers for particular construction types are adjusted to account for the retrofitting of insulation to their roof spaces. This process in effect shifts a proportion of the stock each year from one set of construction types (uninsulated) to another set of construction types (ceiling insulated), however it does not affect the total number or area of the stock.

The rate of retrofitting of ceiling insulation was determined using data from BIS Shrapnel (1994). This report estimated that there were 79,000 retrofits of ceiling insulation in 1994 at an average cost of $777. This cost figure would suggest that retrofitting was consistently done to entire roof spaces rather than selected sections only. On this basis it is calculated that the rate of retrofit is approx. 1.2 per cent of the existing stock per annum. Advice received from FARIMA (1998) was that this rate can reasonably be assumed to be static.

This figure of 1.2 per cent was applied to all scenarios except the HE+ scenario where an aggressive program to accelerate the rate of retrofitting of ceiling insulation to existing uninsulated stock is assumed to have been implemented from the year 2000 onwards. In the HE+ scenario a rate of 3.5 per cent was adopted. This 3.5 per cent rate was found to roughly equate to the rate required to convert approximately 70 per cent of the entire existing stock of uninsulated (ceiling) houses to ceiling insulated stock by the year 2010 — this is considered to be a reasonable practical limit for retrofitting.

3.8 Overall stock trends

By combining the above noted effects of existing stock penetrations at 1986, additions, retirements and alterations between 1987 and 1997 and the projected trends for these various factors to 2010, a model for penetration of construction types over time has been formed. A sample of the results of this analysis are graphically illustrated for the BAU+ case in Figure 25 and the HE case in Figure 26.

Figure 25: BAU+ penetration of construction types — detached housing 1997 and 2010

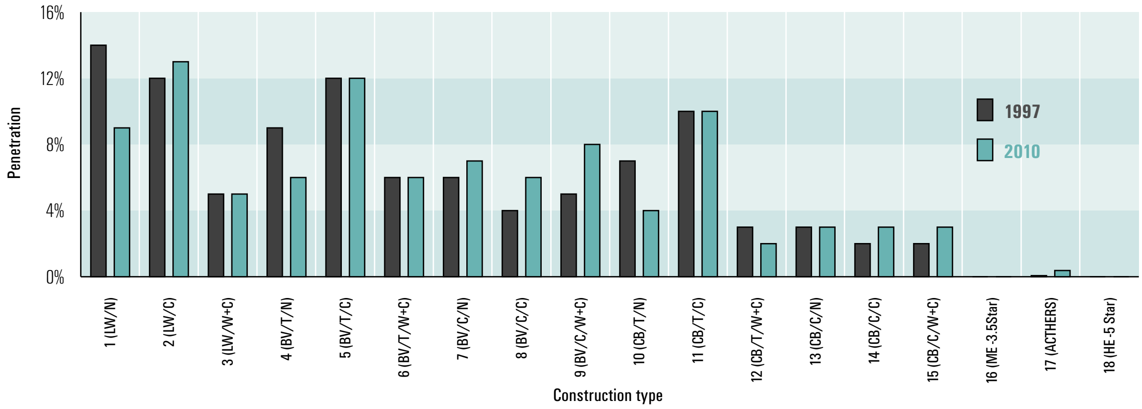
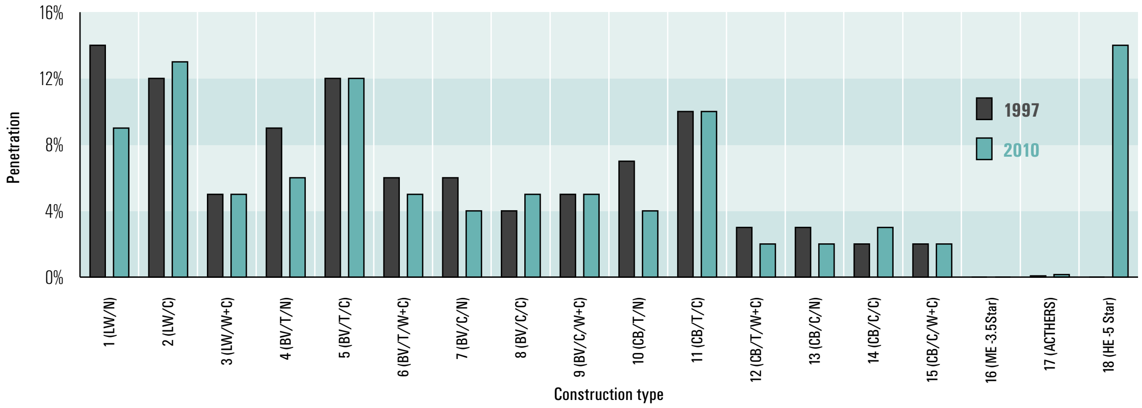


Figure 26: HE penetration of construction types — detached housing 1997 and 2010



3.9 Shell performance modelling

3.9.1 Overview

Shell performance modelling was carried out using NatHERS.

The two main inputs that affect the thermal performance are:

- The shell characteristics as described in the previous sections; and
- The climate zone in which the shell is located

3.9.2 NatHERS thermal performance modelling tool

All original simulations required for this study used NatHERS Version 2.20 with the CHENATH 4.11 “engine”. This is the version currently in limited circulation awaiting approval from the various jurisdictions. This was done in anticipation of the version being endorsed and released around the time of the publication of this study. We understand that this version is identical to Version 2.11 currently in use in NSW with the following exceptions:

- widened restraint of the number of elements bounding a zone from 20 to 50;
- correcting a bug where the slope of skylights was interpreted as its complement;
- state-specific thermostat settings; and
- state-specific modified star band thresholds.

Improvements 1 and 2 have no effect on this study but improvements 3 and 4 have some impact, as described below. Improvement 4 in particular is primarily concerned with rating of dwellings and only affects the non-simulation part of our study in which we evaluate the impact of, say, all new houses being built to a 5 star standard. In addition to these changes in the circulated copy of “draft” version 2.20, a review of the indicativeness of the climate data files currently used has suggested some concerns in some of the 28 climate zones as discussed separately in the Appendix.

3.9.3 Division into climate types in each state

Whilst modelling is generally carried out at a State level, in terms of predicting performance characteristics of building shells it is not State boundaries that are relevant but “climatic zones”. The modelling tool used was NatHERS which distinguishes 28 different climatic zones throughout Australia. It was agreed by the steering committee that modelling of all 28 zones would be overly time consuming and unnecessary. Instead it was agreed to group similar zones together in much the same way as has been done by the Australasian Window Council (AWC) in reducing the country to 6 Climate Groups by parametric simulation using NatHERS to give a ranking of the then 27 Climate Zones, based on the annual relativity of the space demand for heating and cooling. While excellent for the AWC’s purposes of establishing a Window Energy Rating Scheme (WERS), those groups were seen to be inappropriate for this project — particularly as they placed Melbourne and Sydney in the same Climate Group.

Accordingly, the same simulation results were re-analysed in their absolute values at four levels with the inclusion of Climate Zone WSY28 (Western Sydney, which had been differentiated after the WERS project was completed) and the results recorded graphically.

1. Space Heat/Cool Demand Index (the heat required to be added or extracted from the space in MJ/m_/year, as in WERS)

2. Bought Energy Index (as in 1. above but adjusted for average appliance efficiency — assumed 0.75 for heating and 2.00 for cooling)

3. Greenhouse Gas Emissions Index (as in 2. above but adjusted for the greenhouse gas emission intensity assuming national average values for natural gas for the heating and for electricity for cooling)

4. Greenhouse Gas Emissions (as in 3. above but adjusted for the number of households and average dwelling floor area for each of the Climate Zones to give values in kT/year — these should not be read as absolute values as the floor areas used were not statistical values and the results derive from unconstrained demand rather than average occupancy practice in each of the climates).

Accordingly, 5 climate zones were selected for further analysis in this project. These 5 Climate Types are deliberately “centred” on populous climate zones (rather than necessarily the climate most indicative of the meteorological type) to make the results of our simulations more relevant to the outputs we seek from this project. The Climate Types can be generally characterised as in Table 30.

Table 30: Climate type descriptions

Climate type	NatHERS zone	Description
I	TWN05	Cooling dominated (Townsville)
II	BRIS10	Mostly cooling (Brisbane)
III	WSY28	Mixed heating and cooling (Western Sydney)
IV	MEL21	Mostly heating (Melbourne)
V	CAN24	Heating dominated (Canberra)

NatHERS zones are presently reconciled into postcode areas that form the input data for the program. Unfortunately the ABS do not keep household data by either NatHERS zones or Postcode regions. To overcome this problem, data was sourced from Australia Post on the current number of Residential delivery points in each Postcode area. The aggregated national total for the Australia Post delivery points was found to very closely correlate with the National total number of households determined from ABS figures (maximum 5 per cent variation at the state level) and therefore can be considered to be equivalent, especially given that it is the proportions rather than the actual numbers we require.

The Australia Post delivery points by postcode data (Australia Post 1998) were reconciled with the NatHERS climate zone by postcode data to apportion delivery points to NatHERS zones. Many minor postcode regions are not covered by NatHERS listings and had to be apportioned to the geographically closest post code listed in NatHERS. Some postcode regions listed by NatHERS have within the region multiple climate zones, delivery points in these postcode regions were apportioned in equal parts to each climate zone within that postcode region (in reality most of these multiple listings would become part of the single broader climate type adopted for this study). A spreadsheet was then developed to apportion the number of delivery points/households in each postcode region to each of our five climate types on a State by State basis. The final results were expressed as a per cent of housing stock in each climate type in each state. The results are shown in Figure 28.

In National terms the distribution of housing stock into the five climate types are as shown in Figure 28.

Figure 27: Distribution of housing stock by climate type by state 1998

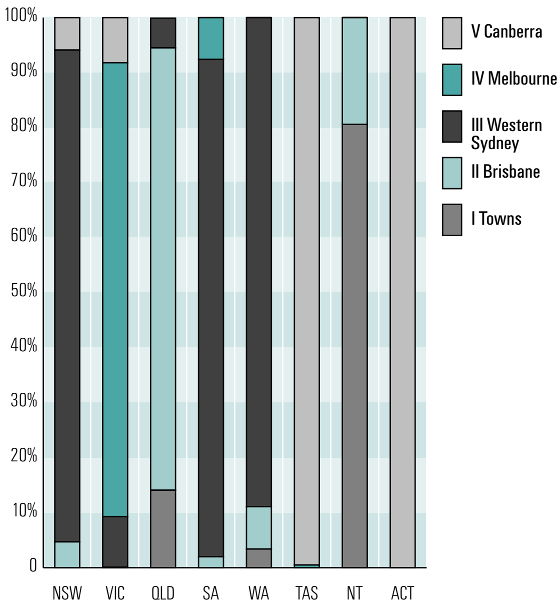
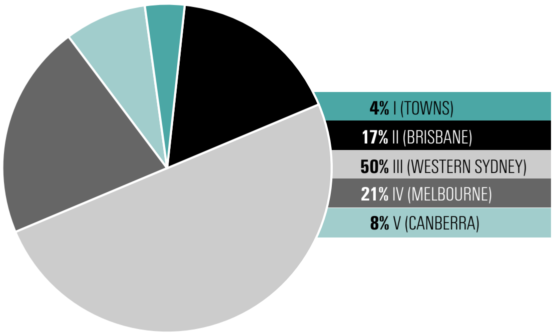


Figure 28: National proportions of housing stock in each climate type 1998



Of course the zone proportions in each state are based upon 1998 Australia Post figures (only available set) and an assumption therefore needs to be made that these proportions are historically consistent back to 1990 and that they will be valid to 2010. Demographic changes are relatively slow over time and so for the study period which sits roughly 10 years either side of this Australia Post data point this would seem to be a valid assumption.

More detail regarding the estimated households by state and NatHERS climate zones can be found in the *Australian Residential Building Sector Greenhouse Gas Emissions 1999–2010 Appendices*.

3.9.4 User behaviour

In addition to the thermostat set points and times of occupation and the operation of ventilation and shading options in response to weather conditions set out under the relevant headings below, other factors are entrenched in the NatHERS internal settings which do not necessarily reflect common household patterns:

1. No allowance for part house heating and/or cooling.
2. No allowance for vacation absences at any time.
3. No differentiation between weekdays and weekends nor public holidays.
4. Preset patterns of lighting and internal appliance efficiency and use.

Factors 1 and 2 will both result in overestimation of actual energy consumption for real households while factor 3 may result in a lesser or greater overestimation of energy consumption depending on the actual "normal" and "holiday" occupancy patterns of the household concerned. Factor 4 is probably neutral in terms of current practice but will not account well for predicted improvements in appliance and lighting efficiencies and user diligence. In terms of future consumptions, this will tend to overestimate cooling energy and underestimate heating energy due to the lower amounts of "internal loads" that we would anticipate in future households.

In addition, there is a fifth limiting factor which is not intrinsic to NatHERS but is worthy of mention. Where a ceiling fan is indicated by the user, NatHERS allows a 3°C increase in cooling set point temperature when calculating the hours of summer discomfort. Fans could have a significant impact on cooling energy use but their effect is not allowed for in the energy calculation routine in Version 2.20 (and neither is the "breeze" effect of wind-driven natural ventilation). Accordingly, for the purposes of this study, no ceiling fan was assumed and so some significant reduction of the NatHERS-indicated cooling energy demand would be appropriate.

These indicated corrections are implicit in the adjustment to the constrained demand case as described in the following section.

3.9.5 Thermostat set points and hours of operation

The following thermostat set points and hours of operation shown in Table 31 are incorporated in NatHERS although, at the time of writing, they are still under state-by-state consideration. They form the basis of the simulations done for this study but are yet to be confirmed by all the jurisdictions (eg, Wilrath 1998).

Table 31: NatHERS assumptions by climate code

Location	Climate	Living	Rooms	Bed	Rooms
code	hours[1]	temps	hours[1]	temps	
Townsville	TWN05	07-24	22°-28°	07-24	22°-28°
Brisbane	BRI10	07-24	21°-27°	07-24	21°-27°
Western Sydney	WSY28	07-24	21°-27°	07-24	21°-27°
Melbourne	MEL21	07-24	21°-26°	07-24	21°-26°
Canberra	CAN24	07-24	21°-26°	07-24	21°-26°

Note 1: Hours relate to assumed hours of space conditioning use as adopted by the NBEECC working party rather than hours of actual occupancy. Note that the "temperature analysis default" facility of the software was not used for modelling in this project.

This assumed "unconstrained"[10] pattern of heating and cooling is not directly related to population behaviour but rather to the performance of the house if its occupants were more or less "always" comfortable (in the absence of cooling air movement). This is well known to give energy consumption results which exceed the known average demand and this is why we have used such results cautiously — "constraining" them in the light of statistical consumption data.[11] For example, the "unconstrained" case predicts that Sydney is a "balanced"[12] climate (ie, heating and cooling loads are approximately the same) whereas the typical household in eastern Sydney actually has heating in winter and only occupant controlled natural ventilation (and its cooling internal "breezes") for the rest of

[10] "Unconstrained" by economic factors, a concern for the environment or other competing benefits like silence versus coolness at night.

[11] For example, the unconstrained energy consumption for heating and cooling of residential houses in Australia (before conversion efficiencies of heating and cooling equipment are considered) is about 390PJ, which exceeds the ABARE forecast for total energy consumption for the residential sector in 1998 of 376PJ.

[12] The house design used for assessing the relative climate severities for WERS purposes had less than average glazing areas facing nominally east and west and so tends to understate the relative significance of cooling demand, adding to the apparent change between NatHERS versions 1.08 and 2.20.

the year. Also, anecdotal evidence suggests that actual average cooling for western Sydney is in fact much less than that indicated by NatHERS. The difference becomes much more marked in the humid tropics where there are many ventilated and uncooled/unheated dwellings whose thermal/energy effectiveness is poorly represented by the predominantly fully enclosed dwelling inherent in the current NatHERS model.

3.9.6 Simulation of beneficial shading and ventilation

The NatHERS Users' Manual (CSIRO, 1998) says:

External blinds

The blinds are drawn if (a) at a given hour the outdoor temperature exceeds a preset value; and (b) at a given hour the incident direct solar radiation on the window (allowing for overhangs and pergolas) exceeds a preset value. The temperatures and solar radiation values for these operations are predefined and cannot be changed by the user. The shading factor is the proportion of total solar radiation that reaches the window when the blind is drawn.

Internal window coverings

The curtains or blinds are assumed to be drawn overnight, and may also be drawn during the day under certain conditions. These conditions are: (a) if there are no external blinds for that window, or the external blinds are not to be drawn; (b) if at a given hour the outdoor temperature exceeds a preset value; and (c) if at a given hour the incident direct solar radiation on that window (allowing for overhangs and pergolas) exceeds a preset value. The times, temperatures and solar radiation values for these operations are predefined and cannot be changed by the user. Window coverings reduce heat conduction through the windows and incoming solar radiation. The window covering also affects the overall window U-value when they are closed. The added resistance depends on which window coverings were selected.

For external blinds, awnings and the like, the activation temperature is at (or about, pending consensus) the mid-point of the heat and cool thermostat settings and the direct irradiation activation value is 75 W/m^2. This represents a very active use of these devices which is a reasonable way of handling the more common strategy of setting them for the summer and rarely retracting them. For internal blinds, the activation temperature is at (or about, pending consensus) the upper thermostat set point and the direct irradiation activation value is 200 W/m^2. This represents a much less active use regime and is reflective of the common occupant preference of not visually "closing up" the house for only modest efficiency gains.

Both values conform with our view of prudent and likely average user behaviour. Objections that this will allow many (and sometimes protracted) instances of the cooler being on with the sun shining (weakly) through the window are accurate observations. Such behaviour obviously falls short of economically ideal occupant action. We do not, however, believe that occupants will generally shut themselves off from the outside world in the absence of strong sun penetrating the window and hence regard this as a suitable simulation of actual household action.

Ventilation

The house is assumed to be able to be cooled using outside air when favourable conditions exist. The windows are opened for ventilation at any time of the day if the zone temperature is too high for comfort and the temperature outside is lower than inside. When the house is cool enough the windows are assumed to be closed again. If the house can be kept comfortable using ventilation only, the air conditioning is not activated. If ventilation is not able to maintain comfort conditions, the windows are assumed to be closed and the air conditioning started.

The ventilation rate is varied in proportion to the square root of the local windspeed, and also depends on the question about cross-flow ventilation on the General Form. If the local wind speed is greater than 1.0 m/s then

Ventilation rate (Air Changes per Hour) = A + B where A and B are constants.

LocalWindSpeed (m/s) = Wind speed x TerrainFactor.

If the local wind speed is less than 1.0 m/s then

Ventilation rate
(Air Changes per Hour) = A + B x LocalWindSpeed.

These temperature conditions and ventilation values conform with our view of prudent and likely average user behaviour (except for their failure to adjust upward the thermostat limit temperature in response to internal air movement generated by the ventilation). Accordingly we expect that the NatHERS results will be an overestimate of cooling energy demand but this overestimation is corrected by the application of "constraint" factors.

3.10 "Constrained" heating and cooling demand

The concept of "constrained" and "unconstrained" heating and cooling demand has been briefly outlined in an earlier section. A fuller understanding of this concept is important to comprehending the analysis of the building shell model used for this report. The amount of energy required to satisfy the heating and cooling requirements of a house must, in part, be based upon a set of assumptions relating to user behaviour. Some of the main factors associated with user behaviour are as follows:

Ownership of conditioning equipment

A potential heating or cooling demand can only be met if the user has installed equipment which can be used to meet that demand (ie condition their home). This factor is most significant in respect of cooling. Whilst almost every house in Australia has at least some potential demand for cooling (based upon accepted levels for thermal comfort), only 30 per cent of all houses in Australia have air-conditioners. In the case of the other 70 per cent of houses, users have decided to accept a less than optimal level of comfort during periods of high temperature.

Occupancy factor

This factor relates to the actual number of hours that a house is conditioned during the year. At various times of the day (eg during working hours) and at various times of the year (eg holidays) a house may be unoccupied. During these times, when excessively high or low internal temperatures may otherwise prompt an occupant to condition their home, it is common for users to switch off conditioning equipment. This behaviour has the effect of reducing the potential energy demand that would be required when compared with a house that is occupied 24 hours a day for 365 days a year.

Zoning

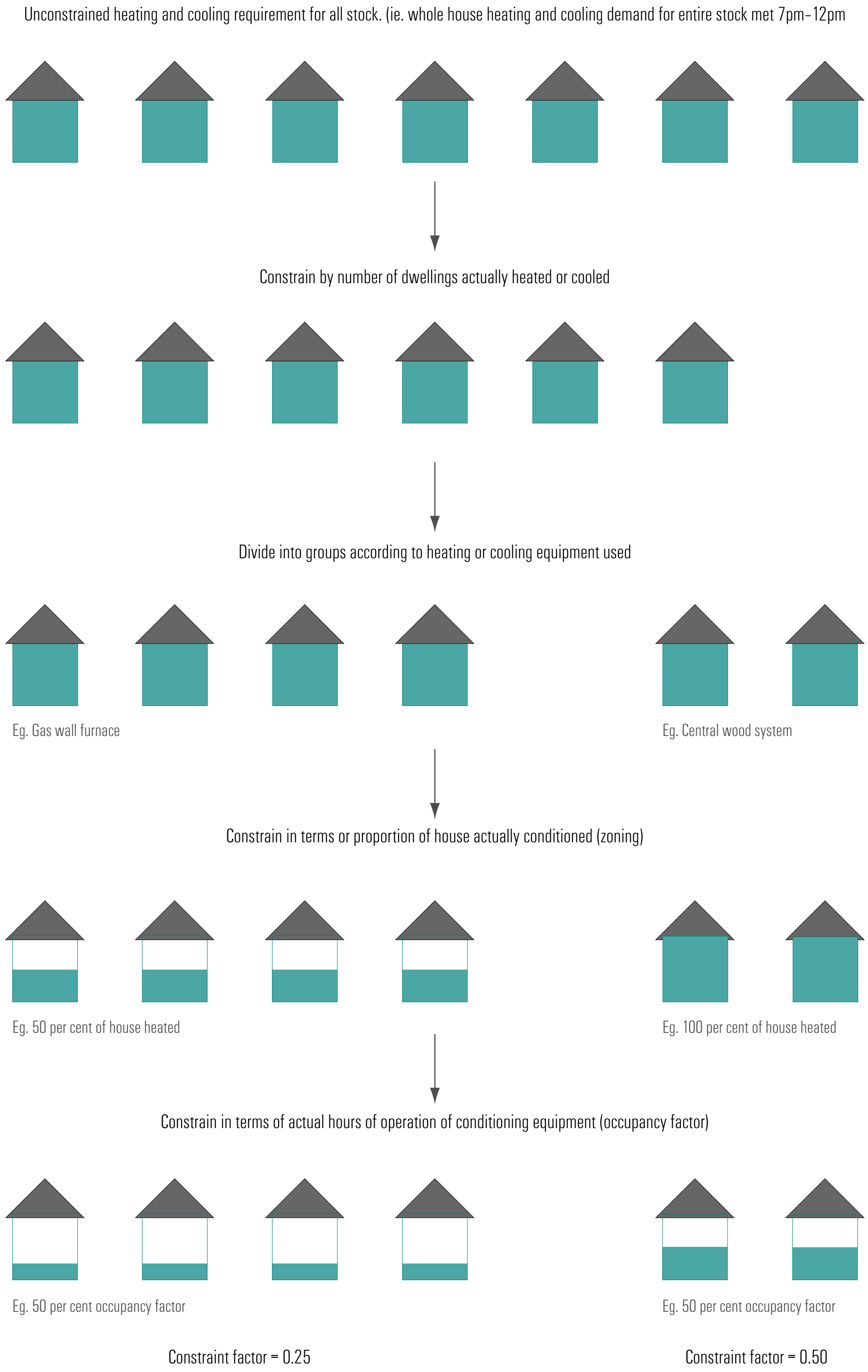
Zoning refers to the tendency of many users to condition only part of their homes. For instance, a user may choose only to heat or cool their living areas and leave sleeping areas and service areas unconditioned. The level of zoning that a user will apply is dependant partly upon the space conditioning equipment installed. For instance, users with only a small electric radiator can practically only heat one or two rooms whereas users with a ducted gas central heating system could adopt whole house heating if desired.

The NatHERS program used for the purposes of modelling the space conditioning energy demands for this study makes a number of assumptions relating to the above user behaviour factors. The program assumes that the house has both heating and cooling equipment is installed, that this equipment is used to heat and cool the entire house (excepting some minor service areas) to a high level of human comfort (this varies depending upon climate) continuously during the hours of 7am to 12 midnight, 365 days a year.

The energy required to meet this level of demand is referred to as "the unconstrained heating and cooling demand". That is, unconstrained by the tendency of most users to reduce their potential demand through the various means outlined above. The output from the shell modelling is in the form of unconstrained demand and therefore represents only the upper most limit of potential demand. To adjust this output to match reality the output needs to be "constrained" by the various behavioural factors.

The process of constraining is graphically described in Figure 29.

Figure 29: Diagrammatic model of constraint process



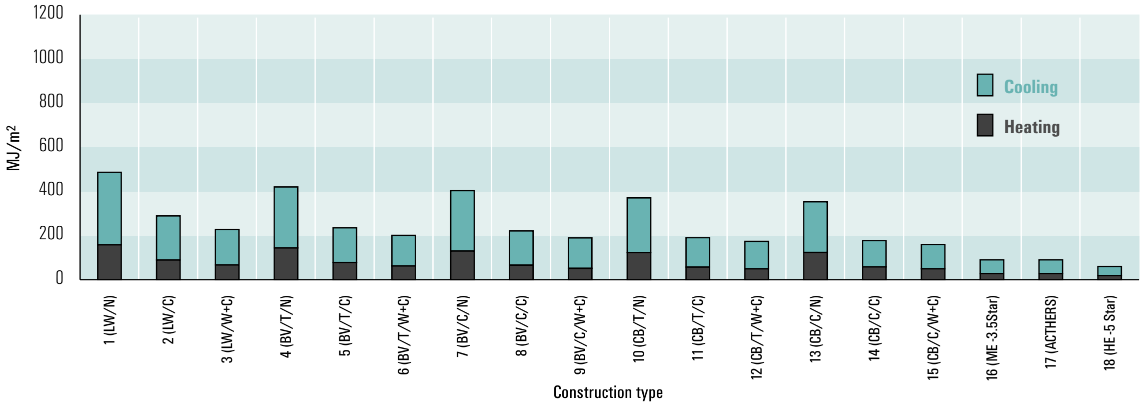
3.11 Results of NatHERS modelling

NatHERS runs on the generic house plans for each of the 18 construction types in each of the five climate types produced a set of performance factors for both heating and cooling. These factors were expressed in terms of unconstrained MJ/m2 of house floor area. The full set of results are contained within the Appendix. It should be understood that these figures represent average figures for each of the particular construction types. In reality, individual houses are likely to have performance factors that will be above or below these averages. For example, if a house has higher infiltration rates than those assumed as the average for that type of construction, then generally speaking it will exhibit higher energy consumption figures than those used in this study. Conversely a lower than average infiltration rate would result in a lower energy consumption figure than those used in the study. These average figures for unconstrained energy consumption for detached houses are summarised in Figure 30. Results for non detached housing exhibits similar trends but in absolute terms are on average approximately 35 per cent lower than for detached housing.

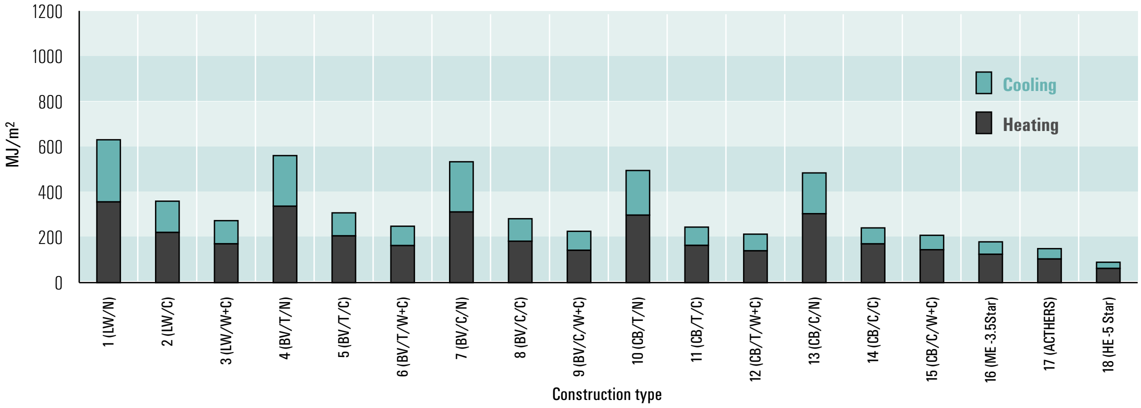
Figure 30: Average unconstrained energy consumption heating and cooling by climate

Climate Type 1 – Townsville

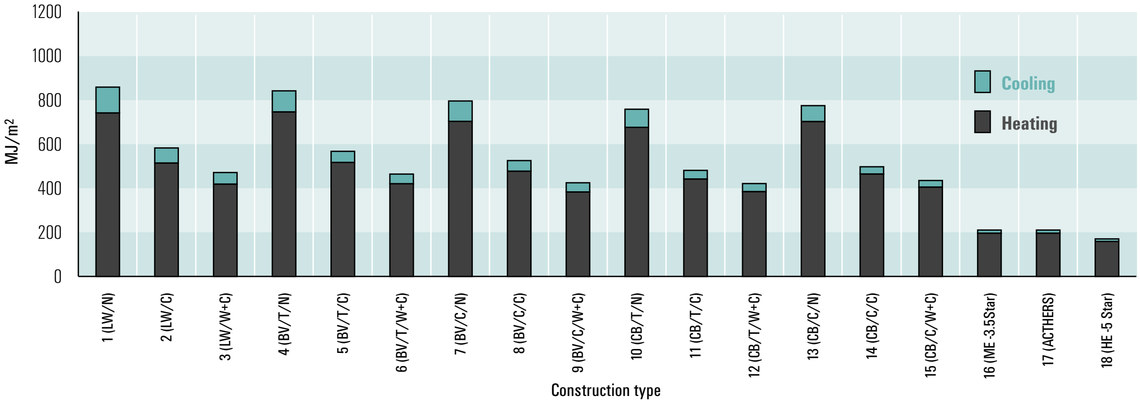
Climate Type 2 – Brisbane



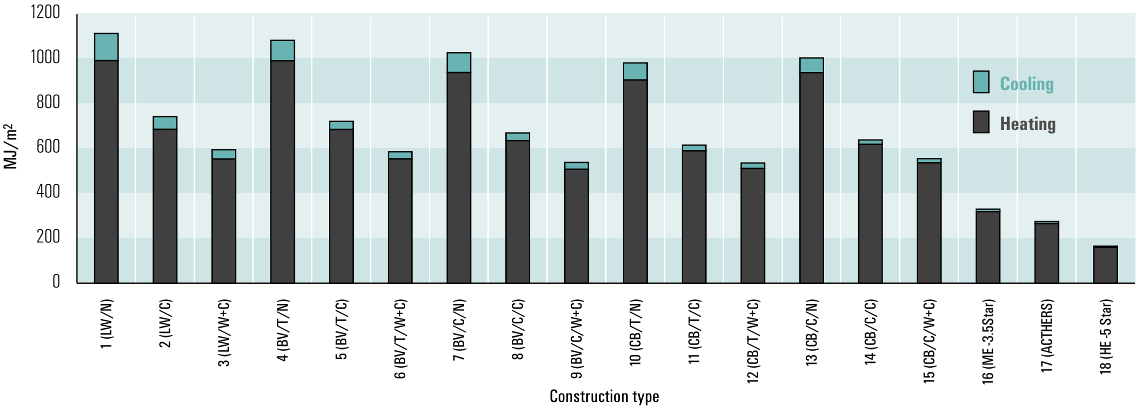
Climate Type 3 – Western Sydney



Climate Type 4 – Melbourne



Climate Type 5 – Canberra



3.12 Calculating unconstrained heating and cooling loads

For each of the five efficiency scenarios, data relating to stock penetration levels (detached and non detached) by state by year is combined with ABS household numbers by state by year and floor area data for new housing, additions and demolitions to give gross floor areas by construction type by state by year by efficiency scenario.

Gross floor areas are then multiplied by the appropriate climate weighted performance factors for both heating and cooling to give state totals for unconstrained energy consumption for each construction type for each state for each year for each efficiency scenario. Values for each of the construction types are then totalled for each state to give a total unconstrained consumption by state by year.

The results of this analysis for combined unconstrained heating and cooling loads are presented in graphical form below in Figure 31. Combined heating and cooling loads are expressed as a percentage of the 1990 level.

Figure 31: Projected trends in unconstrained heating and cooling loads 1990–2010

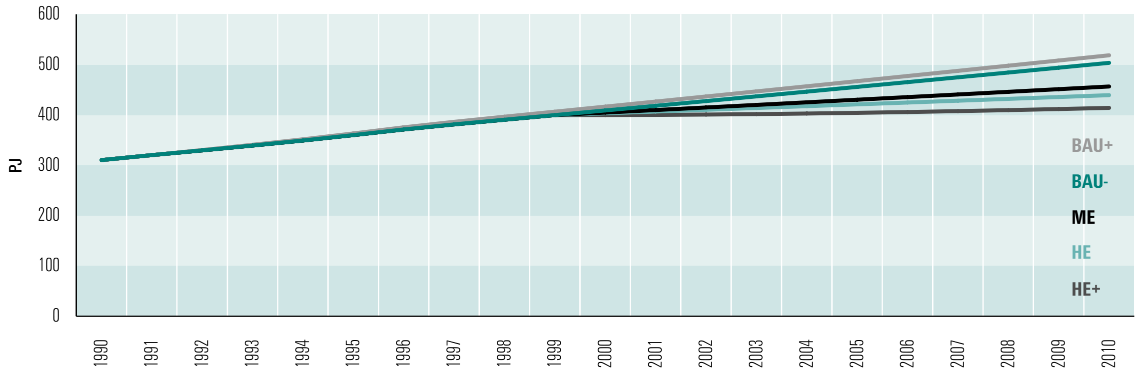


Figure 32: Projected trends in unconstrained heating and cooling loads 1990–2010

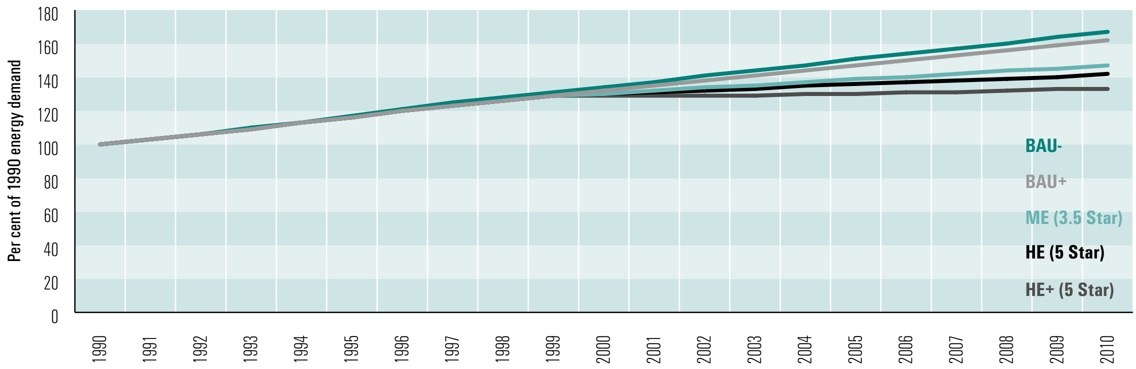
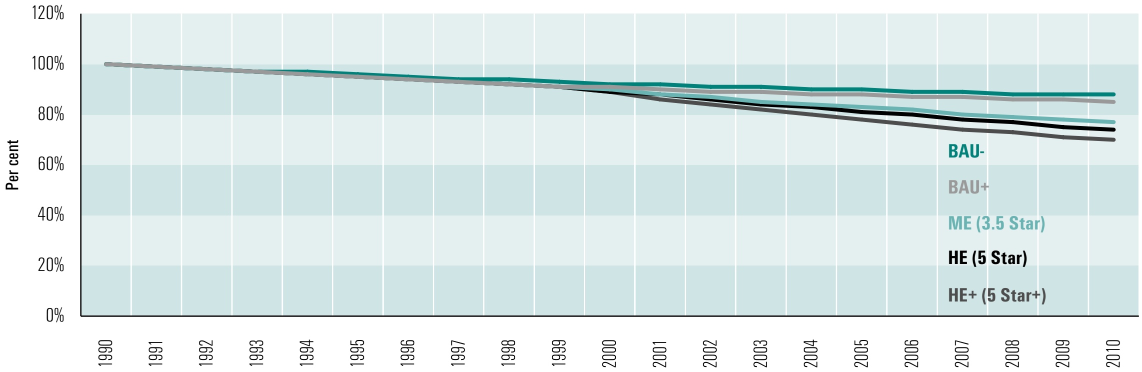
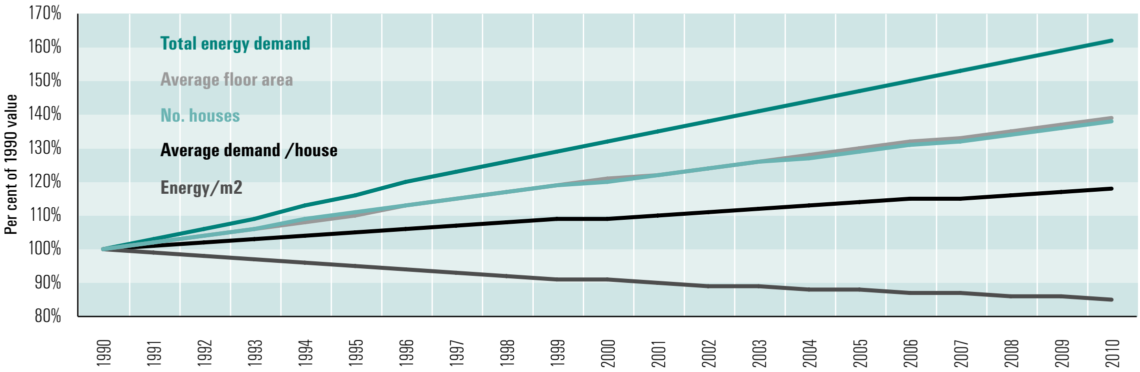


Figure 33: Change in stock building shell energy demand 1990–2010



Note: Energy demand MJ/m2 expressed as per cent 1990 level.

Figure 34: Trends in household characteristics and numbers 1990–2010



3.13 Results and observations relating to building shell modelling

Results and observations in the following sections relate to the unconstrained residential heating and cooling demand profile as determined in this chapter.

3.13.1 Results

- The results indicate that unconstrained heating and cooling energy consumption is likely to rise steadily under the BAU+ scenario to 162 per cent of 1990 levels.
- In the absence of the measures already implemented up until the end of 1997 (ie BAU- case) the unconstrained energy consumption would be expected to rise a further 5 per cent as compared to the BAU+ case.
- The Medium Efficiency (ME) scenario (3.5 stars) would result in a reduction in unconstrained heating and cooling energy consumption of 15 per cent as compared to the BAU+ case (down to 147 per cent of 1990 levels).
- The High Efficiency (HE) scenario (5 stars) would result in a reduction in unconstrained heating and cooling energy consumption of 20 per cent as compared to the BAU+ case (down to 142 per cent of the 1990 levels).
- The High Efficiency Plus (HE+) scenario (5 star plus retrofitting of ceiling insulation) would result in a reduction in unconstrained heating and cooling energy consumption of 29 per cent as compared to the BAU+ case (down to 133 per cent of 1990 levels).
- The BAU+ case was found to equate roughly to an average NatHERS performance level for new housing of 2 Stars.
- In all scenarios examined, including the business as usual scenarios, the building shell thermal performance efficiency of the stock in terms of MJ/m^2 energy demand was found to be improving. In the business as usual scenario the improvement in stock efficiency between 1990 and 2010 is calculated to be 15 per cent. This compares to a 23 per cent improvement for the ME case, and a 26 per cent improvement for the HE case and a 30 per cent improvement for the HE+ case.

3.13.2 Observations regarding shell modelling results

As expected, the effect of the HE and particularly the HE+ scenario is to curtail the rate of increase in energy consumption, but not to the extent that the increase is entirely arrested. Even under the HE+ scenario, the total energy consumption is expected to be approximately 33 per cent above 1990 levels, most of this increase already having occurred by 1998 (approx. 26 per cent). What is clear, however, is that whereas the high efficiency measures will not deliver the required saving alone, they would act to put a brake on further increases in energy consumption and help to close what could become an ever widening gap between target and delivered levels of efficiency improvements.

Whilst the thermal efficiency of the stock of residential building shells is showing modest but steady improvement over time (15 per cent between 1990 and 2010 BAU+), these gains are far outweighed by the more substantial increases both in stock numbers (+38 per cent over the same period) and in average stock floor areas (+39 per cent over the same period). The resultant effect in the

BAU+ case is an increase in energy consumption of +62 per cent in unconstrained terms or +54 per cent in constrained terms.

Building shells generally have a very long life and energy efficiency program measures implemented now will have a very long term impact, well beyond the year 2010, which is the limit of this study. The fact that 80 per cent of all housing stock in the year 2010 has already been built by 1998 would indicate that:

1. Improving the existing building stock through various retrofitting strategies such as retrofitting of ceiling insulation would appear to warrant more detailed investigation.

2. More stringent measures for new buildings are warranted to assist in mitigating the relatively poor thermal performance standards of our existing stock.

Efficiency gains that are associated with retrofitting ceiling insulation (HE+ scenario), whilst significant in the short term, represent a once off saving only. Following such a program, further improvements would be likely to be more highly dependent upon improvements to new stock.

It is clear from this study that present user behaviour drastically reduces the potential maximum energy demands for both heating and especially cooling. Small increases in required user comfort levels could significantly impact on energy demand in this area. This potential for increase can be mitigated to a large extent through improved building shell thermal performance standards.

Should it be decided that new housing stock will be required to meet more stringent thermal performance standards, then the need for land subdivision design to address the issue of solar access and building orientation will be a necessary adjunct to such a program. One of the most cost effective ways of producing more thermally efficient housing is through improved orientation and glazing placement (ie passive solar design principles). This can be made impractical if subdivision design does not facilitate this approach.

House additions are significant in terms of added floor area per annum. Practices in this area warrant further investigation.

Non detached type housing presently provides significantly greater thermal performance efficiency than detached type housing (on average approx. 35 per cent improvement). This difference would however become less significant in absolute terms with general improvements in shell performance.

Whilst the rate of addition of new housing stock is relatively steady over time, a steady trend towards the non detached type has been observed over the past 10 years. In National terms the proportion of non detached type housing has increased from approximately 22 per cent of all new housing in 1987 to about 30 per cent in 1997. This increase has not been uniform on a state by state basis. Some states, such as NSW, have shown a strong increase (24 per cent to 43 per cent), whereas other states such as Tasmania have gone against the National trend with non detached housing decreasing (24 per cent to 13 per cent).

From the NatHERS modelling results insulation can be clearly identified as a significant factor in improving building shell thermal performance.

Whilst prescriptive measures are relatively easy to implement, by their nature they tend to be relatively unsophisticated and their use often results in lost opportunities especially in respect of the principals of passive solar design. In Victoria, for example, there are numerous houses that, despite meeting the mandatory insulation requirements, exhibit poor thermal performance due to poor orientation, lack of shading and or lack of winter solar access, all design aspects that often represent a zero incremental cost in most cases and yet can easily result in more than a 50 per cent decrease in energy use. In the authors opinion the higher the overall thermal performance standard desired, the more likely a performance based measure will produce the most cost effective outcome for the consumer. A small amount of extra effort in design and detailing can result in a large gain in thermal performance.

4 HOUSEHOLD AND POPULATION DATA

4.1 Population

The Australian Bureau of Statistics has conducted a Census of Population and Housing at 5 yearly intervals since 1961 and at ad hoc intervals prior to 1961. Population reported in the census excludes temporary visitors from overseas. Note that the census enumerates the population where they are found on census night (not necessarily in their usual residence) and does not include Australian residents who are temporarily overseas. All censuses have occurred on or about 30 June of the year of the census, except for 1996 which was held in August.

The primary historical population source of data for this study was the Australian Bureau of Statistics document titled Australian Demographic Trends (ABS 3102.0 1997). This document provides an estimate of the population from 1901 to 1996 by Australian state and Territory. This report has used these published values by state from 1966 to 1996. However, the data from 1992 to 1996 is based on the 1991 Census data as this document was published before the 1996 census results were available so small adjustments were made to ERP values from 1993 to 1996 to match ABS population projection data.

Estimated Resident Population (ERP) are estimates of the Australian population obtained by adding to the estimated population at the beginning of a period the components of natural increase (on a usual residence basis) and net overseas migration. For states and territories, account is also taken of estimated interstate movements involving a change of usual residence. After each census, estimates for the preceding inter-censal period are revised by incorporating additional data obtained from the new census. Estimates of ERP are based on adjusted census counts (which tend to under enumerate population) by place of usual residence, to which the number of Australian residents estimated to be temporarily overseas at the time of census.

The concept of ERP links people to a place of usual residence within Australia. Usual residence is that place where each person has lived or intends to live for six months or more in the reference year. Estimates of ERP are available from 1971.

Until 1971 annual estimates of population in ABS 3102.0 are based on unadjusted census counts on an actual location basis, updated for post censal years according to registered births and deaths by State of registration. From 1971 population estimates are Estimated Resident Population (ie enumerated on the basis of place of residence).

Population projections are published on a regular basis by the Australian Bureau of Statistics, the most recent being ABS 3222.0 Population Projections 1997 to 2051. ABS projections are Estimated Resident Population. ABS make the point that these are not predictions or forecasts, but illustrations of what would happen under certain assumptions about future demographic trends. The document examines in detail all of the likely factors that will affect population growth in each state including fertility rates, mortality rates, overseas migration and internal migration (between states) and proposed a range of likely values for each of the key variables. This results in a large number of possible scenarios, but ABS have narrowed this down to essentially three separate series, called Series I, II and III. The assumption for these series are shown in Table 32.

Table 32: ABS population scenarios – Key assumptions

ABS scenario	Total fertility	Overseas migration	Crude birth rate	Crude death rate	Growth rate	Median age	Population at 2010
Series I	1.75	90000	10.4	11.1	+0.3	43.7	21 130 100
Series II	1.75	70000	10.3	11.4	+0.2	44.1	20 856 500
Series III	1.6	70000	9.2	12.1	0.0	46.2	20 666 500

Source: ABS 3222.0

Table 33: ABS Series 2 – Estimated resident population

Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
1966	4209710	3149035	1660076	1081864	837290	369600	55418	92624
1971	4571920	3481370	1812297	1168115	1013455	389739	82996	137605
1976	4946530	3799937	2072044	1270025	1166902	411332	95589	203477
1981	5205830	3931159	2303192	1312810	1284014	425338	121193	226260
1986	5497291	4140430	2597025	1376832	1437490	444628	151933	255420
1991	5865740	4401563	2930154	1439299	1625226	464616	164859	285453
1996	6207002	4570535	3317737	1472971	1768062	472008	183196	305604
2001	6497300	4748600	3640000	1501700	1915100	470500	204700	319200
2006	6745600	4892500	3946900	1523400	2057800	466300	224700	332200
2011	6970300	5015000	4247200	1537200	2199100	459300	245400	343800

Sources: ABS 3102.0 and ABS 3222.0

All three Series have been entered into the model to enable sensitivity analyses to be carried out for the this study. For the base case, Series II (Table 33) has been selected. Results for the other two population projection Series are available on request.

It should be noted that the population ERP estimates for years 1992 to 1996 have been adjusted to match the ERP values provided for the population projections in ABS 3222.0. In this report, ERP values incorporate Jervis Bay residents with the ACT and Cocos (Keeling) Island and Christmas Island residents with Western Australia.

4.2 Households

The primary historical source of data for households was the Australian Bureau of Statistics Census of Population and Housing, which has been held at 5 yearly intervals since 1961. Household types listed in the census include private, non-private (hotels, institutions, barracks, staff quarters etc) and unoccupied. This report has used values for occupied private households. Prior to 1986, caravans were counted as non-private dwellings, but from 1986, they have been included as private occupied dwellings. The census also generally gives limited information on the dwelling structure.

A dwelling is a building or structure in which people live. This can be a building such as a house, part of a building such as a flat, or it can be a caravan or even a tent. Houses under construction, derelict houses or converted garages are not counted as dwellings in the census.

A private dwelling is normally a house, flat or even a room, but it can also be a house or rooms attached to shops or offices. Private dwellings can be either occupied or non-occupied. This study has excluded non-occupied private dwellings.

Non-private dwellings are those dwellings not included in private dwellings, which provide a communal or transitory type of accommodation. These dwellings include hotels, motels, guest houses, prisons, religious and charitable institutions, defence establishments, hospitals and other communal dwellings. For this study, non-private dwellings have been excluded from the household estimates. These are generally associated with commercial sector energy consumption and include such things as prisons, hospitals staff quarters, and residential accommodation in commercial buildings. This study covers all households which live in Class 1 and 2 Buildings as defined under the building Code of Australia.

The definition of a household used by the Australian Bureau of Statistics (ABS) in its appliance surveys is “a group of persons who are the usual residents of a dwelling and who have some common provision for food and other housekeeping arrangements” (ABS 1988, 8218.0).A household can of course consist of one person only, and as the population ages, the proportion of single-person households in Australia is projected to increase, from about 19.8 per cent in 1991 to 21.5 per cent in 2011 (Ironmonger and Lloyd-Smith 1992). It is assumed that there is a single household per “dwelling” for the purposes of this report. From 1966 to 1996, census household counts (for occupied private dwellings) have been used and numbers between census periods have been estimated on the basis of constant growth for the intervening 5 year period at the state level.

In 1997, ABS published a report which estimated resident households in Australia for 30 June 1986 and 1991 and then each year to 1996 (ABS 3101.0). However, data is only available for 1986 and 1991 and it is not possible to get a long term data set for analysis of population and household trends, so this data has not been used in this report. Unfortunately, ABS do not provide projections of households. However they are proposing to publish household projections from late 1999. For this project it has been necessary to use an alternative method of household projections by state.

Household size data from 1966 to 1996 has been examined. The average number of persons per household in Australia has declined over the past 30 years and is projected to continue to decline to 2010. This means that the number of households is increasing faster than the rate of increase in population.

Household estimates to 2010 were obtained by the projection of household size data for each Australian state based on size trends from 1966 to 1991. The change in household sizes shown in Table 34 and the projected values to 2010 are shown in Table 35. Generally, the projected decline in household size to 2010 has been set at about 65 per cent of the 1986–96 decline at the state level.

Table 34: Actual and projected household size changes

Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
1966-71	-1.16 %	-0.73 %	-1.09 %	-1.11 %	-1.05 %	-1.13 %	-6.26 %	-1.78 %
1971-76	-0.33 %	-0.35 %	-0.40 %	-0.97 %	-0.55 %	-1.03 %	-2.54 %	-0.30 %
1976-81	-1.13 %	-1.30 %	-1.00 %	-1.35 %	-1.68 %	-1.45 %	-0.05 %	-1.57 %
1981-86	-0.86 %	-0.78 %	-1.73 %	-0.98 %	-0.66 %	-1.06 %	-3.05 %	-0.56 %
1986-91	-0.33 %	-0.48 %	-0.91 %	-0.72 %	-0.78 %	-0.84 %	-1.56 %	-0.87 %
1991-96	-0.67 %	-0.76 %	-0.87 %	-1.03 %	-1.01 %	-1.12 %	-0.45 %	-1.43 %
1986-96	-0.50 %	-0.62 %	-0.89 %	-0.88 %	-0.90 %	-0.98 %	-1.00 %	-1.15 %
1996-2011	-0.30 %	-0.40 %	-0.60 %	-0.60 %	-0.60 %	-0.63 %	-0.65 %	-0.70 %

Note: Values for 1996 to 2011 have been estimated by authors for this project

As we can use 3 population projection scenarios, we propose to hold the household size projections constant so that we get a corresponding increase or decrease of household numbers. While this may not be strictly true in reality (a faster population growth would tend to slow household formation a little), it is a convenient way of testing the sensitivity of the energy projections to changes in future household numbers.

Table 35: ABS Series 2 — Actual and estimated households

Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
1966	1177355	879598	445520	299408	223301	98309	8545	23304
1971	1355676	1008887	513884	341876	284981	109703	17676	37870
1976	1491242	1120474	599308	390223	337350	121939	23150	56836
1981	1661581	1237483	700585	431759	404048	135615	29421	68410
1986	1831981	1355173	861985	475716	467641	149544	43063	79413
1991	1987265	1475393	1017800	515705	549931	163001	50542	92716
1996	2174917	1591657	1204072	555834	629303	175197	57435	106686
2001	2311096	1687141	1361382	583986	702460	180244	66304	115416
2006	2435734	1773454	1521258	610522	777860	184370	75194	124410
2011	2554965	1854656	1687009	634871	856666	187432	84843	133357

Note: Actual households 1966–1996, projected to 2011

Total residential sector floor area has been estimated by NIEIR (1997) as part of a separate consultancy. There was close agreement on the total number of dwellings estimated by NIEIR and by EES from Census data (generally less than 1 per cent difference), although the differences climbed to as high as 4 per cent in 1996 (it is unclear whether they had access to the latest census data for their estimates). Floor area per separate and non-separate dwelling was derived from NIEIR estimates for total floor area and EES dwelling numbers from the census (including unoccupied dwellings). Subsequent analysis for this project suggests that NIEIR did not take into account increases in total floor area due to extensions.

5 APPLIANCE AND EQUIPMENT DATA

This section provides an overview of the primary elements of input data which are required for the stock model and the data sources used to provide each of the estimates. In summary these are:

- Appliance penetration and ownership estimates (number in use)
- Appliance technical attributes (eg efficiency, losses)
- Discretionary usage factors (eg frequency and duration of use, wash temperatures)
- Climate and physical data
- Overview of energy end use measurements (direct measurements or estimates) by technology type

5.1 Appliance ownership data

5.1.1 Concepts and definitions

Each household has a number of appliances which convert the energy purchased to the desired energy services of cooking, water heating, lighting etc. For this report, the following terms are used:

- **penetration —** the proportion of households in which a particular appliance type is present (irrespective of the number of units of that appliance in the household). This value is usually given as a percentage;
- **stock —** the total number of a particular appliance type in use within households. This value is given as an integer (usually thousands or millions). The stock refers to the number in regular use, or a proxy for the number in regular use;
- **ownership —** the ratio of stock to the total number of households. This value is usually given as a decimal number.
- **saturation —** the average number of appliances per household for those households with the appliance.

Where each household owns a single appliance of a particular type, ownership is equal to penetration. Where some households own more than one of a particular appliance type, ownership is greater than penetration (penetration (saturation = ownership). The main appliances in Australia where the ownership is significantly higher than the penetration are as follows:

- Refrigerators
- Freezers
- Air conditioners
- Portable electric heaters
- Video Cassette Recorders (VCR)
- Televisions
- Hi-Fi systems

Lighting is treated as a single end use even though there are a number of appliances within a house which provide the energy service. Similarly, standby losses are also aggregated from a number of appliances.

5.1.2 Primary data sources

The only national data sets for ownership and penetration of appliances in Australia have been the ABS national energy surveys conducted in November 1980, June 1983 and (nominally January) 1986 (ABS 8212.0 and 8213.0) and an environmental issues survey ABS 4602.0 in June 1994. These surveys collected primarily penetration data, but there is some limited ownership data for some appliances for some years, namely refrigerators, freezers and air conditioners.

The other major early data source is the 1976 census which collected data for all households regarding the main fuel used for lighting, hot water, space heating and cooking (ABS 2409.0 to 2417.0 1976) which have been obtained from ABS for this project.

We have also used our knowledge of the appliance market plus selected interviews with manufacturers to estimate early trends within some market segments.

For more recent years, the survey by Test Research (1995) for NAEEEC was used to a limited extent to establish recent overall trends in cooking appliances. This data is only of limited use for this project as it is a self-completed questionnaire and only national average data is reported (no state estimates are provided — the sample is also NSW biased). This survey was also used to establish some trends in the usage of appliances such as frequency of use and programs, connection modes and water temperatures for washing.

In 1998, BIS Schrapnel conducted their biennial consumer and market prospects survey of the appliance industry (BIS Schrapnel 1998a). These reports provide data on total market sales by major appliance type, average time to replacement for appliances and some characteristics on new appliances. While conducting this survey, BIS Schrapnel undertook a household survey of appliance ownership. BIS Schrapnel have kindly made available unpublished results from the August 1998 survey (BIS Schrapnel 1998b). This data has been used to confirm trends for major appliances and to establish penetration and ownership levels for some appliances such as TVs and VCRs. While the data is available for the 5 large states, it should be noted that the results have not been corrected for demographic factors.

Penetration values for each appliance type and for each state and territory were collected and analysed. Values for 1980 and 1986 were assumed to be in the middle of the calendar years, although this is not strictly true. Values between surveys were determined from linear interpolation. Values for 2010 were extrapolated from the 1994 or 1998 values at the state level based on trend lines. Values from 1966 to 1976–1980 were back-cast at a state level on the basis of the trend from 1980 to 1994. State data was then recombined on a household weighted basis to provide a national estimate of penetration by year. It was necessary to determine penetration and ownership at state level as energy, and more importantly greenhouse gas emissions, are modelled at the state level. The stock model requires values back as far as 1966 for appliances that have longer lives.

This project has developed only a single scenario for future ownership and penetration trends. However, the modelling approach developed for this project could easily accommodate alternative ownership and penetration forecasts, such as high penetration gas or wood scenarios, should this be required after the completion of this project.

While specific issues for each appliance are discussed below, it should be noted most appliances were assumed to have a saturation of 1.0 except were otherwise noted. There are always some households with additional appliances (apart from those with known high levels of saturation listed above), but in most cases these additional units are rarely used. Fuel share projections for large energy end uses such as space heating and hot water took account of current and projected increases in the natural gas supply system in each state and the likely saturation of gas appliances at the state level. Further data from AGA about forecast infrastructure development could help to improve these estimates.

For multi-fuel end uses such as main space heating, cooking and hot water, saturation was assumed to be 1.0 and penetration 100 per cent. State totals were reconciled for every year to add to 100 per cent for all fuel types (where no appliance was present, this was counted as a separate fuel type for these types of appliances to ensure consistency — the main cases of note are the large proportion of households in Queensland and Northern Territory without any form of space heating). Some secondary heating appliances (portable electric heaters) are also known to exist in about 50 per cent of households, although the level of data on the ownership and their patterns of use are quite poor. Therefore these appliances have not been specifically modelled in this project. This means that some miscellaneous electricity consumption will in fact be associated with space heating, but data is too poor to separate this end use any further.

Generally speaking, reference to “gas” means natural gas (or mains gas) plus LPG. LPG penetration for most thermal appliances is generally low and steady, while natural gas is increasing in most states. The ACT started to receive natural gas supplies in 1982 and increases in penetration since that date has been dramatic (AGA 1998). In about 1976, Sydney was connected to the Moomba gas field and conversion to natural gas from town gas occurred over the following 10 years. Prior to 1978, mains gas in NSW was “town gas” generated from coke and limited to parts of Sydney, Newcastle and Wollongong. Mains gas in Tasmania was town gas until 1996, at which time the system closed down. In all other states, gas supplies have been natural gas (methane) for the duration of the study. ABARE still record a very small amount of town gas in NSW, Victoria, Queensland and Western Australia, which is mostly piped LPG.

As a general note, data for the Northern Territory is often spurious due to the small sample size in many surveys. However, this is of little consequence as the Northern Territory is quite small and only impacts minimally on the national results.

A summary of the major appliance data sources used in this study is shown in Table 36.

Table 36: Summary of major appliance data sources

Appliance	Census 1976	ABS8212 1980	ABS8212 1983	ABS8212 1986	ABS4602 1994	BIS Schr. 1998b
Refrigerator/freezer	-	P	O/P	P	O/P	O/P
Air conditioners *	-	P	P	P	O/P	P
Clothes washer	-	P	P	P	P	O/P
Clothes dryer	-	P	P	P	P	O/P
Dishwasher	-	P	P	P	P	O/P
Space heaters *	P	P	O/P	O/P	P	P
Water heaters *	P	P	P	O/P	P	P
Cookers *	P	P	P	P	-	-
TV	-	-	-	-	-	O/P
VCR	-	-	-	-	-	O/P

*Note: P = Penetration, O = Ownership, * = multi fuels/technologies*
Notes: Other sources used for cookers, TV and VCR such as ABS 4172.0, Test research (1995)

State level penetration and ownership data from 1966 to 2010 is shown in the Appendices for each appliance and fuel type. The following section provides an overview of the data.

Refrigerators and freezers

Data on penetration is available from 1980 to 1998. Ownership and saturation levels are available at state level from 1983 and 1994. Saturation and penetration levels were forecast and backcast to determine ownership levels, refer Figure 35. Refrigerators have a uniformly high level of penetration across Australia and an ownership level of about 1.30. Freezer ownership varies considerably across states and appears to be stable or declining in most states, refer Figure 36.

Figure 35: Refrigerator ownership by state and year

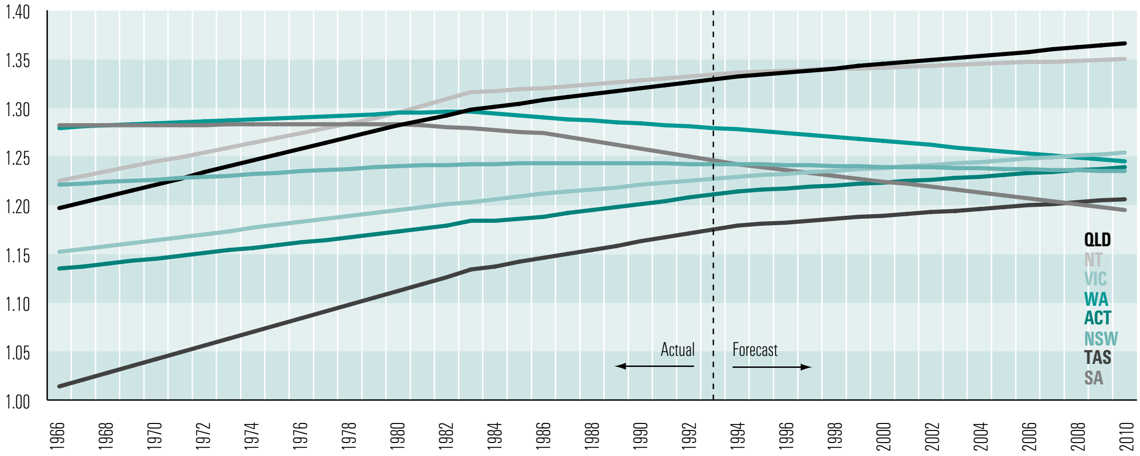
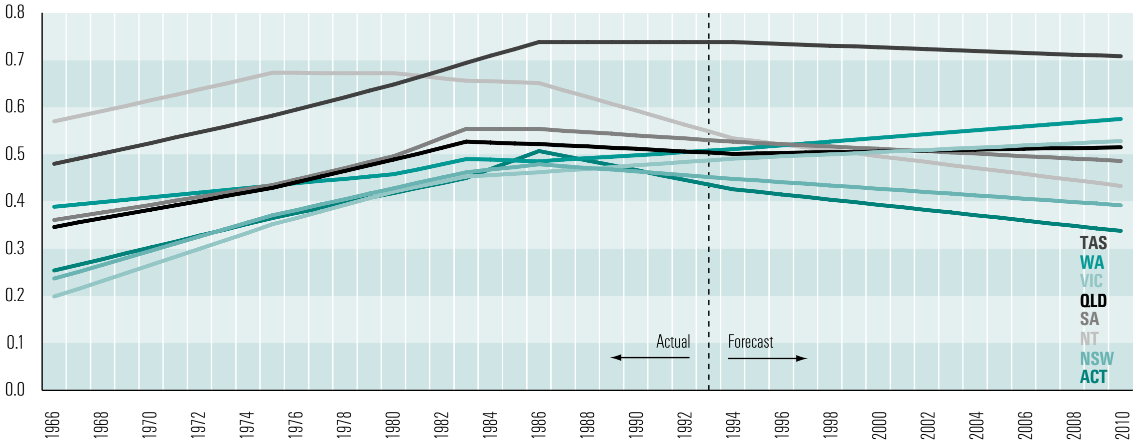


Figure 36: Freezer ownership by state and year



Air conditioners

Data on penetration is available from 1980 to 1998. Ownership and saturation levels are available at state level in 1994 only. Saturation levels were assumed to trend to 1.0 in earlier years and penetration was forecast and backcast to determine ownership levels. Note that ABS include ducted, non-ducted and evaporative air-conditioners within the definition of "air conditioner".

Air conditioner ownership varies considerably across states, as expected. In addition the share of technology within each state is also quite different.

Figure 37: Air conditioner ownership by state and year — all types

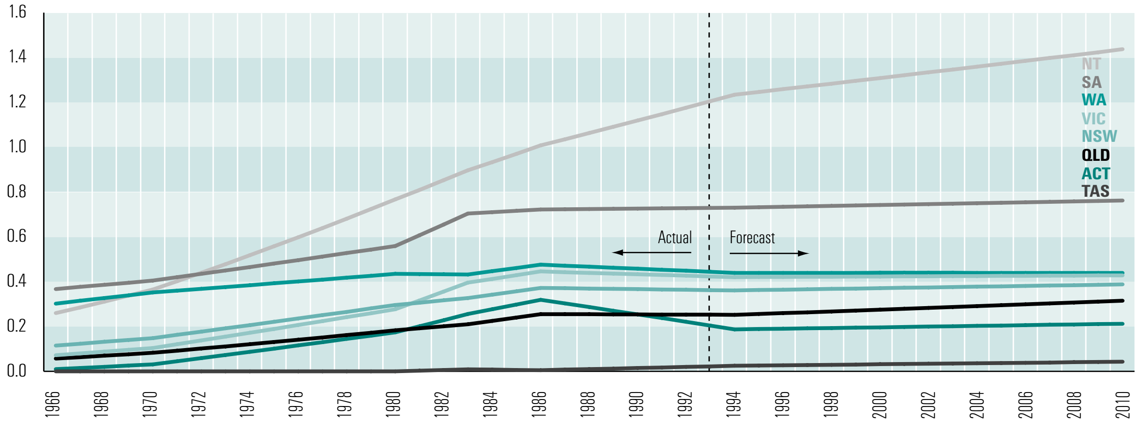
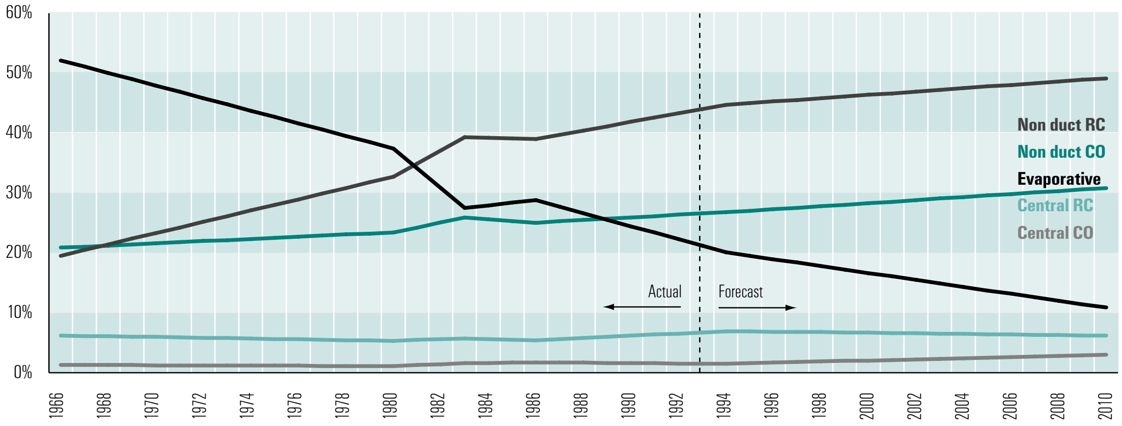


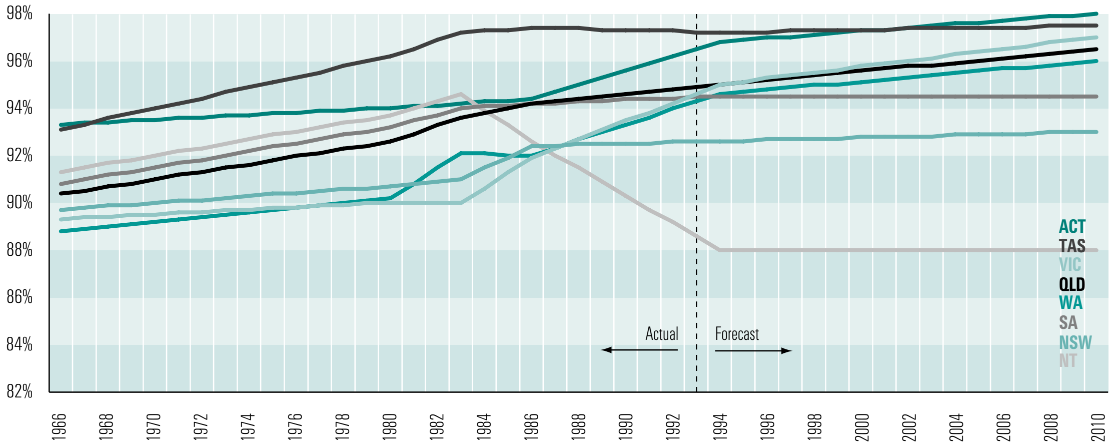
Figure 38: National share of air conditioner technology type by year



Clothes washers

Data on penetration is available from 1980 to 1998. Saturation levels are assumed to be 1.0 for all years (ie that additional appliances, if owned, are not regularly used). Clothes washers have a uniformly high level of penetration across Australia.

Figure 39: Clothes washer penetration by state and year

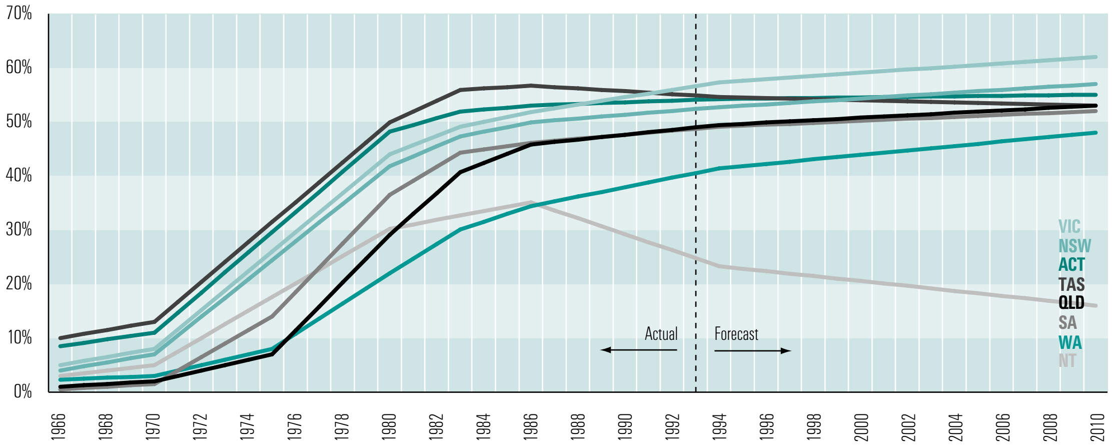


Clothes dryers

Data on penetration is available from 1980 to 1998. Saturation levels are assumed to be 1.0 for all years (ie that additional appliances, if owned, are not regularly used).

Clothes dryers penetration varies from 50 per cent to 60 per cent across most states penetration appears to have reached a plateau in many states.

Figure 40: Clothes dryer penetration by state and year

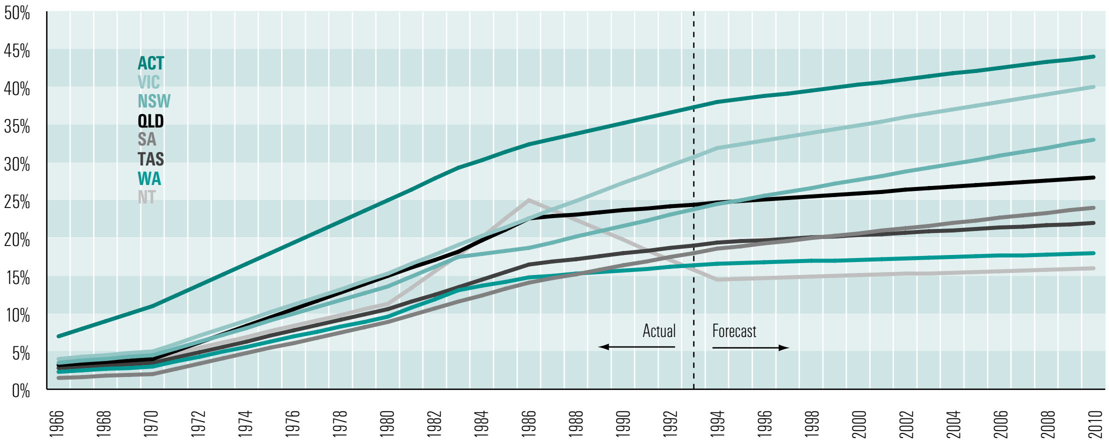


Dishwashers

Data on penetration is available from 1980 to 1998. Saturation levels are assumed to be 1.0 for all years (ie that additional appliances, if owned, are not regularly used).

Dishwasher penetration varies from 15 per cent to 35 per cent in 1998 and appears to be slowly but steadily increasing in all states.

Figure 41: Dishwasher penetration by state and year



Space heaters

Data on penetration is available from 1976 to 1998. Saturation levels for “main space heating” are assumed to be 1.0 for all years (secondary heaters are separately modelled in addition to main space heating). The fuel for main space heating was determined for all households. Those households without space heating were also tracked (ie “no heating” was a technology type) to ensure that main one heating type was allocated to every household. The proportion of households without space heating is increasing significantly (mainly in Queensland and Northern Territory), while wood and gas are also increasing. Electric space heating (which includes a share of reverse cycle air conditioners) is decreasing. Oil heating, which enjoyed quite high penetration in the 1970’s, has now almost disappeared.

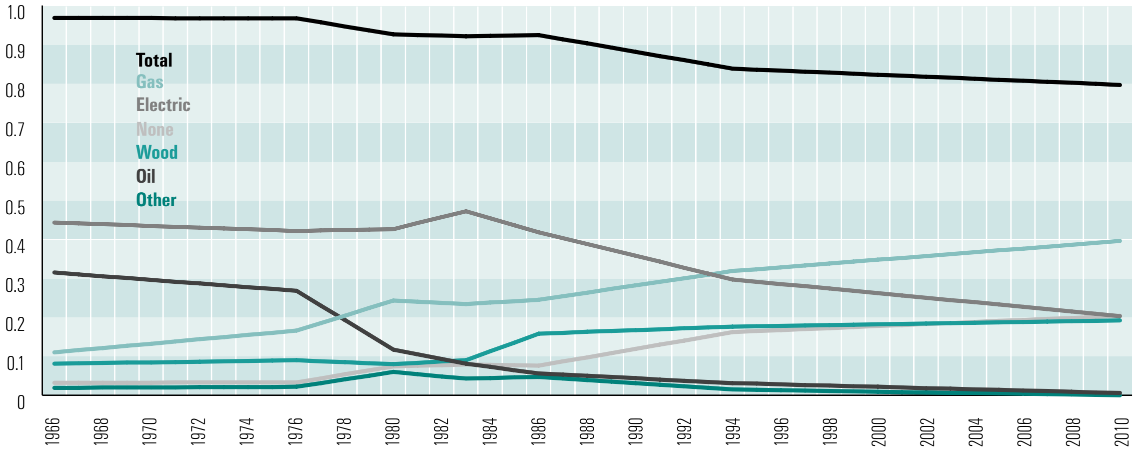
The technologies tracked by state and year for space heating include:

- Electric (resistive and reverse cycle air conditioners)
- Natural gas
- LPG
- Oil (including kerosene and fixed oil heaters)
- Wood
- Other (mostly coal products in VIC and WA)
- None

Note that energy consumption and greenhouse gas emissions are only estimated for electricity, gas and wood.

Secondary space heaters (mainly portable electric units) are quite common although there is only poor data on ownership and possible use, so this end use has not been separately included in this project.

Figure 42: Main space heater penetration by fuel type — Australia



Water heaters

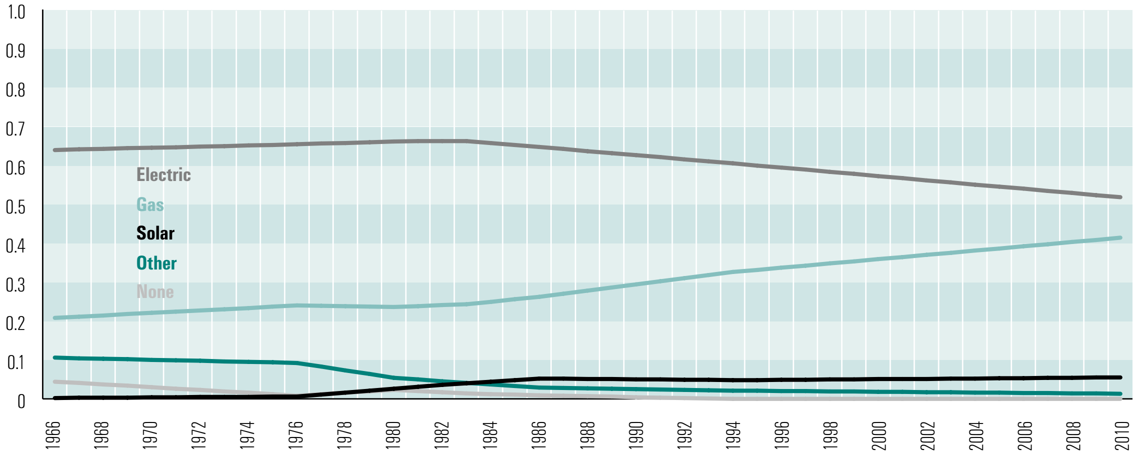
Data on penetration is available from 1976 to 1998. Saturation levels for water heating are assumed to be 1.0 for all years (even though there are a very small number of households with more than one water heater, these are assumed to provide the same total energy service). The fuel for water heating was determined for all households. There are now very few households without a water heater. The share of gas water heating is increasing, while electric water heating is decreasing. "Other" water heating (mostly wood, with a small amount of oil and coal products) has a very low and stable penetration.

The technologies tracked by state and year for water heating include:

- Electric
- Natural gas
- LPG
- Solar
- Other (mostly wood)
- None

Note that energy consumption and greenhouse gas emissions are only estimated for electricity, gas and solar.

Figure 43: Water heater penetration by fuel type — Australia



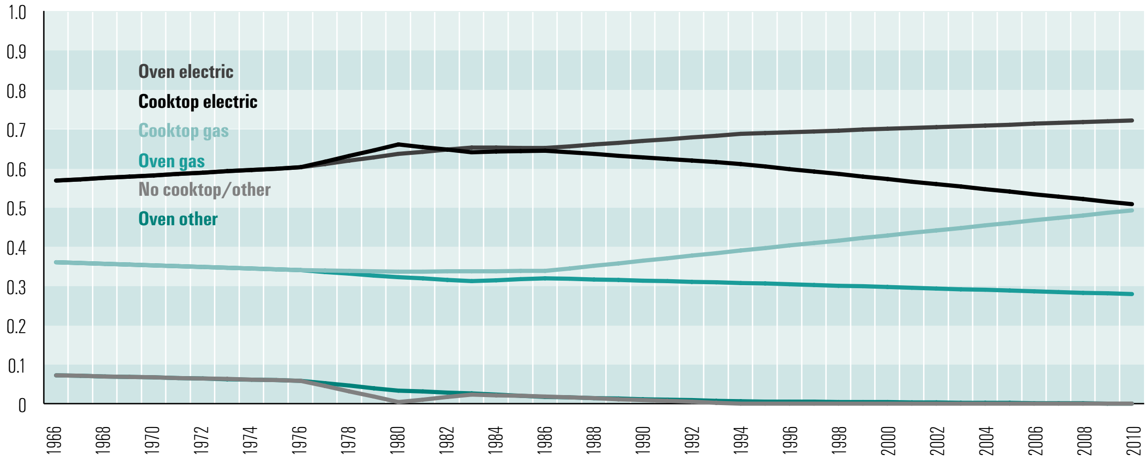
Cooking appliances

Data on penetration is available from 1976 to 1986. Data past 1986 is rather poor, although some obvious trends have emerged from Test Research (1995) and discussions with manufacturers. An integrated unit with a cooktop and oven (called a range) running on the same fuel predominated in the 1970's. Recent trends indicate separate cooktops and ovens are now dominant in the market place and that there is a strong trend towards a gas cooktop in combination with an electric oven. In 1995, it is estimated that the stock of cooking appliances was about 50 per cent ranges and about 50 per cent separate cooktops and ovens. The penetration of cooktops and ovens has been tracked separately for this report, even though in many cases these may be in fact integrated as a single "range". Data measurements tend to indicate that a range uses a similar amount of energy to a separate cooktop and oven so there is merit in this approach as it allows the fuels to be separately tracked. Saturation levels for cookers are assumed to be 1.0 for all years (even though there are a very small number of multi-fuel ovens or multi-fuel cooktops). There are virtually no households without an oven or a cooktop in some configuration.

The share of gas cooktops is increasing while electric cooktops is decreasing. Conversely, gas ovens are decreasing while electric ovens are increasing. It is likely that superior performance attributes of gas cooktops and electric ovens over their competitors is driving this trend. There is virtually no other fuel used for cooktops. There is a very small share of other fuels used for ovens (mostly wood — about 0.5 per cent in 1998) but this has now virtually disappeared. The technologies tracked by state and year for cooking include:

- Electric
- Natural gas
- LPG
- Other (mostly wood)
- None (disappeared by late 1980's)

Figure 44: Cooking penetration by fuel type – Australia



Televisions

Television penetration in Australia is now virtually 100 per cent. The ownership levels are very high, with 40 per cent of households owning one television, 40 per cent owning 2 televisions, 15 per cent owning 3 televisions and 5 per cent owning 4 or more televisions in September 1996 (ABS 4172.0 1997) (total ownership of about 1.90). Ownership levels are relatively uniform across states, so a uniform national value is used in all states for this report.

Colour television was introduced in the mid 1970's and there would have been a rapid turnover of the stock from black and white to colour from 1975 to 1985. Wilkenfeld (1989) shows that black and white TV penetration increased very rapidly through the 1960's. However, the transition from black and white to colour is not tracked by penetration (a constant high penetration is assumed through this period), but the characteristics of new TVs have been adjusted through the 1980's to reflect this transition.

Modelling penetration and ownership of televisions presents some interesting dilemmas. The energy consumption of TVs is dominated by the hours of operation (although standby is becoming increasingly important). Data is available on the hours per week of watching television(s), but this is likely to be total hours watched rather than *hours for each television.* On this basis, it has been decided that for energy consumption modelling purposes that only the "first" or primary television will be modelled. The penetration for these units is assumed to be 100 per cent. Additional units will be largely accounted for as hours watching a second television will result in reduced watching of the primary set. It is assumed that the standby losses for second and subsequent televisions are accounted for in Standby Electricity.

Video cassette recorders

VCRs started at a low penetration and have quickly grown through the 1980's and 1990's. Penetration is now about 90 per cent. Interestingly, about 20 per cent of households own 2 VCRs while 3 per cent own 3 or more (BIS Schrapnel 1998b).

Unlike televisions, the majority of energy consumption of a VCR is during standby as the difference between consumption during use and standby is quite small (see section on appliance attributes for more details). On this basis, the ownership of VCRs has been estimated for the purposes of energy modelling. As for televisions, ownership levels for VCRs are relatively uniform across states, so a uniform national value is used in all states for this report.

Standby power consumption

A large number of small appliances now have standby losses. Details of the range of standby energy consumption for different products is shown in the section on appliance attributes. Standby losses for major appliances (clothes washers, clothes dryers, dishwashers, air conditioners, heaters, cookers, televisions and VCRs) are modelled specifically for this project. Standby losses are meant to cover other types of equipment that are on continuously such as answering machines, transformers (various small appliances), battery chargers, central vacuum cleaners, clock radios, automatic garage door openers, intercoms, door bells, stereo systems, burglar alarms, control systems etc (ie anything which draws a constant small mains power supply). For illustrative purposes, the number of items with standby losses is assumed to grow from 1.0 per household in 1980 to 7.0 in 1994 to 9.0 in 2010. The energy consumption of such devices (even if only a few watts each) is very significant. However, the reality is that very little is known regarding the number or characteristics of such equipment in residential households in Australia, so author estimates have been used.

Lighting

All households are assumed to have electric lighting. Lighting energy is modelled on the basis of share of technology type (incandescent, quartz halogen and fluorescent) and a standardised lighting Lumen requirement per square metre of floor space per year. This is outlined in the appliance attributes section.

Miscellaneous electricity consumption

All households are assumed to have miscellaneous electricity consumption. This covers all end uses not explicitly covered above. This covers small appliances, home computers, pool pumps, water beds, stereo equipment, microwave ovens and so forth. The most significant components of miscellaneous electricity not specifically modelled are likely to be pool pumps (and other water pumps such as pressure pumps), water beds, secondary electric space heating and secondary lighting (eg plug loads such as standard lamps).

5.2 Appliance attribute data

5.2.1 Overview

Energy consumption is influenced significantly by the appliance "attributes". Attributes of each appliance are those factors which determine energy consumption independently of how the user operates the appliance. Attributes are primarily energy efficiency related (capacity, unit efficiency or losses), although some factors are required to derive the requirements for secondary appliances (eg hot water consumption of clothes washers will affect total hot water requirements, spin performance of clothes washers will affect dryer energy consumption) and are usually determined under standardised conditions.[13] Where necessary, values determined under standardised have been varied at state level to reflect actual conditions (eg colder air and water temperatures in Tasmania result in higher heat losses and energy consumption for water heaters, the converse is true for Queensland). The values for these attributes can be varied from year to year and reflect the average value of new appliances sold in that year. Attributes include:

- average size (eg litres) or capacity (eg kg of clothes);
- energy consumption of certain components in the appliance (eg pumps and motors per load) or of the whole appliance (eg refrigerators and freezers under standard conditions);
- standby losses (electronic controls) or standing heat losses (eg water heaters)
- intrinsic energy efficiency, eg kWh per kg water removed for clothes dryers, coefficient of performance for air conditioners, burner efficiency for gas appliances, Lumens per Watt for lighting appliances;
- intrinsic water efficiency, eg total and hot litres per wash under standard conditions;
- spin performance for clothes washers
- for dishwashers, the proportion connected to hot only, cold only and both.

The appliance attributes are derived from a range of sources. These include the analysis of GfK retail appliance sales data for refrigerators, freezers, clothes washers, clothes dryers and dishwashers from 1993 to 1997 (EES 1997), energy labelling registers, Australian Gas Association data on energy labelling of gas appliances (AGA 1997), various Choice Magazine test results over the years, GWA (1991a) and interviews with various manufacturers over the years.

Energy Efficient Strategies (EES) was commissioned to undertake a full analysis of appliance model sales data that has been purchased from GfK Market Research. This report includes the analysis model sales data in Australia for the years 1993 to 1997 inclusive, thus giving five years of appliance efficiency trends (EES 1997). The report was prepared under contract to NAEEEC. NAEEEC is made up of New Zealand and Australian state and federal government representatives who are responsible for energy efficiency programs for appliances and equipment. The information provided by GfK was in the form of national sales data plus sales data for five state groupings. The appliance lists show the largest selling models for each of the main appliance categories. These model sales have been cross matched to energy labelling registration data to provide considerable detail regarding the performance of each model. GfK claim to cover some 98 per cent+ of retail sales. Data provided by GfK for analysis generally covered 80 per cent to 90 per cent of the total market so there is a high degree of certainty regarding the values estimated.

It is important to note that the stock model requires data only on new appliances installed in each year. It subsequently determines the stock weighted average values for these attributes as an average of the remaining stock less retirements plus the weighted average value of new appliances entering the market.

From the above sources, there is a high degree of confidence in the values specified for appliance attributes for new appliances entering the stock from 1992, since they are derived from an actual analysis of the national market. It is however necessary to estimate how each of these values has changed for appliances entering the stock in each year since 1966, and to project further changes to 2010. This has been done with the assistance of published data and also with the assistance of discussions with local appliance manufacturers, who have been very helpful in providing data.

Specific programs that have been factored into the appliance attributes include Minimum Energy Performance Standards (MEPS) for refrigerators, freezers and electric storage water heaters which are scheduled to come into force in October 1999. For the base case it is assumed that no further MEPS for these products or any new products come into force before 2010. However, the influence of the energy labelling programs for gas and

[13] Standardised in this sense refers to those conditions set out in a test procedure, such as an industry or Australian Standard.

electrical appliances is assumed to have an ongoing effect in the base case.

All of the main data sources suggest that the technical attributes of appliances sold around Australia are generally fairly uniform. On this basis, a single set of appliances attributes has been used for all states.

The only exception is likely to be for refrigerators where the market share of the different Groups (eg frost free versus cyclic defrost) does vary somewhat at the state level. However, the attributes within each Group are very uniform. A refrigerator and freezer sub-model has not been developed for this project (this adds an additional 5 sub-groups to the stock model which has to remain internally consistent in terms of market share at the state level). However, the basic data is available should this require investigation subsequently to this project.

5.2.2 Attributes by appliance type

Appliance attributes by year are shown in the Appendices. The main components are discussed below by appliance type.

Refrigerators and freezers

Accurate weighted performance data for new refrigerators and freezers is available from the analysis of GfK model sales (EES 1997) which is now available for the years 1993 to 1997 inclusive. Values from this study have been used for these years in the appliance. Values in previous years were estimated from a range of sources including GWA 1991a, EES 1995 and EES 1996.

Projections to 2000 include the impact of Minimum Energy Performance Standards (MEPS) which come into force in October 1999. Beyond 2000, energy consumption per unit is projected to reduce at about 1 per cent per annum. Volumes of new refrigerators and freezers have nearly stabilised, and both are projected to start to decline slightly by 2010.

Clothes washers

Accurate weighted performance data for new clothes washers is available from the analysis of GfK model sales (EES 1997) which is now available for the years 1993 to 1997 inclusive. Values from this study have been used for these years in the appliance. Values in previous years were estimated from a range of sources including GWA 1991a and EES 1995.

Capacity is projected to decline slightly, while water consumption is also projected to decline. It is assumed that all clothes washers are connected to hot and cold water and that no water is heated internally, as only a few European machines on the market with a small number of sales now offer cold only connect machines. The existence of internal heaters only shifts some energy from an external hot water system (of various fuels) to “plug load” electricity, which on average is more greenhouse intensive.

Water consumption for a warm wash is provided to the stock model. The clothes washer module then export the total hot water demand to the water heater stock module. The clothes washer stock module takes account of the share hot, warm and cold water washing and the trends within each state (see discretionary data below). The volume of external hot water consumed by clothes washers is adjusted for cold water temperature variations by state. Zero external energy is assumed for cold water washing (even where local cold water temperatures are low).

Mechanical energy consumption of pumps and motors is small and is likely to remain relatively static. The spin performance in 1997 improved significantly compared with the 1996 value due to increased market share of models with good spin performance (top and front loading machines), but the projected value only shows a small additional decline. Standby energy consumption is assumed to have started in the early 1990’s with the introduction of electronic controls, with future values projected to decrease as standby energy consumption is likely to be included into energy labelling tests in the near future and as a result of increased government pressure to reduce standby losses for appliances.

External hot water consumption is estimated by the stock model. The clothes washer module then exports the total hot water demand to the water heater stock module.

Standby energy consumption is assumed to have started in the early 1990’s with the introduction of electronic controls, with future values projected to decrease as standby energy consumption is likely to be included into energy labelling tests in the near future and as a result of increased government pressure to reduce standby losses for appliances.

Clothes dryers

Accurate weighted performance data for clothes dryers is available from the analysis of GfK model sales (EES 1997) which is now available for the years 1993 to 1997 inclusive. Values from this study have been used for these years in the appliance. Values in previous years were estimated from a range of sources including GWA 1991a and EES 1995.

Capacity is projected to decline slightly, while the raw efficiency (kWh per kg water removed) is also projected to decline slightly. The spin performance of the clothes washer stock will affect the energy consumption of clothes dryers, so this attribute is exported from the clothes washer stock model module and imported into the clothes dryer stock model module as “discretionary” data (see following section on discretionary data and use patterns).

The share of autosensing dryers is projected to increase at a steady rate to 2010. The actual energy impact of autosensing versus timer controls is unclear (EES 1998), but it assumed that the field use factors in AS/NZS 2442.2 (timer energy = 1.1, autosense energy = 1.0) are reflective of actual use (this has been supported qualitatively by recent limited laboratory tests with consumers).

Standby energy consumption is assumed to have started in the early 1990’s with the introduction of electronic controls, with future values projected to decrease as standby energy consumption is likely to be included into energy labelling tests in the near future and as a result of increased government pressure to reduce standby losses for appliances.

Dishwashers

Accurate weighted performance data for dishwashers is available from the analysis of GfK model sales (EES 1997) which is now available for the years 1993 to 1997 inclusive. Values from this study have been used for these years in the appliance. Values in previous years were estimated from a range of sources including GWA 1991a and EES 1995.

Dishwasher capacity is projected to remain static, while the water consumption is projected to decline slightly (the market average in 1997 dropped to 18 litres per wash). Program wash temperatures have declined in recent years and this is projected to fall slightly. Mechanical and drying energy is projected to decline only slightly to 2010, with most net energy savings coming through reduced water consumption (and related water heating).

Water connection mode for dishwashers (cold only, dual or hot only) is usually fixed for the life of the dishwasher at the time of installation so this is treated as an appliance attribute. Data in Test Research (1995) and QEC (1993) have been used to set the values share of each mode in the stock model. There is no data on the trend of share of water connection mode, so this is held constant in the model. Connection mode determines the proportion of water heated internally and external hot water imported into the machine. For hot connection, all operations are assumed to use hot water (hot water consumption = total water per program). For dual connection, 2 operations are assumed to import hot water (balance is cold water). For cold connection, cold water is heated internally for 2 operations. As the volume of water consumed by dishwashers is quite small, energy resulting from internally heated water is not adjusted for cold water temperature variations by state. However, external hot water requirements are adjusted in this fashion.

External hot water consumption for hot and dual connect machines is estimated by the stock model. The dishwasher module then exports the total hot water demand to the water heater stock module.

Standby energy consumption is assumed to have started in the early 1990’s with the introduction of electronic controls, with future values projected to decrease as standby energy consumption is likely to be included into energy labelling tests in the near future and as a result of increased government pressure to reduce standby losses for appliances.

Air conditioners

Data for room air conditioners was obtained from average values registered for energy labelling in various years. The main attributes are capacity (heating and/or cooling) and efficiency (coefficient of performance). Modules for cooling only, reverse cycle heating and reverse cycle cooling are included as separate technologies. Capacity and efficiency have been projected on the basis of recent trends, with small increases in capacity and efficiency.

Modules for ducted systems are also included as separate technologies. These systems are generally considerably larger than room air conditioners. However, similar trends in performance and capacity are also projected.

A module for evaporative air conditioners is also included. While there are some portable units in the stock, the bulk are assumed to be central ducted systems. A constant value for capacity and energy has been used for the study period, based on conditions in dryer hotter states, where their use predominates.

Standby energy consumption is assumed to have started in the early 1990's with the introduction of electronic controls, with future values projected to decrease as standby energy consumption is likely to be included into energy labelling tests in the near future and as a result of increased government pressure to reduce standby losses for appliances.

Space heaters

Both primary and secondary electric resistive space heaters are considered to be primarily 10 amp plug loads with an effective efficiency of 100 per cent and a heating capacity of 2.4 kW. There are likely to be a small number of fixed built in electric space heaters with high capacity and use factors, but these are limited in number due to their high cost of operation.

Gas space heater attributes have been derived from modelling work undertaken by GWA (1999). The attributes and market share of the main technologies for wood heaters are not well documented at this stage. Current characteristics are derived from limited market data collected by the authors. Mogg (1999) of the Australian Home Heating Association hopes to be able to provide some more detailed industry data later in 1999.

Water heaters

Water heater performance is expressed as a standing heat loss value and a conversion efficiency. For electric water heaters, standing heat loss values in AS1056.1 pre-1985, 1985 to 1999 and post 1999 (according to recent MEPS levels) have been incorporated into the attributes of new water heaters on a sales weighted market basis as per GWA 1993. The conversion efficiency during heating is assumed to be 98 per cent (with 2 per cent of the heat lost to atmosphere during heating).

For gas water heaters, a range of values published by AGA (1997) were considered and these were market weighted according to dominant sales shares. Model data for a range of energy delivery scenarios using the TRNSYS model (AS4234 — see below) was also used (refer to EEA 1993 for detailed data for a wide range of climates and technologies). Trends in gas maintenance rates are assumed to continue to decrease (with an increase in market share of instantaneous units) while burner efficiency is assumed to remain fairly static (burner efficiency for instantaneous units is higher than standard storage models but lower than high efficiency storage). No standby losses or electricity consumption has been assumed for water heaters, although instantaneous units with electronic ignition are likely to have some electricity consumption both during operation and on standby. However, these have only a small market share.

AS4234 sets out a method of determining the annual performance of domestic solar and heat pump water heaters using a combination of test results for component performance and a mathematical model to determine annual load cycle task performance. It contains a program for evaluation of energy consumption of the solar water heaters under testing.

For solar water heaters, standard "no solar" characteristics for heat loss were obtained for a range of climates and technologies from EEA (1993) using the methodology set out in AS4234. Most solar water heaters are connected to off-peak electricity tariffs, so this mode is assumed to be dominant. Solar water heater performance is sensitive to hot water draw-off profile (especially on off-peak boost), so a flat draw-off profile was assumed. Solar performance was averaged for a jacketed and selective surface units and the performance expressed in terms of a solar contribution to total heat requirements for each state (water use plus standing heat losses).

Cooking

Data on performance of cooking appliances is limited. For cooktops, gas burner efficiency is assumed to be about 45 per cent and trending slightly upwards, while electric cooktop efficiency is assumed to be about 59 per cent and also trending slightly upwards (with an increase in solid base elements).

For electric ovens, energy consumption per hour of operation was determined from heat loss values obtained from AS1549. This value has been increased by 30 per cent to account for preheating the oven shell. Similarly, a value for gas ovens which includes a standing heat loss from the oven space (as per AG101) and accounting for the gas burner efficiency has been determined. As for electric ovens, this value has been increased by 30 per cent to account for preheating the oven shell.

Lighting

Three basic lighting technologies are assumed to be in common use in the residential sector. These are incandescent (at 10.5 Lumens per Watt), quartz halogen lamps, mainly down lights and wall washers, (at 23 Lumens per Watt) and fluorescent lamps, a mixture of linear lamps and compact fluorescent, (at an average of 70 Lumens per Watt). The stock share of each lighting technology is projected by year.

Televisions

Television energy consumption is dominated by the hours of use. A small proportion of energy consumption is associated with standby losses. The in use power and standby energy values for typical TVs have been determined from a range of sources including recently published values in Choice magazine.

For televisions, the power consumed during operation can vary from 40 Watts for small colour units to over 250 Watts for large high definition systems. Recent US studies suggest average operational energy consumption levels of 60W-76W (Floyd 1998, Brodrick et al 1998).

While most electronic appliances are manufactured for an international market, there is some indication that TVs in Australia are poorer performers than those in the US and Europe, where there has been pressure in recent years to improve energy standards of electronic equipment. Products arriving or assembled in Australia are generally designed for the Asian market, where performance standards have not been introduced to date.

Evidence for this is found in relation to standby energy consumption in TVs. All modern TVs have a standby facility which shuts down the unit ready for operation by the remote control. Under this mode of operation, TVs still use a significant level of power. Around 85 per cent of the current stock have standby facilities. However, some consumers will turn the TV off when not in use (see discretionary data for further discussion).

The results of two recent tests by the Australian Consumer Association provided in Table 37 below, indicate that standby electricity consumption in Australia may be higher than the average of 4W to 4.3W found in the US. A power consumption of 110 Watts in use is assumed for 1998 increasing to 120 Watts by 2010.

Table 37: TV electricity consumption – Australia

Size	Total operation range (W)	Standby range (W)	Standby average (W)
68cm TV (10 units)	102-134	3.2 - 23	9.8
51cm TV (17units)	-	4.6 - 17	9.0

Source: ACA(b) 1997 and ACA 1998

However, it is likely that Australia will benefit from the improved standards in other markets over forthcoming years. So a standby value of 9.5 Watts has been assumed for 1998 declining slowly to 2010.

Video cassette recorders

There is little data on VCR power consumption, however it is assumed to be similar to those tested in the US (see Table 38, below). It is therefore assumed that the power consumption during operation for VCRs in Australia varies between 11–16 Watts. An average value of 12 Watts is assumed for the model.

Table 38: VCR electricity consumption – United States

Study	Operational power consumption (W)	Standby power consumption range (W)	Standby power consumption average (W)
Study 1 (Floyd 1998)	12	1.5 - 13	5.6
Study 2 (Brodrick 1998)*	10.7-15.7	-	5.6

All VCRs have a standby facility and most machines tend to be left connected to the power at all times, so that the clock and calendar functions do not have to be regularly reset. The total hours of operation for VCRs are expected to be low, around 150 hours/household/year. It has been assumed that the standby power consumption for

VCRs is 7 Watts. It should be noted that the total energy consumption of VCRs is fairly insensitive to assumed usage levels.

Standby power consumption

Standby power consumption has been explicitly modelled for most of the major appliances. However, there are now numerous other end uses which draw small continuous amounts of power.

Growth in the numbers of small household appliances and information technology equipment in Australian means that these appliances now contribute significantly to household energy consumption. Since many of these use a low voltage transformer for a power supply, they will also have a significant “no load” power consumption.

For example there is evidence that the average household in the US now “leaks” more than 50 W, and in some cases as high as 100W, with no appliances being used (Floyd 1998 and Brodrick 1998). If Australian households are similar, this is equivalent to nearly 6 per cent of total electricity consumption.

Small household appliances include:

- Hi Fi or sound system etc
- Answer phone
- Portable phone
- Radio clocks
- Battery chargers
- Low voltage power supplies
- Computers
- Printers
- Modem
- Alarms
- Control systems
- Fax machine
- Cable TV decoder

Appendices provide data from US studies into the consumption, in operational and standby mode, for many of these items. Some information on home office appliances in Australia is provided in Table 39 below, which is fairly consistent with the US studies.

Although there is little comprehensive data for Australia, it can be assumed that there is little difference between the products utilised in the US and Australia, and that “average” power consumption figures for appliances will be similar.

Table 39: Operating and standby power for computer equipment

Equipment	Victoria 1992 (EPPB, 1994)			Western Australia 1994 (EPPB, 1994)		
	Operating (W)	Standby (W)	Sleep (W)	Operating (W)	Standby (W)	Sleep (W)
Computers						
1	70	69	-	36	36	-
2	47	46	-	69	-	17
3	34	32	-			
VDUs						
1	52	48		51	51	
2	55	50		46	46	
3	48	47		69	-	
4				50	40	0.5
Printers						
Inkjet (2-3ppm)	17	7	-	15	3	-
Dot matrix (1ppm)	18	10				
Colour inkjet (0.2ppm) A				13	3	
Colour inkjet (0.2ppm) B				3.6	1.5	-
Laser (4ppm)	1130	60	-			
Laser A (4ppm)				154	55	21
Laser B (4ppm)				209	24	1
Laser C (8ppm)				271	45	33
Fax machines						
Thermal fax 1	50	11	-	35	23	-
Thermal fax 2	49	21	-	27	19	-
Inkjet fax				19/22	12	-
Laser fax				48/123	31	

Australians are well known for their willingness to adopt new telecommunication and information technologies, as demonstrated in data on penetration rates, Table 40 and Table 41. The growth in these appliances reflects in part an increase in the use of "home offices", up by 28 per cent between 1989 and 1995. This trend is likely to increase and add to the energy consumption of average households.

Table 40: Household ownership and use of information technology 1998

Type	Australia	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Computers	'000	'000	'000	'000	'000	'000	'000	'000	'000
Ownership	2,524	829	664	448	200	245	55	18	65
Frequent use*	2,425	792	642	440	194	229	49	19	62
CD-ROM	1,793	592	473	327	137	171	35	14	45
Printers	2,157	710	574	384	174	205	42	17	52
Character or image reader	426	175	106	62	25	41	6	3	8
Facsimile	1,048	380	231	207	72	110	15	7	24
Pay TV	694	202	206	180	61	35	2	6	4
Cordless phone	1,972	676	486	335	183	198	47	10	36
Answering machine	2,251	728	624	384	176	234	41	12	51

Source: ABS (b) 1998b

Table 41: Household ownership and use of information technology, trends 1996–1998

Computers	Australia 1996	Australia 1998
Ownership	31.2 %	37.2 %
Frequent use*	30.4 %	35.8 %
CD-ROM	N/a	26.4 %
Printers	N/a	31.9 %
Modem	N/a	17.3 %
Character or Image reader	N/a	6.3 %
Facsimile	N/a	15.5 %
Pay TV	N/a	10.2 %
Cordless phone	N/a	29.1 %
Answering machine	N/a	33.2 %

** Frequent use defined as once per week or more.*
Source: ABS 1998b

For modelling purposes, it is assumed that all standby appliances have a continuous energy consumption of 5 Watts declining to 4 Watts in 2010 in the appliance base case.

Miscellaneous electricity consumption

This end use accounts for all electricity use not explicitly modelled within the above appliances. There are no technical attributes associated with this end use. Even with the rapid increase in ownership of appliances modelled with standby through the 1980's and 1990's for this project, miscellaneous electricity consumption appears to be increasing rapidly. There may be a significant proportion of standby energy incorporated in this end use and possibly some other growing end uses not specifically tracked by this study, such as home offices. The amount of miscellaneous electricity consumption varies somewhat by state which suggests that there is some variation in secondary electric heating not explicitly modelled.

5.3 Discretionary appliance use data

5.3.1 Overview

Discretionary use factors are those applicable to the whole stock of appliances in use in any particular year, regardless of the appliance age. This includes frequency and duration of use and climatic related factors (such as average water and air temperatures) which affect the performance of an appliance. Discretionary factors include:

- frequency of use, eg loads per week, hours of use of an appliance such as a heater or cooker, hours of television viewing etc.;
- overall energy adjustment factors to account for climate (eg refrigerators, heat losses for water heaters) and cold water temperatures for water heaters.

The discretionary factors can also be varied from year to year (ie a gradual increase in hours of TV viewing, increase in loads of washing per year), but the model is so constructed that all units in operation in that year are equally affected. This is consistent with the fact that most trends in appliance-using behaviour affect all households equally, not just those households which happen to purchase appliances in a given year. An example of this is the trend to lower clothes washing temperatures which is occurring independently of the turnover of the clothes washer stock.

The model is constructed so that discretionary data specified in the stock model applies to any alternative technology scenarios (such as a high efficiency case), so that all differences between the two cases arise from appliance attributes alone, not from user behaviour. If it is necessary to model differences in behaviour as well as appliance attributes, two scenarios (eg with and without lower wash temperatures) can be run sequentially. If the second run contains the desired changes in both the appliance attributes and the discretionary data then the difference between its “high efficiency” case and the “base case” in the first run will represent the combined energy impact of the two sets of changes.

The following section provides a brief overview of the discretionary factors applied for each of the major appliances modelled.

5.3.2 Discretionary data by appliance type

Refrigerators and freezers

The main factor affecting energy consumption of refrigerators is ambient temperature. The performance of refrigerators and freezers is complex and changes in energy consumption per oC change in temperature varies considerably between models and depends on design and construction of each unit (EES 1998). Data monitored by ACA (1990) has shown that refrigerators in Sydney tended to consume about 90 per cent of the energy value shown on the unit’s energy label (ie under standard conditions). However this factor varied somewhat by unit.

For this study and overall climatic adjustment factor has been estimated for each state to adjust for the average difference between AS4474 energy consumption and actual in use consumption. For refrigerators the values range from 80 per cent in Tasmania to 100 per cent in the Northern Territory. For freezers the values range from 75 per cent in Tasmania to 95 per cent in the Northern Territory.

Clothes washers

The main discretionary factors for clothes washers are washes per year and selected wash temperature.

Test Research (1995) which suggests an average number of “washing sessions” of about 3.7 per week with each session consisting of around 2.34 loads of washing, giving the total washes per week as 8.7, which means that the current label CEC understates the frequency, if anything. QEC 1993 also shows a Queensland average for 1992 at about 3.7 washes per week, but there is some uncertainty as to whether this is “loads” or “sessions”.

Some data is available in ABS8218.0 (1988) based on diary records in 1985–1986, but this is based on hours of use rather than loads and is difficult to use directly (program times vary considerably between machines). Data collected in ABS4602.0 (1994) suggests that the average number of loads per week is 5.3.

Another key source is the Pacific Power Residential End-Use Study (Pacific Power 1996). The raw data contains actual in-use information for some 151 clothes washers for a period of about 18 months from early 1993 to mid 1994. The raw data is likely to be analysed in the near future to determine actual frequency of use, but this data is not yet available. The reported energy consumption is 55 kWh per year (Pacific Power 1996), which is consistent with 300 to 350 loads per year at 0.15 kWh per load (almost all units in Australia will use external hot water).

The assumed use for the model is 6 times per week (312 per year).

The other discretionary factor for clothes washers is selection of wash temperature. Trends in wash temperatures in Australia are as follows:

Table 42: Trends in washing temperature — Australia

Wash Temperature mostly used	Cold	Warm	Hot
1988	31 %	53 %	16 %
1992	44 %	49 %	7 %
1995 **	54 %	41 %	4 %

Source: Chapter 5, GWA 1993, Test research 1995

*Note**: 1995 figure was for last wash load, not mostly used, but should be equivalent*

Wash temperature by state was collected in ABS4602.0. The results for 1994 are shown as follows:

Table 43: Wash temperature by state 1994

Temperature	Australia	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Cold	73 %	51 %	76 %	51 %	63 %	61 %	74 %	65 %	65 %
Warm	23 %	41 %	21 %	39 %	29 %	34 %	23 %	32 %	30 %
Hot	5 %	8 %	3 %	9 %	8 %	5 %	4 %	3 %	6 %

Source: ABS 4602.0 1994

The proportion of cold washes reported by this survey is substantially (about 10 per cent) higher than reported in the data sources referenced in Table 42. The state based values in Table 43 were used in the stock model, with the historical trend line in Table 42 used to backcast and project these values at state level. The actual values used are shown in the *Australian Residential Building Sector Greenhouse Gas Emissions 1999–2010 Appendices*.

Clothes dryers

The main discretionary factor for clothes dryers is loads dried per year.

Data collected in Queensland (QEC 1993) suggests that average use is about 3.5 times per month (around 40 times per year) which broadly corroborates data collected by Pacific Power.

ABS 8218.0 (1988) collected diary data from 19,331 households over the period from 17 June 1995 until July 1996. A new group of about 750 households collected one week's diary data commencing at the start of each fortnight, so that usage patterns for the whole year were covered. A summary of the data is shown Table 44 to Table 46. Table 45 clearly shows the seasonal pattern of use by state, with peak use in winter and minimum use in summer, as expected. Annual use by state in 1985–1986 was derived from ABS8218.0 (1988) and is shown in Table 46. Some data on frequency of use was collected in ABS 4602.0 (1994), but this was poorly structured and could not be used directly to estimate uses per year.

Table 44: Clothes dryer penetration by state 1985–1986

State	Households $'000	Own CD $'000	Penetration
NSW	1744.5	850.2	48.7 %
VIC	1300.2	667.6	51.3 %
QLD	811.1	362.1	44.6 %
SA	475.1	221.2	46.6 %
WA	462.6	154.7	33.4 %
TAS	145.1	83.3	57.4 %
NT	26.7	8.4	31.5 %
ACT	78.8	42.4	53.8 %
Australia	5044.1	2389.9	47.4 %

Source: ABS8218.0–1988

Table 45: Proportion of all clothes dyers used on at least one day in seven

State	Winter	Spring	Summer	Autumn
NSW	62.4 %	61.9 %	43.1 %	48.5 %
VIC	76.5 %	60.7 %	43.6 %	59.3 %
QLD	52.9 %	47.0 %	42.1 %	48.1 %
SA	73.7 %	45.9 %	37.1 %	54.3 %
WA	78.3 %	47.8 %	24.1 %	57.3 %
TAS	67.0 %	48.4 %	45.7 %	55.2 %
NT	61.1 %	17.4 %	57.1 %	35.9 %
ACT	75.2 %	63.2 %	24.5 %	64.1 %
Australia	67.6 %	56.3 %	41.1 %	52.9 %

Source: Table 15, ABS8218.0–1988.

Table 46: Annual clothes dryer use by state during 1985–1986

State	Annual average use (Hours)	Cycles per year
NSW	86	37
VIC	123	54
QLD	70	30
SA	91	39
WA	98	43
TAS	109	47
NT	37	16
ACT **	84	37
Australia	96	42

Source: Table 15, ABS8218.0–1988, assumes 13 weeks per season.

Cycles per year based on cycle time of 2.3 hours from EES (1997).

*Note**: Values for NT are estimates only due to small sample size.*

The loads per year assumed for the model are shown in Table 46.

Dishwashers

The main discretionary factor for dishwashers is loads washed per year.

Test Research (1995) suggests an average number of uses of about 4.0 per week (210 times per year). Some data is available in ABS8218.0 (1988) based on diary records in 1985–1986, but this is based on hours of use rather than loads and is difficult to use directly (program times vary considerably between machines).

The model assumes a usage of 250 times per year.

Space heating and cooling loads

Space heating and cooling loads are determined on the basis of heating and cooling requirements estimated by the building shell module (see the section on Building Shell Modelling for more details). Building shell heating and cooling loads are estimated using the performance engine in the National House Energy Rating Scheme (NatHERS) model. As the NatHERS model estimates unconstrained heating and cooling requirements for a high level of occupancy, the HERS estimates are reduced by the following factors:

- only households with heating and cooling equipment can fully or partly satisfy the demand for heating and cooling;
- actual average occupancy levels somewhat less than the occupancy levels assumed in the NatHERS model (ie many people are absent during the day at work, occasionally away on weekends, etc.);
- the NatHERS model assumes that practically the whole house is heated or cooled, whereas in reality most households zone heat and cool ie only part of the total house floor area heated or cooled.

Hot water

The main discretionary factor for hot water is the litres of hot water per day per household. In addition to general hot water use, the hot water module also imports the hot water demand generated by clothes washers and dishwashers.

Major hot water applications include:

- Showers,
- Baths;
- Basins and sinks;
- Clothes washing;
- Dishwashing.

There is little data on regional variations in usage patterns for hot water. However, showers will typically comprise between 40–60 per cent of hot water usage for personal washing and Table 47 provides some information about shower usage patterns.

Table 47: Shower usage — Australia

Source	Average duration per person	Frequency per household
Perth (MWA 1985)	8.1 minutes	2.3 /day
NSW (ABS 1987)		16 / week
Sydney (Yann 1990)	7.3 minutes	
QLD - Winter (SRC 1993)	8.6 mins	3.2 / day (weekday)
QLD - Summer (SRC 1993)	8.1 mins	3.7 / day (weekday)

Assuming the flow rates are reasonably similar, it would appear that hot water usage in showers is greater in the warmer states. It should be noted that because the ambient water temperature in these locations is also higher, the impact on water heating energy consumption will be slightly reduced.

There is little data on hot water consumption, however Table 48 provides some data from Queensland. Personal washing (ie. excluding clothes and dishwashing) is assumed to account for around 106 litres per day.

Table 48: Hot water usage — QLD 1993

end use	Litres/day
Dishwasher	2
Kitchen sink	22
Washing machine	7
Bath	15
Shower	60
Hand basin	10
Average	115

Source: SRC 1993

Based on usage patterns in Table 47, average showering time per day in Queensland is 27.5 minutes (3.2 x 8.6). Combined with the above data, this suggests an average flow rate for hot water of 2.2 litres/minute, which is unlikely. Average flow rates measures elsewhere in showers are between 10–17 litres/minute for all water (Yann 1990).

Hot water consumption is assumed to be about 90 litres per household per day (equivalent litres at 60°C adjusted for actual state average based cold water temperature — see below) excluding dishwasher and clothes washer demand. Warmer states are assumed to use slightly less hot water per person.

Ambient water temperatures will also cause some regional variations in energy consumption. Data for average water temperatures in Australian capital cities is provided in Table 49.

Table 49: Average cold water temperatures by city

State	City	Temperature °C
NSW	Sydney	18.3
VIC	Melbourne	16.2
QLD	Brisbane	21
SA	Adelaide	17.9
WA	Perth	20.7
TAS	Hobart	12.9*
ACT	Canberra	15
NT	Darwin	28

** Water temperature assumed to be similar to ambient air temperature*
Source: WSA 1998

In most cases, electric water heaters will raise water temperatures to 75°C, while gas water heaters will achieve 60°C water temperatures. Base water inlet temperatures used in the model are those shown in Table 49. Heat losses have also been adjusted to reflect differences in average ambient temperatures by state. Mean air temperatures shown in Table 50 have been used in the model to adjust heat loss values.

Table 50: Average air temperature by city

State	City	Temperature ºC
NSW	Sydney	18.2
VIC	Melbourne	15.5
QLD	Brisbane	20.5
SA	Adelaide	16.4
WA	Perth	18.4
TAS	Hobart	12.9
ACT	Canberra	13.1

Source: ABM 1997

Cooking

ABS 8218.0 (1988) collected diary data from 19,331 households over the period from 17 June 1995 until July 1996. A new group of about 750 households collected one week's diary data commencing at the start of each fortnight, so that usage patterns for the whole year were covered. The results show that an average oven is used for about 150 hours per year and an average cooktop is used for about 250 to 300 hours per year. This broadly consistent with expected patterns of use for these appliances.

The model assumes 250 hours of oven use and 0.4 GJ of primary cooktop energy is required.

Televisions

The main discretionary factor for televisions is hours of use. A range of sources suggest figures ranging from 21 hours per week (ABS 4172.0) per person to as much as 30 hours per week. For modelling purposes, an average of 25 hours per week for the main television in 1998 is assumed (trending to 30 hours per week by 2010) and no hours for second or subsequent televisions.

Video cassette recorders

The total hours of operation for VCRs are expected to be low, around 150 hours/household/year in 1998 (trending to 160 hours per week by 2010). Because the energy consumption during use and on standby is similar for VCRs, total energy consumption is fairly insensitive to hours of use. The same hours of use are assumed to apply to all VCRs in the stock.

Lighting

A uniform lighting requirement of 107 kLumens per square metre per annum has been derived as the primary lighting requirement for households. The lighting requirement is therefore proportional to average floor area of the housing stock, which is estimated as part of the building shell model.

Miscellaneous electricity and standby power

There are no discretionary attributes associated with miscellaneous electricity consumption and standby consumption.

5.4 Third party end use energy estimates for appliances

5.4.1 Overview

This section overviews third party data sources where estimates by end use have been made or where end uses have been metered directly.

Total residential energy consumption has increased steadily in past decades and this trend is predicted to continue to 2010. The increase in the number of Australian households together with alterations to the fuel mix used in Australia households, has been significant in the past decade. Electricity continues to be the major fuel source up to 2010 (growth of 24 per cent from 1990 to 2010), although it is predicted that natural gas consumption will grow by 68 per cent over the same period. Most of the increase in gas usage is expected to come at the expense of electricity in the area of space heating and water heating.

It is noteworthy that with an increasingly elderly population, more people in part-time employment, and more people choosing to work from home, the hours that people spend in their houses will grow. This is likely to increase average energy consumption in the residential sector, although some of it may be reflected in reduced consumption in other sectors.

Energy consumption varies considerably between states. This reflects climatic differences across Australia: heating loads are significant in the southern states, while cooling loads increase in the northern states.

Other factors which influence average energy consumption include:

- The type of the building stock — some building forms such as non-detached houses are typically more efficient that detached dwellings;
- Household income — higher income levels tend to live in larger houses and purchase more energy consuming appliances than less affluent households (although poorer households may use older, less efficient appliances);
- The availability of fuels — neither electricity or reticulated gas is available to all Australian households. Around 10,000 permanent houses and 60,000 holiday homes are not connected to the electricity grid (Watt 1996) (but these are considered insignificant in number with respect to the total stock of households of 6.7 million). Around 41 per cent of Australian households utilise reticulated gas. Availability of other useful fuels, such as solar energy, is also not uniform across Australia.

Such factors may lead to considerable variations between regions within states.

Average electricity consumption has actually declined slightly over recent years. In 1992 it was 6,780 kWh/household (ESAA 1993), compared to 6,283 kWh in 1997. Studies of household consumption patterns conducted during the past decade indicate that this is due mainly to:

- an increased number of households;
- lower average occupancy numbers;
- increased use of gas for space heating and water heating (rather than reduced consumption due to end-use energy efficiency).

Direct end use measurements are relatively rare. There are very few examples where end uses have been directly metered for a large sample. The only notable exceptions in Australia are Pacific Power (1996) and off peak/controlled tariff water heating which is usually separately metered (South Australia, Victoria, NSW, Queensland and Tasmania). Bartels (1985 and 1988) and Fiebig and Woodland (1989 and 1993) used a technique called Conditional Demand Analysis to estimate energy consumption of various appliances in NSW. This technique is also used by some other authors (SECWA 1991).

5.4.2 Third party estimates by appliance

Refrigerators and freezers

A comparative study of energy consumption of appliances offered for sales in 1980 and 1992 (GWA 1991) demonstrates efficiency improvement and this appears to have been sustained up to the present day, with an increase in efficiency of around 1.5 per cent pa over the past 15 or so years.

Table 51: Energy consumption of refrigerators

Appliance	Bought 1980 kWh pa	Bought 1992 kWh pa	Annual rate of change 1980–1992 (% pa)
Refrigerator			
Single door	650	536	-1.6
2 door cyclic defrost	1100	826	-2.4
2 door frost free	1300	1097	-1.4

Source: GWA 1991

Table 52: Energy consumption of refrigerators – NSW 1993–1994

First refrigerator	944
Second refrigerator	828

Units are kWh/year
Source: Pacific Power (1996)

Table 53: Energy consumption of refrigerators – QLD and WA

Refrigerator Qld	836
Refrigerator – 1 door WA	470
Refrigerator – 2 door WA	1127

Units are kWh/year
Sources: QEC 1993, SECWA 1991

Although refrigerator efficiencies are increasing, this is being offset to some degree by increases in the size of units, particularly freezer compartments. The uptake of frost free units is also increasing, although frost free units now are generally at least as efficient as their cyclic defrost counterparts. The average number of units per household is basically stable.

Table 54: Freezer energy consumption

NSW 1993 (Pacific Power 1996)	648
QLD 1993 (QEC 1993)	517
WA 1988–9 (SECWA 1991)	592

Units are kWh/year

Electric water heaters

Electric Water Heating appliances include:

- Off-peak storage;
- Peak storage;
- Instantaneous;
- Electric boosted solar.

In NSW, around 50 per cent of households used off-peak storage water heaters in 1989. In 94/95, 4,060 GWh of off-peak electricity was consumed by 1.152m households (DOE, 1996). Assuming that this was all used in water heating, average household consumption by off-peak users was 3,524 kWh. This is broadly consistent with other studies undertaken in NSW (shown in Table 55). Variations may be explained by the differing methodologies used.

It should also be noted that many users of solar water heaters use off-peak electricity, although average consumption amongst these households is likely to be around 900–1000 kWh (with 70 per cent solar contribution). The inclusion of these households within overall figures for off-peak users will therefore reduce the rate of average consumption. However, this is not significant since there is evidence that the stock of solar water heaters in NSW has been declining since the 1980s and is currently only around 3 per cent of households.

Around 30 per cent of NSW households used peak electricity to heat water in 1989. During the 1980's the number of households using peak electricity for water heating fell, and this trend has probably continued through the 1990's, as use of off-peak electricity and gas has increased.

Estimates for average household consumption varies considerably, see Table 56 below, but rates are generally lower than for off-peak water heating.

Table 55: Water heating by off peak electricity – NSW (kWh/HH/year)

1983 (Bartels 1985)	1984 (Bartels 1988)	1985–1986 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)	1993 (Pacific Power 1996)
3,369	3,433	3,627	3,819	3,350*

**calculated*

Table 56: Water heating by peak electricity – NSW (kWh/HH/year)

1983 (Bartels 1985)	1984 (Bartels 1988)	1985–1986 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)	1993 (Pacific Power 1996)
1,800	1,990	2,678	2,331	2,918

Units are kWh/year

Metered data for off peak electricity consumption for hot water in Victoria in the early 1990's was about 3,700 kWh per annum (author analysis of SECV data). Very few households use peak electricity for water heating in Victoria. Electricity for hot water is separately metered for many houses in Queensland (off peak tariffs T31 and T33). The following table shows metered data for all of Queensland. Some consumers use continuous boosted systems which are included with general supply. However the supply industry in Queensland suggest that water heater energy is about 2,400 kWh per annum for continuous boosted systems (T11 tariff). These households tend to be small and lower income.

Table 57: Off peak energy consumption for water heating by electricity 1986–93 – QLD

Year	T31 Customers	kWh/ cust	GWh	T33 Customers	kWh/ cust	GWh
1986	31,760	3,116	79.8	311,067	2,876	780.2
1987	48,705	3,071	123.5	371,498	2,667	910.1
1988	64,185	3,266	184.4	440,085	2,766	1,122.3
1989	81,447	3,210	233.7	482,687	2,792	1,288.3
1990	96,962	3,254	290.3	516,872	2,858	1,428.6
1991	112,002	3,214	335.8	533,424	2,805	1,473.2
1992	130,143	3,128	378.7	552,417	2,780	1,509.4
1993	150,384	3,068	430.4	572,205	2,789	1,568.0

Source: EES 1995

In 1988–1989, 55 per cent of WA households used electric or solar-electric water heating. 16 per cent utilised off-peak electricity to heat water, 16 per cent utilised the peak rate and 23 per cent had a solar-electric combination.

Table 58: Average energy consumption for water heating by electricity 1988–1989 – WA

Tariff	KWh/a
Off-Peak	1,822
Continuous (peak)	913
Solar-Electric	622

Source: SECWA 1991

These figures for electric water heating in WA are considerably lower than elsewhere and cannot adequately be explained by differences in water temperature or consumption rates. We suggest that the very low penetration rates of hot water in Perth, combined with the sampling methodology, have caused substantial errors, so this data has been disregarded for this study.

Table 59: Average energy consumption for water heating by gas – NSW

1983 (Bartels 1985)	1984 (Bartels 1988)	1985–1986 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1991)
12,920	16,157	18,317	17,975

Units are MJ/year

Table 60: Average energy consumption for water heating by gas 1988–1989 – WA

Type	MJ/year
Storage	20,592
Instant	13,831

Source: SECWA 1991

Space heaters

Data on space heating consumption by region reflect information of hours of use and is presented in Table 61 and Table 62.

Table 61: Space heating by electricity – NSW

Source	1983 (Bartels 1985)	1984 (Bartels 1988)	1985/6 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)	1993 (Pacific Power 1996)
Main heating		791	519	488	996 *
Secondary heating		433	186	216	427 **
Total				555	

** Room heater   ** Space heater*
Units are kWh/year

Table 62: Space heating by electricity – QLD and WA

State	QLD, 1993	WA, 1998/9
Main heating	122	422
Secondary heating	248	
Refrigerative a/c heating	70	146

Sources: QEC 1993, SECWA 1991
Units are kWh/year

Table 63: Energy consumption for space heating by gas – NSW

Source	1983 (Bartels 1985)	1984 (Bartels 1988)	1985/6 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)
Main heating		10,771	12,917	13,118
Secondary heating		2,117	7,146	9,238
Total	8,561			

Units are MJ/year

Table 64: Energy consumption for space heating by gas 1988–1989 – WA

Main heating	Secondary heating
2,273	680

Source: SECWA 1991
Units are MJ/year

Table 65: Air conditioning by electricity – NSW

1983 (Bartels 1985)	1984 (Bartels 1988)	1985/6 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)	1993 (Pacific Power 1996)
547	588	556	629	698*
				216**

** reverse cycle   ** cooling only*
Units are kWh/year

Table 66: Air conditioning by electricity – WA

State	QLD, 1993	WA,1988/9
Evaporative A/C cooling	140	221
Refrigerative A/C cooling	667	420

Sources: QEC 1993, SECWA 1991
Units are kWh/year

Electric cooking

There have been several technology advancements in cooking appliances over the past decade which have resulted the availability of new cooking products. For example, induction and some halogen hobs are more efficient than electric radiant coil hobs, and fan-forced ovens are more efficient than conventional ovens. In the case of hobs, these efficient options command very significant price premiums. Other new products include ceramic and solid disc hobs, both of which are less efficient than electric resistance hobs. Despite these developments, it is assumed that resistance hobs comprise the bulk of the electric cooker stock.

It is noteworthy that ownership of microwaves is currently at around 82 per cent of Australian households, compared to around 10 per cent in 1983.

Table 67: Cooking by electricity – NSW

Source	1983 (Bartels 1985)	1984 (Bartels 1988)	1985/6 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)	1993 (Pacific Power 1996)
All cooking appliances	989*	912*	571	629	663

** Gas and electric, all units in kWh*

Pacific Power recorded microwave electricity consumption (directly metered) as 67 kWh per year (Pacific Power 1996). Most of this is likely to be associated with standby electricity consumption.

Table 68: Cooking by electricity – QLD and WA

State	QLD 1993	WA 1988–1989
Oven	131	378
Cooktop	169	245
Griller	12	54
Microwave	140	221

Units are kWh/year
Sources: QEC 1993, SECWA 1991

For those with access to gas, gas hobs are common. However the trend towards separate hobs and ovens over recent years has meant that more than one fuel can be used for cooking. There has been a steady growth in the popularity of electric ovens even in households with gas hobs.

Table 69: Cooking by gas – NSW

Source	1983 (Bartels 1985)	1984 (Bartels 1988)	1985–1986 (Fiebig and Woodland 1991)	1989 (Fiebig and Woodland 1994)
All cooking Appliances	4,979	3,884	2,279	4,547

Units are MJ/year

Table 70: Cooking by gas – WA

Oven	961
Cooktop	2,624
Griller	126

Units are MJ/year
Source: SECWA 1991

Lighting

There is very little measured data on lighting energy consumption, however data provided below indicate levels of around 600 kWh/a.

Table 71: Electricity for lighting

State	NSW 1993	QLD 1993	WA 1988–1989
	566	518	652

Units are kWh/year
Sources: Pacific Power 1996, QEC 1993, SECWA 1991

There has been an increasing use of low voltage lighting in residential buildings over recent years; these use transformers and quartz-halogen lamps, and are relatively inefficient (cf fluorescent lighting). Sales of outdoor lighting have also increased for recreational and security purposes. For these reasons it is conceivable that current average electricity consumption for lighting is increasing and may do so for a number of years.

6 APPLIANCE MODELLING METHODOLOGY

6.1 Overview of the stock model

The stock of each appliance type in service in each state and in each year of the projection period (1998 to 2010) is calculated in the following way:

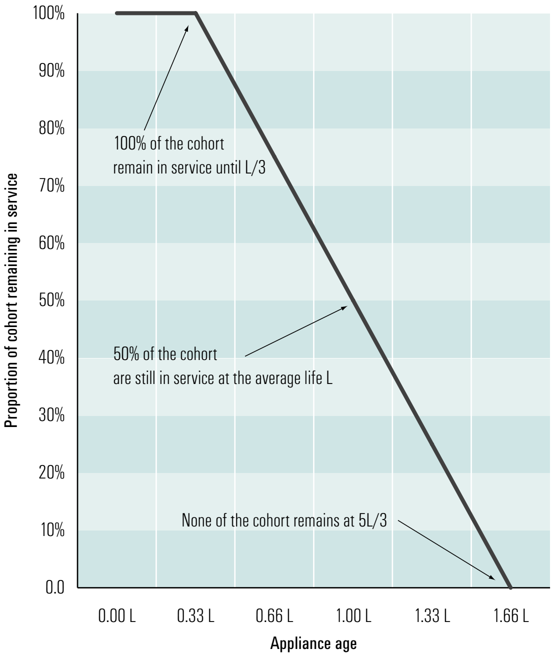
1. the number of households in the state is estimated;
2. the stock of each appliance type in use is calculated as the product of the number of households and the historical or projected ownership rate;
3. the number of units retiring from the stock is estimated, using a stock sub-model for each appliance;
4. the number of new units added to the stock in each year is calculated as the sum of the increase in the total stock and the number retiring in that year.

The number of units retiring from the stock in each year is a function of the number installed in previous years and their expected service life. In practice the service life of appliances installed in a particular year (a "cohort") follows a decay curve. There is no research data on average service life and/or decay curves for Australian appliances, but US data suggests that only a proportion — perhaps even a minority — actually fail at the average service life (ie total years of service divided by total stock). The function used in this study is the simplified decay curve developed by Lawrence Berkeley Laboratory (LBL) in the USA, which was also used in the MEPS study (GWA 1993a) and for EES (1995). The assumptions are:

- all appliances in a cohort survive for 1/3 of the average service life;
- there is a linear decay such that 50 per cent of the cohort survive to the average service life, and the last appliance in the cohort retires at 5/3 of the average service life.

A graphical depiction of the units remaining in service is shown in Figure 45.

Figure 45: Appliance retirement function



If the average service life for a particular appliance type is set at 15 years, for example, the oldest appliance leaving service in 1995 will have been installed in 1970 (5L/3 = 25 years). Therefore it is necessary to estimate the numbers and energy characteristics of units installed in 1970 and in every subsequent year in order to calculate the impact of their retirement on the energy consumption of the total stock in 1995. The model has been designed to accommodate average appliance service lives up to about 21 years (even though the earliest data is currently for 1966 — the model assumes constant characteristics before this date, if required). The appliance life entered in the model must be an integer.

The historical, current and projected ownership estimates for each state for each appliance type are contained in the ownership module. This series goes back to 1966. All state total estimates have been cross checked and adjusted to be internally consistent for all years. The stock of each appliance for each year and each state from 1966 to 2010 is determined by combining the ownership values with the household numbers.

The stock model also imports the appliance attributes for each year for each appliance from 1966 to 2010 from the attributes module. As discussed in the previous section, it is assumed that appliance attributes are uniform for each year.

An initial estimate of retirements in each year is generated within the model by dividing the stock at the end of the previous year by the average assumed service life (this will be the true retirement number only if stock numbers have remained constant for greater than 5/3 times the average service life, which is clearly not the case in practice for any appliance type). This approach, while not giving a precise estimate of retirements, gives a consistent starting point for the period up to where forecasting is commenced.

This process produces an initial estimate of the existing appliance stock for every year. This will inevitably diverge somewhat from the *known* stock value, for the following reasons:

- the service life may have been slightly over or under estimated;
- the service life may vary over time (eg units installed in earlier years may have been built to higher construction standards and so may have lasted longer, or householders were less inclined to upgrade working appliances);
- there may be inaccuracies in the historical stock surveys.
- where the total stock is increasing (which is the case for most appliances), the retirements in any one year will be somewhat less than stock in that year divided by the average life.

In order to overcome this discrepancy, the number of retirements are then adjusted by increasing or reducing the retirements in previous years to make the total stock profile estimated by the model as close as possible to the actual stock for each year. In practice, the stock curve produced by the model can never be identical to the actual stock curve generated by the household and ownership surveys in every year, as appliance sales vary due to a range of exogenous factors such as economic activity and weather which cannot be modelled using end use techniques. However, it is possible to select a year for the stock as estimated by the model to equal the actual stock. For this project, the projected model stock has been adjusted to equal the actual stock in 1998.

The number of units retiring in each year after 1998 is estimated by the stock sub-model. After 1998, the calculated retirements and the actual increase in stock are added to estimate actual sales.

It is important to note that for all years, the actual (historical and projected) stock values are always used to generate the energy consumption for the particular end use. The stock model is really only a calculation engine which is used to determine average attributes (eg energy efficiency) of all units remaining in operation in a particular year given particular installation and retirement profiles. These average characteristics estimated by the stock model are then applied to the actual stock in each year. The stock model carries a profile for each state and each appliance for each year. In most cases, the stock weighted attributes vary little between states.

The stock model generates a time series of estimated sales for each year from 1966 to 2010. This part of the model calculates the sales generated by increasing penetration and ownership (called “new” sales) and the sales due to the replacement of retired units (called “replacement” sales).

Another way to alter the series of sales and retirements is through specifying different average service lives. As assumed appliance life increases, the number of units retiring in each year decreases. This would mean that fewer total sales would be necessary to replace existing stock which is retired and therefore “new” appliances would make up a larger proportion of total sales. Where known, the total sales estimated by the model can be checked against known sales in the market place. The estimated life can be shortened to increase sales or lengthened to decrease sales. A long time series of actual sales is most desirable so that an accurate trend match over the period can be made (avoiding the annual fluctuations in actual sales). However, this can be difficult to do for appliances that have very volatile sales from year to year, such as air conditioners.

The appliance life assumed in the model is not particularly critical when estimating appliance attributes and energy consumption projections. Underestimating the life means that estimated sales are higher than actual sales and therefore new appliances influence the stock average slightly more quickly than in reality. Similarly, if the appliance life is overestimated, the influence of new appliances will be slower than in reality. This is really only critical where the attributes of new units are substantially different from the average stock value (ie where change is rapid), which is relatively uncommon. An exception here is the introduction of MEPS for electric storage water heaters, where a 30 per cent improvement is expected to occur in 1999.

6.2 Assumed appliance lives

The only published data relating to appliance life in Australia is reported in BIS Shrapnel surveys of customers purchasing new appliances (BIS 1998a). Recent purchasers of new appliances were asked to estimate the age of the appliance which they were replacing. Since the data was based on consumer recall during a telephone interview, it was not likely to be highly reliable (there tends to be a high incidence of responses at 5, 10 and 15 years, for example, although recent changes to their questionnaire are aimed at overcoming this problem). Furthermore, only about 25 per cent to 50 per cent of *replaced* appliances were reported as actually leaving the stock (ie being scrapped). The rest were either retained by the household, sold or handed down, and so possibly remained in service (noting that many of the retained units will not be used). While some of these units may not in fact be used regularly, these movements will mean that the effective service life of appliances is longer than the estimated ages reported in BIS Shrapnel (1998) and reported in GWA (1993a). Consequently longer service lives are assumed in this study (see Table 72). If improved information on appliance life were available, the stock model could be adjusted to accurately reflect this data.

Table 72: Assumed and reported average appliance lives

Appliance	Assumed life for this study	Reported age of replaced appliance
Refrigerator	17	13.1
Freezer *	21	13.0
Clothes washer	14	11.9
Dishwasher	12	11.7
Clothes dryer	16	11.8
AC - non ducted	10	11.5
AC - ducted	10	7.2
Portable heaters	10	7.4
Gas heaters	10	11.1
Hot water systems	12	12.7
Cooking appliances	15	N/A
Televisions	10	N/A
VCRs	12	N/A
Generic standby	8	N/A

** Sales for freezers are still too high given penetration data.*
Source: BIS Schrapnel 1998

The model can accept average appliance lives ranging from 5 to 21 years (as whole years). In general terms, the appliance lives have been set so that the sales generated by the model broadly match total appliance sales where these are known. Lives of refrigerators, freezers, clothes washers, dishwashers and clothes dryers were lengthened to ensure that sales estimated by the model were roughly equal to known market sales. The sales of freezers estimated by the stock model is still far too high in comparison with known sales of freezers for the past 10 years, even when the life has been set to 21 years. This would suggest that either the average life of freezers is very long, or that the penetration of freezers is falling rapidly, but that ownership surveys have not yet detected this trend. However, BIS (1998) suggests that the latter is not the case.

7 GREENHOUSE GAS INTENSITY PROJECTIONS

Greenhouse gas emissions from electricity and natural gas supply in 1995 were calculated in GWA (1998). Table 73 summarises the emissions per unit of electricity delivered to users in each State, and Table 74 summarises emissions per unit of natural gas delivered (and burned). Combustion emissions are the emissions from the power stations or gas appliances themselves. The CO_2-equivalent values are slightly higher than the CO_2 value because of the global warming impact of the small amounts of CH_4 (methane) and N_2O (nitrous oxide) emitted during combustion.

Full fuel cycle emissions also include the combustion and fugitive emissions associated with the production, processing and transport of the fuel. For example, there are fugitive CH_4 emissions associated with the production of the black coal used in generating electricity, and naturally occurring CO_2 is vented at the wellhead in gas production.

Table 73: Greenhouse gas emissions per kWh electricity delivered 1995

	Combustion		Full fuel cycle	
	CO_2 kg/kWh	CO_2-e kg/kWh	CO_2 kg/kWh	CO_2-e kg/kWh
NSW+ACT	0.895	0.897	0.902	0.956
VIC	1.348	0.354	1.370	1.381
QLD	1.007	1.009	1.018	1.028
SA	0.960	0.963	1.020	1.024
WA	1.002	1.005	1.050	1.075
TAS	0.001	0.001	0.002	0.002
NT	0.663	0.666	0.720	0.771

Source: GWA 1998

Table 74: Greenhouse gas emissions per GJ natural gas delivered 1995

	kg/GJ delivered and burned	
	CO2	CO2-e
NSW+ACT	65.2	70.2
VIC	63.6	68.7
QLD	56.8	62.3
SA	63.2	68.0
WA	61.6	67.0
TAS	NA	NA
NT	56.1	60.5

Source: GWA 1998

Emissions per unit of electricity delivered change over time with the following factors:

- the share of electricity generated from fossil fuels and from renewable energy: the higher the renewable component, the lower the emissions intensity;
- the fossil fuel mix: coal for example has higher emissions per PJ burned than does natural gas;
- the efficiency of thermal power stations: the higher the efficiency the lower the emissions intensity, all else being equal.

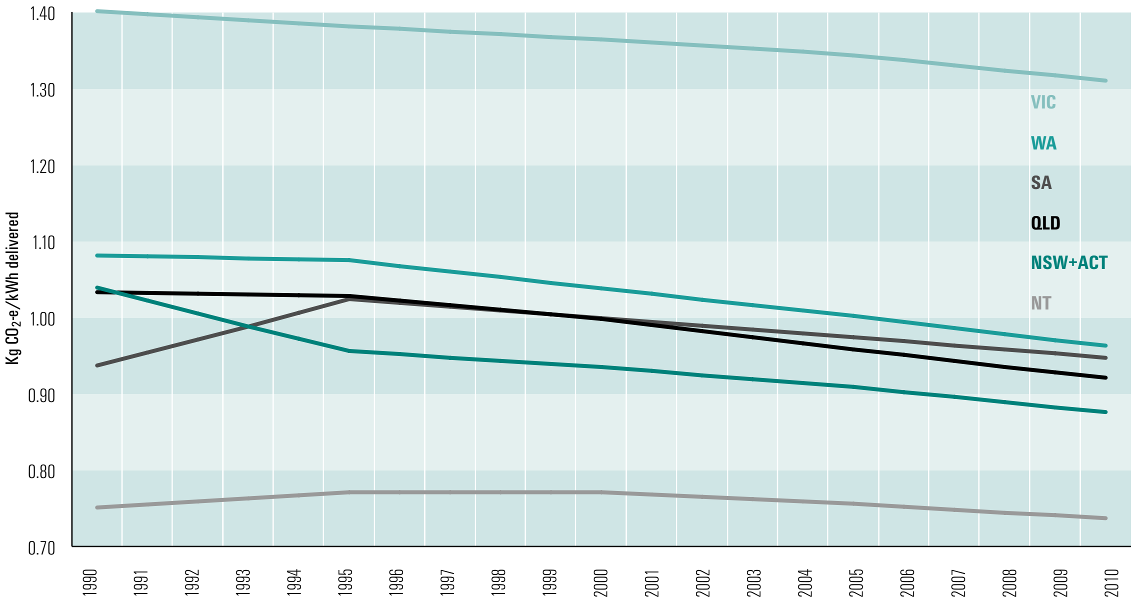
In November 1997 the Prime Minister announced a number of greenhouse gas reduction policies including the objective of increasing the renewable energy share of electricity generation by 2 per cent in 2010, and setting efficiency improvement targets for thermal power stations to be achieved by 2010. The first objective would achieve a 2 per cent reduction in greenhouse gas intensity, all else being equal. While no targets have been announced for the second objective, it has been assumed that this will result in a further 1 per cent reduction in intensity by 2010.

The Australian Bureau of Agricultural and Resource Economics (ABARE) projects the coal share of the fossil fuels used for generation to decline from 89 per cent in 1996 to 77 per cent by 2010, and the natural gas share to increase from 9 per cent to 21 per cent (ABARE 1997). This change alone would reduce the greenhouse gas intensity of electricity delivered by nearly 6 per cent.

The greenhouse gas intensity of electricity delivered in each State has been projected on the assumption that the objectives of the Prime Minister's program will be met, and that fuel mix will change as projected by ABARE.

Figure 46 illustrates the result of these trends. The trend for Tasmania is not shown since it is projected that virtually all of Tasmania's electricity generation will continue to be from hydro (with zero greenhouse gas emissions). These emission projections are used to calculate the greenhouse gas emissions from electricity to be supplied for residential uses in each year to 2010. The emissions from residential natural gas supply are assumed to remain constant at the values in Table 74.

Figure 46: Greenhouse gas emissions per kWh electricity delivered by state and year



Source: GWA 1998

8 EMBODIED ENERGY

8.1 Outline of the issue

Embodied energy, while discussed in some areas of the literature since the 1970s energy crisis (IFIAS 1974), may be a term still unfamiliar to many. Embodied energy is the energy required to be consumed directly and indirectly in order to produce a good or service, such as a building. “Direct energy” is, as its name implies, the energy required directly by the process. “Indirect energy” is the energy embodied in products that are consumed in the main process, such as building materials.

Embodied energy is a significant component of the life cycle energy requirements of buildings, which also include their operational energy requirements (this includes energy services such as space heating and cooling, hot water, cooking, lighting and general power-ie, the main focus of this report). Embodied energy relates to the operational energy of a building ‘upstream’ of the construction process as shown in Figure 47.

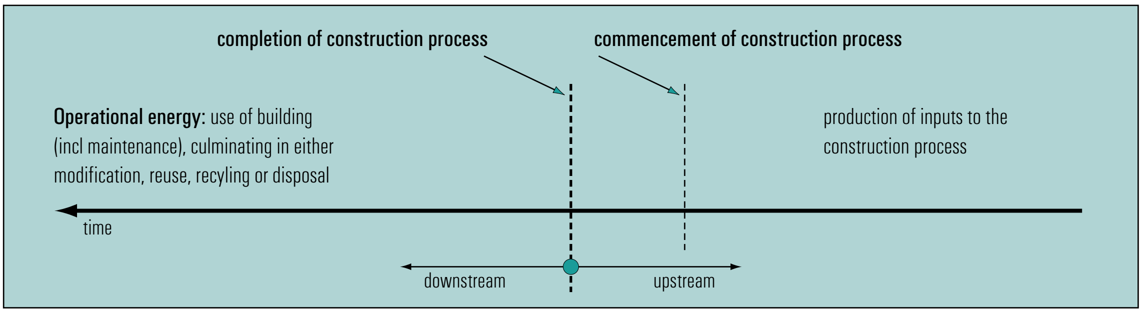
The terms of reference of the project precluded a detailed study of greenhouse gas emissions embodied in construction materials and emissions associated with the construction or demolition process, rather it is required that this study should:

> “... identify the level of information relating to emissions and/or energy embodied in the fabric of the building or associated with the construction/demolition process, and which could form the basis of a future quantitative and qualitative study.”

Despite the limitations of the terms of reference, it was decided that the relative significance of embodied energy as compared to the operational energy (the latter being the main focus of this study) should be investigated. Should it be found that the proportion of embodied energy formed a significant proportion of the total life cycle energy of a residential building, embodied energy would need to be considered in future assessments of policy options regarding residential buildings.

Therefore, the aim of this chapter is to demonstrate the significance of embodied energy in the context of greenhouse gas emissions attributable to residential building construction and operation.

Figure 47: Phases of a building’s life cycle



Firstly, the term embodied energy is discussed. Secondly, embodied energy analysis methods are outlined. Thirdly, embodied energy data are evaluated. Fourthly, greenhouse implications are outlined. Fifthly, the life cycle greenhouse gas emissions implications of embodied energy are discussed. Finally, a pilot study of the embodied energy implications of various construction options is presented, to demonstrate the greenhouse gas emissions context.

8.2 Definition of embodied energy

Embodied energy, as introduced above, is the energy required directly and indirectly to manufacture a product. For building construction the direct energy includes the energy used for on site activities, while the indirect energy includes the energy embodied in building materials. The energy required directly and indirectly is then determined for each of the building materials (as can be envisaged by applying Figure 47 to the building material manufacturing process, rather than to the construction process).

For the purpose of examining the greenhouse implications of activities such as construction, an embodied energy analysis must be as comprehensive as possible. This applies to the direct energy requirements of the process itself as well as each input to the process. Under these conditions, the above examples used to describe the direct and indirect energy of construction give an incomplete picture of the embodied energy analysis framework. For example, the energy required directly by construction may also include energy used off-site for pre-fabrication, transportation, administrative and storage activities–if and only if the energy is purchased by the construction firm. The indirect energy is more comprehensively defined as the energy embodied in goods and services consumed by the construction contractor and sub-contractors and may include both basic building materials, complex components and systems, as well as other goods and services that may not be incorporated in the finished building but are nevertheless required for the process to continue (for example, banking services and wastage).

If the embodied energy analysis framework is not complete for any crucial inputs to the process, then comparisons may be invalid (affecting materials and systems selection) and the total embodied energy of the building may be significantly incomplete (affecting the overall impression of the significance of embodied energy relative to the operational energy of the building).

The difference between this and other definitions of embodied energy is a focus on the economy as the system within which construction and other industry occurs. As such, the system boundary for the analysis occurs in an economic framework and is thus more comprehensive than the standard industrial paradigm (Boustead and Hancock 1979). Whenever energy is purchased by a firm, it is counted as part of the direct energy requirements of that firm. Whenever a good or service is purchased, the energy required directly by the company that provided it is passed on to the purchasing company as part of its indirect energy. Several characteristics emerge from this economic framework for embodied energy analysis:

- fuels that are not purchased from energy supply sectors are not included;
- it is assumed that fuels purchased from energy supply sectors are consumed;
- the calorific value of materials not combusted is not included;
- the energy required to support humans is not included, unless purchased by firms; and
- the metabolic energy value of human labour is not included.

One characteristic of the economic framework for embodied energy analysis that is not ‘inherent’ is the application of ‘primary energy factors’ (ie, the ratio between the energy value of fossil fuels in the ground to the energy value of the fuels manufactured from them). Measured quantities of electricity thus reflect the coal or other fossil fuels used to generate the electricity, as well as any distribution losses (again, this definition is incomplete, and useful only for introductory purposes). Consequently, primary energy terms relate linearly to energy related greenhouse gas emissions.

8.3 Methods

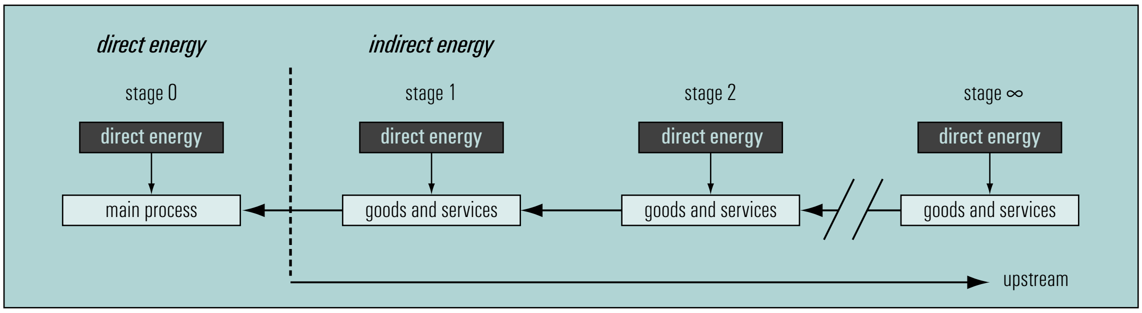
To perform an embodied energy analysis, data is required for:

1. the direct energy use for the activity under consideration (for example, construction);
2. inputs of products to the activity under consideration (ie, the inventory); and
3. the energy required directly and indirectly to manufacture these other products.

The methods used for embodied energy analysis thus vary from the very detailed (ie, for the process under consideration, about which much may be known) to very general (ie, for upstream processes which may comprise only a very small part of the inventory, about which little-if not nothing-may be known). The method is recursive, as indicated by the third step in the above list, with each stage of the upstream chain of supply leading to more and more processes.

A comprehensive embodied energy analysis framework is represented diagrammatically in Figure 48. Stage 0 represents the direct energy required by the process under consideration. Stage 1 represents the sum of the direct energy required to provide direct inputs to the main process, and so forth to stage (. The 'main process'–and the 'goods and services' at each stage-can be any sector of the economy, such as 'residential building construction', 'concrete slurry' or 'banking'. This diagram represents the general case of a 'horizontal' expansion of the right-hand side of Figure 47. A 'vertical' expansion of Figure 48 below would comprise the itemisation of individual or groups of goods and services at each stage.

Figure 48: A comprehensive embodied energy analysis framework



The level of detail reached in an embodied energy analysis is dependent upon the method used. There are three methods available: process analysis; input-output analysis; and hybrid analysis.

In a process analysis, the energy embodied in a product is traced laboriously upstream by examining the inputs to each process, starting with the main process. Process analyses can be significantly incomplete, due to increasing upstream complexity (inherent to developed or developing economies). For example, in a process analysis, the framework rarely extends beyond stage 2 (Figure 48). A related technique is "life cycle assessment", which has similar framework limitations but more environmental detail is gathered at each node in the supply chain.

Input-output analysis comprises the use of national statistics, and uses a mathematical technique to account for practically all upstream stages (Leontief 1966; Miller and Blair 1985). While the input-output framework is practically complete, many inherent assumptions make the results unreliable (for more information, refer to Treloar 1998).

Hybrid analysis involves the combination of the two major embodied energy analysis methods discussed above (Bullard et al 1978), and can be based either on the process analysis framework or the input-output analysis framework (Treloar 1997). The intention of hybrid analysis methods is to reduce errors associated with the base embodied energy data. However, the problems inherent to each of the original methods tend to remain, to some degree, in the associated hybrid versions.

Nevertheless, the preferred hybrid analysis method is input-output-based hybrid analysis (such as developed by Treloar (1997) and demonstrated in Treloar (1998)), because regardless of the amount of process analysis data available, the framework of the analysis remains comprehensive due to the use of input-output data as "background".

8.4 Available data

There is little recent process analysis data available for Australian construction materials and products. In the international body of embodied energy literature, the process analysis data that is used tends to be old (ie 10–25 years). Typically, virtually any data that can be sourced from anywhere and any period is used in embodied energy studies (for example, D'Cruz et al 1990; Treloar 1996). This is because process analysis data is difficult to obtain due to the cost of research and the perceived need in industry to treat embodied energy data as confidential.

However, it is not just in rare cases that an industry or manufacturer will make available energy usage data at various levels of detail. Considerable effort is required to verify the figures supplied by industry, to determine that the framework of the analysis is complete enough for the purpose at hand (see Figure 48). It may be that an industry will supply data on the direct energy usage of a primary process such as metal refining, but will withhold (or be simply unaware of) the other energy required directly by them to support this primary process as well as the energy required indirectly in the form of goods and services required by the primary and ancillary processes. Consequently, much published process analysis data is of low completeness and hence low quality.

Input-output data, on the other hand, is available from the Australian Bureau of Statistics. However, as discussed above, there are many errors associated with input-output data that make it unreliable for all but the most coarse analyses. Furthermore, input-output tables are always at least three years out of date, due to the time required to collect and collate the data. Nevertheless, the input-output method produces results which often compare closely to process analysis results for some materials (Treloar 1998). The input-output method also suggests a comprehensive framework for embodied energy analysis which has been shown to be sufficiently reliable as the basis for hybrid analysis of residential buildings in preliminary studies (ie an input-output-based hybrid analysis method, Treloar (1998)).

There are several publications which list embodied energy data for Australia (see Table 75). Each source has certain limitations, either methodological or in terms of the number of building materials and products for which embodied energy and greenhouse gas emissions data are supplied.

There are also several other international publications and analysis tools available of a similar nature to those listed above, except for Treloar (1998) (ie, none were found to have used the preferred input-output-based hybrid analysis method). However, these international sources are not worth discussing in detail, as they are not generally applicable to Australia. Some computer based tools comprise databases which are often applied in Australia. However, these databases, while containing information on Australian processes, often comprises mostly international and old process analysis data. Furthermore, since they are almost all derived using process analysis, their use will most likely result in significant incompleteness, perhaps invalidating any comparisons made between competing products, systems or strategies.

Table 75: Sources of embodied energy data — Australia

Source	Comments
Hill 1978	Now considered very old, used process analysis
D'Cruz et al 1990	Used data from old sources, including Hill (1978), and international sources
Tucker et al 1993	Used national and international process analysis data and 1986-87 Australian input-output data-included greenhouse gas emissions data
Treloar 1996	Based on work presented in Tucker et al (1993) but with minor methodological improvements-but no greenhouse gas emissions data
Pullen 1995	Similar to Treloar (1996) and Tucker et al (1993) included greenhouse gas emissions data
Lawson 1996	Using solely process analysis data of unstated derivation-but no greenhouse gas emissions data
Tucker et al 1996	Similar to Tucker et al (1993) but far more numerous-included energy related greenhouse gas emissions emission data-however, this database was encrypted within the 3D CAD software it was developed for
Treloar 1998	Similar to Treloar (1996) but used 1992-93 input-output data and, for the first time, an input-output-based hybrid analysis method

Note: See bibliography for a full description of these sources

The only further Australian study known is an update of the Tucker et al (1996) project (by Treloar). A database of primary embodied energy and CO_2 emissions is being created for most building materials and products for Australian construction with the aim of producing as consistent and comprehensive a database as possible with a known degree of reliability (in some sense). The 1992–93 input-output data is being used, together with recent Australian process analysis data using the input-output-based hybrid analysis method derived in Treloar (1998). For each embodied energy intensity value, the proportion of process analysis data incorporated into the input-output model will be supplied, giving a measure of relative reliability.

While the database will be a significant advance over any currently available and will be most useful for modelling the effects of general design decisions, some further refinements will be necessary to create the definitive database which would able to be used for comparing specific products. Among these refinements, which at this stage of development are currently assumed to be adequately modelled by the input-output model, are to improve the reliability of the following components:

- direct energy of construction;
- processes which combine basic materials into complex products;
- services, such as banking, government services and insurance; and
- areas where non-energy greenhouse gas emissions are modelled.

8.5 Significance of embodied energy

Embodied energy is an important concept because, in conjunction with operational energy, it allows energy efficiency to be considered within a life cycle perspective. The life cycle of a product includes a manufacturing phase and an operational phase, prior to the product's reuse, recycling or disposal (Bekker 1982).

There have been several studies investigating the life cycle significance of the energy embodied in construction at the individual building level. Pullen (1995) and Treloar and Fay (1998) found that the energy embodied in house construction was equal to approximately 15–20 years of operational energy. With periodic maintenance and refurbishment, over a typical house life of 100 years, the embodied energy in the building, furniture and equipment could represent up to 50 per cent of the total. For very efficient houses, the embodied energy could be more important than the operational energy, both in energy and greenhouse terms. More significantly, in the short term the initial embodied energy may be the most important component (Treloar and Fay, 1998).

Ballinger et al (1995) stated that the life cycle energy of buildings (ie, including the operational energy and initial embodied energy) represents approximately 28 per cent of national energy consumption (comprising 10 per cent embodied energy and 18 per cent operational energy). Other estimates have been higher. For example, Tucker et al (1993) suggested the initial embodied energy of construction could be 20 per cent, adding to the operational energy quoted by Ballinger et al (1995), giving a total of 38 per cent. This discrepancy could be due to at least the following two factors:

1. changes in the level of construction activity between the times of the estimates; and

2. differentiate levels of completeness in the embodied energy analysis methods (see discussion above).

Embodied energy represents an important aspect of the energy and greenhouse gas emissions problem not frequently addressed by conventional methods used to evaluate the life cycle implications of energy efficient devices (such as thermal insulation and energy efficient lighting in buildings). Rarely is the energy required to manufacture such products discussed. In contrast, in economic evaluations, both the capital cost and the operating costs are taken into account in a “life cycle costing”.

Increased operational energy efficiency alone, such as in the heating of buildings, may not result in minimum energy consumption in an overall life cycle sense (due to the additional embodied energy requirements, for example, for passive or active solar design features or equipment). The energy embodied in energy saving features needs to be “paid back” within a reasonable period (England and Cassler, 1995). This also applies to the embodied greenhouse gas emissions. Furthermore, the efficient use and reuse of products represents a substantially untapped source of energy conservation and greenhouse gas emissions abatement-albeit indirectly (Berntsen, 1995).

However, in the quest for energy conservation, a main focus seems to be the direct operational energy consumption of buildings (such as exemplified in this report). This is partially due to lack of understanding about embodied energy, and partially due to its increasing significance, with buildings becoming more efficient and with more energy intensive materials being used in their construction. Table 76 gives examples of possible outcomes from life cycle energy and greenhouse gas emissions abatement scenarios.

Especially in cases like the third example in Table 76 the critical issue becomes the period of time required for the operational energy savings to pay back the initial embodied energy requirement-ie, the “payback period”, calculated in both energy or greenhouse gas emissions terms. However, there are other factors to be considered in decision-making besides life cycle energy and greenhouse gas emissions abatement, including appearance, durability, cost, practicality, availability, regulatory legality and marketability.

Improvements in manufacturing efficiency will reduce the embodied energy of buildings, but assessing embodied energy during the design process provides an opportunity for conservation (Berntsen 1995). All potentially significant areas of the problem should be investigated, including operational energy, initial embodied energy, ongoing embodied energy, design process and changes in industry.

In policy terms, embodied energy may be addressed by building in some factor into say a HERS scheme, if implemented. For example, a four star house (operational energy) using low embodied energy materials (for example, timber) may rate as equivalent to a five star house (operational energy) using higher embodied energy materials (for example, concrete and clay brick).

Material substitution is a difficult scenario to present to industry, because it suggests that one material or system is preferred over another. It would be better to develop tools to assist designers in the development of buildings which have considerably lower life cycle energy and greenhouse gas emissions, regardless of which system or product is chosen. This could be achieved by identifying generic low embodied energy/high performance options, such as reusing building materials, insulating, sourcing low greenhouse gas emissions fuels and educating industry, designers and occupants.

Table 76: Possible outcomes from life cycle emissions abatement scenarios

Example strategy	Embodied energy	Operational energy	Likely life cycle result
Use of timber window frame as compared to standard aluminium window frame	Saving	Saving	Win/win
Use of concrete roof tile as compared to terracotta roof tile	Saving	Neutral	Win/draw
Use of double glazing as compared to single glazing	Increase	Saving	Loss/win

8.6 Sample analyses

An initial study using the generic house plan was conducted to help provide some perspective to this issue of embodied energy. This limited study is to be considered as indicative rather than rigorous.

Two comparisons were made, one between concrete slabs and timber floors and the other between single and double glazing. All other variables in terms of construction were kept constant. Walls were assumed to be of brick veneer construction and both walls and ceilings were assumed to be insulated (as per section on Building Shells in this report). The increased embodied energy and greenhouse gas emissions associated with the concrete floor slab and the double glazing were compared with their estimated resultant savings in operational energy consumption and greenhouse emissions. The study was carried out for two climate zones: the Western Sydney zone (the most common) and the Canberra zone (being the most heating dominated is assumed to be the most likely to benefit from these measures). For the purposes of the study the factors shown in Table 77 were used.

Table 77: Embodied energy factors used for analysis

Building shell component	Embodied energy (GJ/m²) 1
Elevated timber floor	0.586
Concrete slab on ground	1.29
Single glazing	1.54
Double glazing	3.08
Brick veneer wall 2	1.122

Item	Factor
Greenhouse gas emissions associated with heating (assumed natural gas)	64kg/GJ
Greenhouse gas emissions associated with cooling (coal fired electrical power)	287kg/GJ
Greenhouse gas emissions associated with building materials	70kg/GJ
Ratio of primary energy to delivered energy for gas (national average)	1.3
Ratio of primary energy to delivered energy for electricity (national average)	3.0
Heating appliance efficiency (average for gas heating appliances)	70 per cent
Cooling appliance efficiency (average for refrigerative cooling)	250 per cent
Constraint factor 3 – Heating	0.4
Constraint factor 3 – Cooling	0.2

8.6.1 Concrete floor versus timber floor

The pilot study reveals that, for the generic house, the use of a concrete floor as a means of reducing operational energy consumption as compared to a timber floor is effective in the very long term and would result in a total operational primary energy saving of approximately 208 GJ over a 100 year building life span in the Western Sydney climate type. At this rate, the added embodied energy in the concrete floor as compared to the timber floor would be paid back[14] in approximately 47 years (see Figure 49). In terms of greenhouse gas emissions, this return period is higher at 62 years (see Figure 50) making this strategy marginal in terms of improving the buildings life cycle greenhouse gas emissions. If constructed now, by 2010 the additional embodied energy for the concrete floor relative to the timber floor would not have been paid back (ie, resulting in a significant net increase in greenhouse gas emissions over the 11 year period).

The results for the same comparison in the colder Canberra climate type show an improvement in the payback period to approximately 22 years in terms of energy (see Figure 51) and 30 years in terms of greenhouse gas emissions (see Figure 52). This makes concrete floors a more viable strategy than timber floors in Canberra compared to West Sydney for improving the buildings life cycle greenhouse gas emissions.

This study considered a generic detached house. However, if a similar study were to be done on a passive solar designed house it would be expected that there would be a significantly greater improvement in the operational energy performance of the concrete floored house as compared to the timber floored house and a subsequent shortening of the pay back periods.

Note 1: These figures were derived by converting those quoted in Lawson (1996), for the construction systems used to primary energy terms using an estimated primary energy factor of 2.0
Note 2: Timber floored houses were assumed to have an additional 600mm of base walling to the sub-floor area as compared to concrete floored houses.
Note 3: Refer to section 3 for definition of "constraint factors".

8.6.2 Double glazed versus single glazed

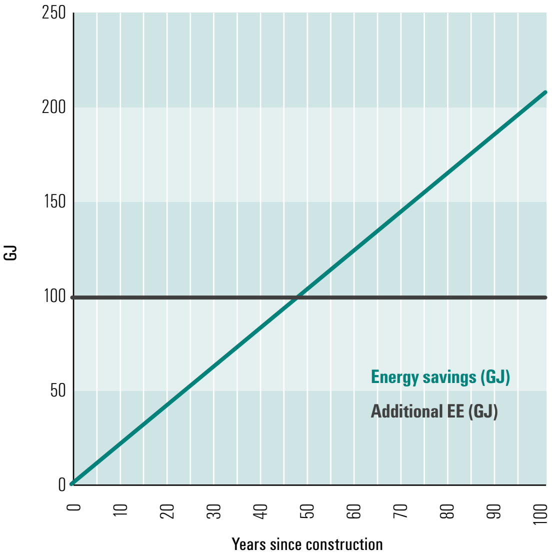
From the pilot study it was found that, for the generic house, the use of a double glazing is an effective means of reducing operational energy consumption compared to single glazing and would result in a total operational primary energy saving of approximately 430 GJ over a 100 year building life in the Western Sydney climate type. At this rate the added embodied energy in the double glazed as compared to the single glazed house would be paid back in approximately 9 years (see Figure 53). In terms of greenhouse gas emissions this payback period is approximately 12 years (see Figure 54) making this strategy effective in terms of improving the buildings life cycle greenhouse gas emissions15.

The results for the colder Canberra climate type show an improvement in the payback period to approximately 3.5 years in terms of energy (see Figure 55) and 4.7 years in terms of greenhouse gas emissions (see Figure 56). Double glazing thus appears to be an effective strategy for improving the buildings life cycle greenhouse gas emissions.[15] In this case the use of double glazing may be considered justified in the limited time frame of the study period. For other climates, building designs, maintenance and operational scenarios, double glazing may be more or less effective.

8.7 Conclusions

- Embodied energy and its resultant greenhouse gas emissions form a significant proportion of the life cycle energy of a residential building. Any measures designed to abate greenhouse gas emissions could not be considered to be comprehensive if they did not address this issue.
- Current poor levels of public awareness of the significance of embodied energy in the life cycle energy equation of residential buildings, especially within industry, is seen as an impediment to gaining public support for initiatives in this area. Options for raising the profile of embodied energy issues therefore need to be explored.
- Currently, data and methods for embodied energy analysis require improvement, requiring a staged introduction of the concepts and methods to industry and the public.
- Whilst a financial incentive exists for home owners to reduce operational energy demands, no such similar incentive exists to induce home owners, or for that matter builders, to choose low embodied energy materials/components for their houses. When considering greenhouse gas emission abatement measures, some form of credit system associated with the use of low embodied energy materials/components could provide such an incentive. Other embodied energy savings which could attract credits could be: use of materials and products with recycled content, waste minimisation strategies, building maintenance and refurbishment initiatives, strategies to reduce the transportation of building materials and use of transportation upstream in the supply chain (for example, for imported stone).
- A further study of the more significant building elements would be required to quantify the impact of embodied energy and related greenhouse gas emissions in terms of the life cycle analysis of residential buildings. A baseline study for embodied energy of residential buildings (and another for other building types, such as commercial) similar to this report for operational energy related greenhouse gas emissions is recommended.
- Realistic policy options need to be researched/ discussed. A report on policy options relating to embodied energy of residential buildings (and another for other building types, such as commercial) similar to the companion project to this one on the operational energy related greenhouse gas emissions is recommended. Strategies need to be developed for informing and educating design teams, changing the market-place and empowering consumers, enabling the design, construction and operation of residential buildings with optimised life cycle greenhouse gas emissions.

Figure 49: Net energy: Concrete floor versus timber floor (Generic house, Western Sydney)



[14] Note: Payback in this context does not mean in economic terms but rather in energy/greenhouse gas terms.

[15] Note: This analysis does not account for the possibility of either glass breakage or double glazing seal failure. Both these factors would be expected to increase projected average payback periods.

Figure 50: Net emissions: Concrete floor versus timber floor (Generic house, Western Sydney)

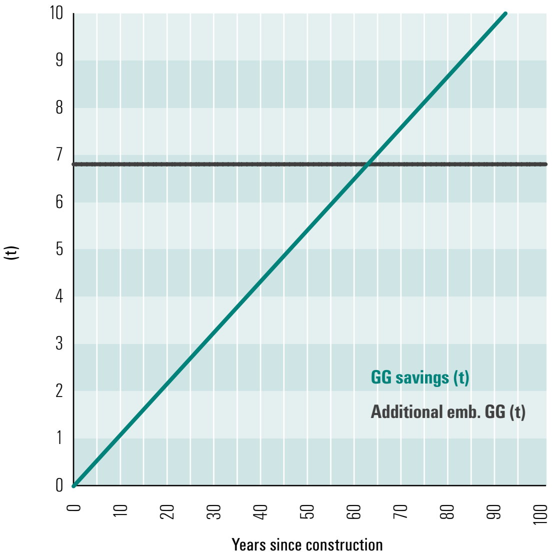


Figure 52: Net emissions: Concrete floor versus timber floor (Generic house, Canberra)

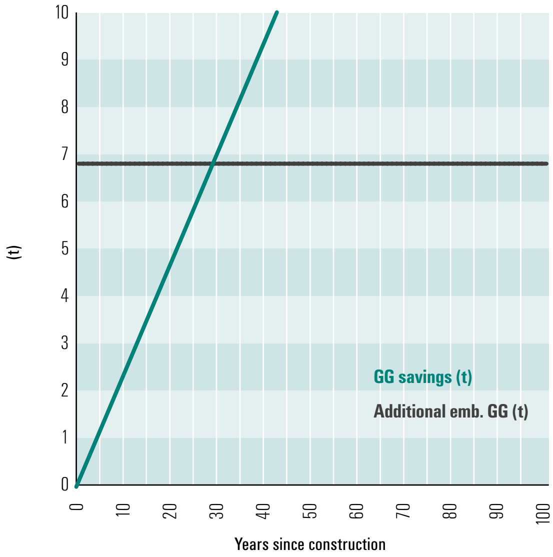


Figure 51: Net energy: Concrete floor versus timber floor (Generic house, Canberra)

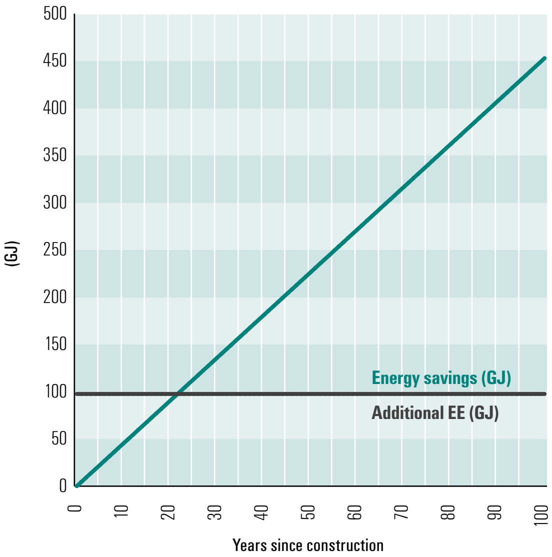


Figure 53: Net energy: Double glazing versus single glazing (Generic house, Western Sydney)

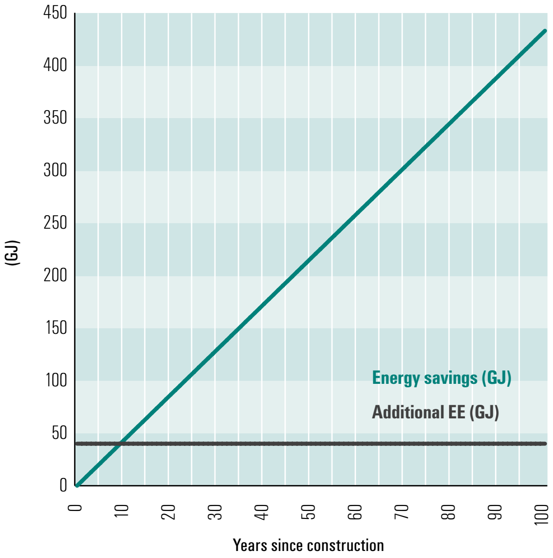


Figure 54: Net emissions: Double glazing versus single glazing (Generic house, Western Sydney)

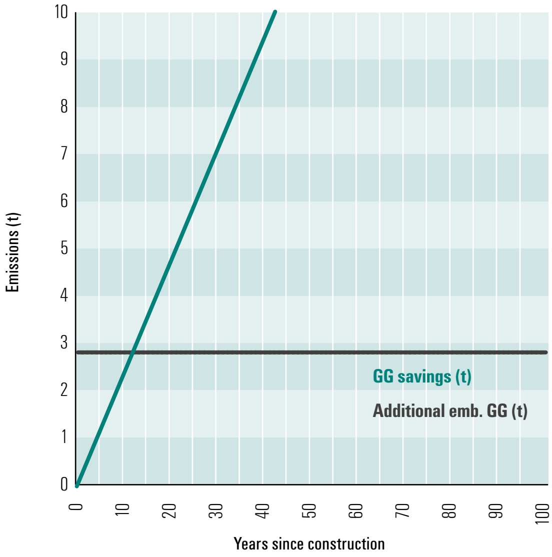


Figure 56: Net emissions: Double glazing versus single glazing (Generic house, Canberra)

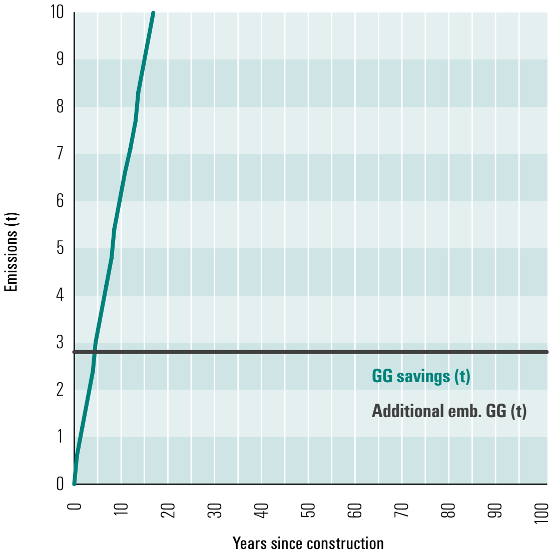
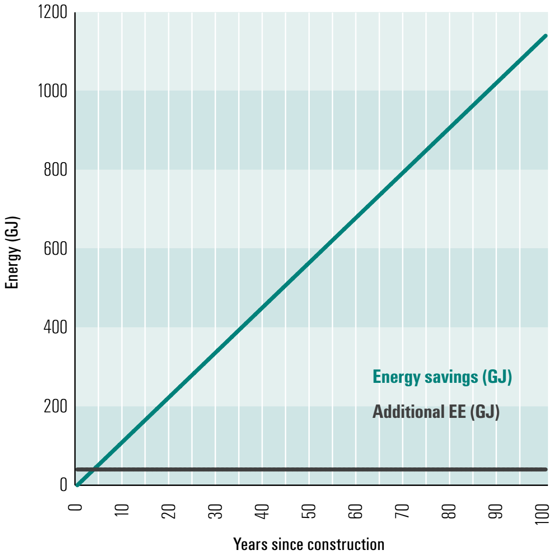


Figure 55: Net energy: Double glazing versus single glazing (Generic house, Canberra)



9 REFERENCES

Project data sources and references

ABARE 1997, Australian Energy Consumption and Production: Historical Trends and Projections to 2009–10, ABARE Research Report 97.2, February 1997.

ABARE 1998, State Level Energy Consumption from 1972 to 1997 with National Projections to 2010 (unpublished), personal communication with Shane Bush, Australian Bureau of Agriculture and Resource Economics (ABARE), Canberra, November 1998.

ABM 1997, Daily Maximum and Minimum Temperature Data for 8 Australian Capital Cities from 1970 to 1997, data purchased in electronic form from the Australian Bureau of Meteorology, National Climate Centre, Melbourne, October 1997.

ABS = Australian Bureau of Statistics

ABS Census of Population and Housing — 1966, 1971, 1976, 1981, 1986, 1991 and 1996 (summary data reported in various Year Books and various Census reports).

ABS 2015.0, 1996 Census of Population and Housing — Selected Social and Housing Characteristics.

ABS 2409.0 to 2417.0, 1976 Census of Population — Housing Summary Files.

ABS 2452.0, 1981 Census Summary Tables.

ABS 2498.0, 1986 Census Summary Tables.

ABS 2710.0, 1991 Census Summary Tables.

ABS 3101.0, 1997 Australian Demographic Statistics.

ABS 3102.0, 1997 Australian Demographic Statistics, 1997.

ABS 3222.0, Projection of the Populations of Australia, States and Territories 1997 to 2051.

ABS 3229.0, 1996 Household Estimates Australia.

ABS 4133.0, 1988 Housing Survey — Characteristics of Dwellings.

ABS 4172.0 1994 Cultural Trends in Australia, May 1994.

ABS 4172.0 1997 Cultural Trends in Australia, December 1997.

ABS 4602.0, 1994 Environmental Issues — People's Views and Practices.

ABS 8212.0, 1981, National Energy Survey — Household Appliances, Facilities and Insulation, Australia 1980, published July 1981.

ABS 8212.0, 1984, National Energy Survey — Household Appliances, Facilities and Insulation, Australia 1983, published June 1984.

ABS 8212.0, 1987, National Energy Survey — Household Appliances, Facilities and Insulation, Australia 1985–1986, published June 1987.

ABS 8213.0, 1984, National Energy Survey: Annual Consumption of Reticulated Energy by Households, Australia 1983.

ABS 8213.0, 1987, National Energy Survey Annual Consumption of Reticulated Energy by Households, Australia 1985–1986, Canberra.

ABS 8218.0, 1988, National Energy: Survey Weekly Reticulated Energy and Appliance Usage Patterns by Season Households, Australia 1985–1986, October 1988.

ABS 8719.1, 1987, Domestic Water Use in NSW.

ABS 1998a — Buildings Research and Outputs Group, Building approvals data 1987–1997, state data purchased for the project, November 1998.

ABS 1998b, Household Use of Technology, Australian Bureau of Statistics.

ACA 1990, Energy Consumption of Refrigerators and Freezers Used Under Normal Conditions of Use, Australian Consumers' Association for NSW Department of Minerals and Energy, Sydney, November 1990.

ACA 1997a. Washing Machines — from the high end of the market. Choice. April 1997, Australian Consumers Association, Sydney.

ACA 1997b. Choice Magazine, Australian Consumers Association. January 1997.

ACA 1998, Choice Magazine, Australian Consumers Association. May 1998.

AG101, Approval Requirements for Gas Cooking Appliances, Australian Gas Association.

AG102, Approval Requirements for Gas Water Heaters, Australian Gas Association.

AG103, Approval Requirements for Gas Space Heaters, Australian Gas Association.

AGA 1998, Gas Statistics Australia, Australian Gas Association, Canberra. Selected data has been extracted from previous versions of this report back to 1985.

AGA 1997, Approved Appliances and Components, Australian Gas Association and the Australian LPG Association, 1 January 1997, Canberra.

Antweiler, W. 1996, The Pollution Terms of Trade, Economic Systems Research, Vol. 8, No. 4, pp. 361–366.

AS1549, Performance of Household Electrical Appliances — Ranges, Cooking Tops and Wall Mounted Ovens, Standards Australia, Sydney.

AS2007—1998, Performance of Household Electrical Appliances — Dishwashers, Standards Australia, Sydney.

AS2040—1998, Performance of Household Electrical Appliances — Clothes Washing Machines, Standards Australia, Sydney.

AS2442—1996, Performance of Household Electrical Appliances — Clothes Dryers, Standards Australia, Sydney.

AS2627.1, Thermal Insulation of Dwellings — Thermal Insulation of Roofs/Ceilings and Walls, Standards Australia, Sydney, 1993.

AS2984, Solar Water Heaters — Methods of Test for Thermal Performance — Outdoor Test Method, Standards Australia, Sydney.

AS3823 — 1998, Performance of Household Electrical Appliances — Room Air Conditioners — Part 1.1 Non Ducted Air Conditioners and Heat Pumps — Testing and Rating for Performance, Standards Australia, Sydney.

AS 4234 — 1994, Solar Water Heaters – Domestic and Heat Pump – Calculation of Energy Consumption, Standards Australia, Sydney.

AS4744 — 1997, Performance of Household Appliances — Refrigerators and Freezers, Standards Australia, Sydney.

Australia Post 1998, Postal delivery points, an in-house database provided on request.

Ballinger, J., Prasad, D., Lawson, B., Samuels, R., and Lyons, P. 1995, R and D of Current Environmental Technologies in Australia, Proceedings: Pan Pacific Symposium on Building and Urban Environmental Conditioning in Asia, Nagoya, March, pp. 9.

Bartels R., Household Energy Consumption (Analysis of the ABS 1983 Household Energy Survey), for Energy Authority of NSW, report EA85/50,1985.

Bartels R., Lopert P., Williamson S., The Residential Demand for Electricity in NSW, Energy Authority of NSW, report EA85/9,1985.

Bartels R., Household Energy Consumption (Analysis of the ABS 1984 NSW Household Energy Survey), for NSWDOE/ECNSW, report DOE88/102 1988.

Bartels R., Fiebig D., Aigner D. and le Roux T., Domestic end use Study (Load Shape Study) , for Electricity Commission of NSW, report PD88/5, 1988.

Bekker, P.C.F. 1982, A Life Cycle Approach in Building, Building and Environment, Vol. 17, No. 1, pp. 55–61.

Berntsen, T. 1995, Oslo Roundtable Chairman's Report, Proceedings of the Oslo Ministerial Roundtable Conference on Sustainable Production and Consumption, Oslo, February 6–10.

[http://www.iisd.ca/linkages/consume/oslochar.html, last accessed June 1997].

BIS Shrapnel 1994, Study to Investigate the Alterations and Additions Sector of the Housing Industry, BIS Schrapnel, Sydney.

BIS Schrapnel 1998a, Household Appliances Market in Australia 1998–2000, BIS Schrapnel, Sydney, September 1998, Volume 1 — Whitegoods, Volume 3 — Climate Control.

BIS Schrapnel 1998a, Household Appliance Survey, BIS Schrapnel, Sydney, September 1998, unpublished results of August 1998 household survey.

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

Brodrick, Zogg and Alberino 1998. Size and Importance of Small Electrical End Uses in Households. Paper presented at the 1998 ACEE Summer Study on Energy Efficiency in Buildings.

Bullard, C.W., Penner, P.S. and Pilati, D.A. 1978, Net Energy Analysis: Handbook for Combining Process and Input-Output Analysis, Resources and Energy, Vol. 1, pp. 267–313.

Building Control Commission, 1998, Basis Reports.

Building Control Commission, Building Code of Australia.

Cement and Concrete Association — personal communication, November 1998.

Choice Magazine, consumer magazine published monthly by the Australian Consumers' Association, Sydney.

Coldicutt AB, et al, 1977, The Value of Insulation, Thermal Insulation Institute of Australia, Melbourne.

Cobas-Flores, E., Hendrickson, C.T., Lave, L.B. and McMichael, F.C. 1996, Life Cycle Analysis of Batteries Using Input-Output Analysis, Proceedings: 1996 International Symposium on Electronics and the Environment, np.

Crabb N., Tang P., Gangopadhyay G, Bartels R. and Fiebig D., Domestic End Use Study in NSW, paper presented to ESAA Forecasting Forum, 18–19 November 1993, Adelaide.

CSIRO 1980, Heating Degree Days for Australian Localities, by P.J. Walsh and J.W. Spencer, Division of Building Research, Technical Paper number 35, Commonwealth Scientific and Industrial Research Organisation, 1980.

CSIRO 1998, "User Guide for NatHERS — The Computer Simulation Tool for House Energy Rating", Nationwide House Energy Rating Scheme, Version 2.20, unpublished draft, March 1998.

D'Cruz, N., Evans, P., McGeorge, D. and Price, R. 1990, An Investigation of the Energy Implications of Various Wall Types Currently used in Domestic Construction in Western Australia, Curtin Consultancy Services, Curtin University of Technology, Perth, p. 61.

DOE 1996, Engineering and Financial Statistics of Electricity Supply Authorities in NSW 1994/5. NSW Department of Energy, Sydney.

EEA 1993, Solar and Heat Pump Hot Water Systems — Considerations for Proposed Financing Program, for ERDC by Energy and Economic Analysis with GWA and EES, Canberra, December 1993.

EES 1995, Potential for Greater Energy Efficiency in Domestic Appliances in Queensland, prepared for the Queensland Electricity Commission by Energy Efficient Strategies and George Wilkenfeld and Associates, April 1995.

EES 1996, Energy Efficiency Standard for Traded Products: Refrigerators and Freezers in Australia and New Zealand, prepared for OECD Environment Directorate by Energy Efficient Strategies and Fisher and Paykel.

EES 1997, Analysis of GfK Appliance Sales Data, An analysis to assess energy consumption and performance trends of major household appliances in the Australian market from 1993 to 1996, prepared by Energy Efficient Strategies for the Department of Primary Industries and Energy and NAEEEC, draft report dated 12 September 1997. Unpublished data for calendar year 1997 also incorporated into the project results.

EES 1998, Appliance Energy Labelling Review Committee Support Documentation, prepared for NAEEEC by Energy Efficient Strategies, 20 March 1998.

Energy Victoria 1994, Energy Efficient Housing Manual — Design Guidelines and Case Studies.

EEV 1998, "Recommendations for Revised Climate Files and Star Bands for NatHERS", Energy Efficiency Victoria, unpublished report for NBEECC Residual tasks Working Group, Melbourne, 1998.

England, R.W. and Casler, S.D. 1995, Fossil Fuel Use and Sustainable Development: Evidence from U.S. Input-Output Data, 1972–1985, Advances in the Economics of Energy and Resources, Vol. 9, pp. 21–44.

EPPB, 1994. Energy Efficient Environment-Friendly Office Equipment. Energy Policy and Planning Bureau and the Greenhouse Co-ordination Council, W.A. 1994.

ESAA 1998, Electricity Australia, Electricity Supply Association of Australia, Sydney.

ESAA 1993 Electricity Australia, Electricity Supply Association of Australia, Sydney.

FARIMA 1983, Energy Conservation Through Insulation Incentives, Fibreglass Insulation Manufacturers Association, Melbourne.

FARIMA 1997, Incentives to Encourage Home Insulation, Submission to the Commonwealth Department of Primary Industries and Energy Task Force White Paper on Sustainable Energy.

Fay, R., 1998, Life Cycle Energy: A Method of Assessing the Long-Term Environmental Impact of Buildings, Proceedings: Buildings and the Environment in Asia, Singapore, February 11–13, pp. 119–123.

Floyd, W., 1998. Leaking Electricity: Individual Field Measurement of consumer Electronics. Presented at the 1998 ACEE Summer Study on Energy Efficiency in Buildings.

Fiebig, D., and Woodland A.1993, Residential Energy Consumption in NSW (Analysis of the ABS 1989 NSW Household Energy Survey), for NSW Office of Energy.

Fiebig, D., and Woodland A.1991, Residential Energy Consumption in NSW (Analysis of the ABS 1985–1986 Household Energy Survey), for NSW Dept Minerals and Energy and ECNSW, report DME 91/110, 1991.

GWA 1991a, Appliances — Assessment of Energy Efficiency Trends, prepared for SECV by George Wilkenfeld and Associates, June 1991.

GWA 1991b, Review of Residential Appliance Labelling, prepared for SECV by George Wilkenfeld and Associates, with Test Research and Artcraft Research, September 1991.

GWA 1992, Household Refrigeration Energy Efficiency in Victoria — Technology, Costs and Prospects, prepared for SECV by George Wilkenfeld and Associates, August 1992.

GWA 1993, Benefits and Costs of Implementing Minimum Energy Performance Standards for Household Electrical Appliances in Australia, Final Report, prepared for SECV by George Wilkenfeld and Associates, with Lawrence Berkeley Laboratory, for ANZMEC, July 1993.

GWA 1998, Australia's National Greenhouse Gas Inventory 1990 and 1995: Cross-Sectoral Analysis of Emissions. Report prepared for Environment Australia, by George Wilkenfeld and Associates Pty Ltd, February 1998.

GWA 1999, George Wilkenfeld and Associates, personal communication.

Hill, R.K. 1978, Gross Energy Requirements of Building Materials, Proceedings: Department of Environment Housing and Community Development Conference, Sydney, March, pp. 179–190.

IFIAS 1974, Energy Analysis Workshop on Methodology and Convention, International Federation of Institutes for Advanced Study, Workshop Report No. 6, Stockholm, August 25–30.

Ironmonger, D., and Lloyd-Smith, CW., 1992, Projections of Households and Household Populations by Household Size Propensities, in Journal of the Australian Population Association, Vol 9(2), pp. 153–172.

Ironmonger, D., 1994, Personal communication, University of Melbourne, June 1994.

Knowles, R. Ed., 1997, "Ethical Investment", Choice Books, Sydney.

Lawson, B., 1996, Building Materials Energy and the Environment: Towards Ecologically Sustainable Development, Royal Australian Institute of Architects, Red Hill, ACT, p.135.

Lave, L.B., Cobas-Flores, E., Hendrickson, C.T., and McMichael. F. 1995, Life Cycle Assessment: Using Input-Output Analysis to Estimate Economy-Wide Discharges, Environmental Science and Technology, Vol. 29, No. 9, pp. 420A–426A.

Lawson, W.R., 1996, Building Materials, Energy and the Environment: Towards Ecologically Sustainable Development, The Royal Australian Institute of Architects, Red Hill, p.135.

Leontief, W., 1966, Input-Output Economics, Oxford University Press, New York.

McArdle, S.A., Moylan, S.J., Pedler, S.D.M. and Webb, G.J. 1993, Case Study Analysis of the Embodied Energy of Office Construction, Joint Final Year Bachelor of Architecture Thesis, Deakin University, Geelong.

Miller, R.E. and Blair, P.D. 1985, Input-Output Analysis — Foundations and Extensions, Prentice Hall, New Jersey.

Milne 1998, Scoping Study into Standby Energy Use by domestic Electronic Appliances. A Report for SEDA by Geoff Milne.

Moller 1997, Frequency analysis of capital city weather data used for Bunyip modelling program, personal communication, Steve Moller, BCE, CSIRO (via Graham Armstrong).

Mogg 1999, personal contact with Mr Bruce Mogg, Environmental Director for the Australian Home Heating Association (formerly the Australian Wood Heating Association), Queensland, January 1999.

MWA 1985, Domestic Water Use in Perth, WA. Metropolitan Water Authority.

NatHERS software and data files.

NIEIR 1997, Estimates of Residential Household Numbers and Floor Area, for Department of Primary Industries and Energy, by National Institute of Economic and Industry Research, Melbourne.

Pacific Power 1996, The Residential End-Use Study, A detailed study of how and when electricity is consumed by the residential class in NSW, Pacific Power and NSW Electricity Supply Industry.

Pears, A., 1998, Strategic Study of Household Energy and Greenhouse Issues. A Report for Environment Australia Melbourne.

Pullen, S. 1995, Embodied Energy of Building Materials in Houses, Master of Building Science Thesis, University of Adelaide, Adelaide, p. 184.

QEC 1993a, Queensland Domestic Appliance Usage Survey 1992, Queensland Electricity Commission, Brisbane, Report 1 — February 1993, Report 2 — May 1993.

QEC 1993b, Queensland Domestic Electricity End Use Study, Queensland Electricity Commission, Brisbane, March 1993.

Oka, T., Suzuki, M., and Konnya, T. 1993, The Estimation of Energy Consumption and Amounts of Pollutants Due to the Construction of Buildings, Energy and Buildings, No. 19, pp. 303–311.

Peet, N.J. and Baines, J.T. 1986, Energy Analysis: a Review of Theory and Applications, Report No. 126, New Zealand Energy Research and Development Committee, Auckland, p. 56.

Pullen, S. 1995, Embodied Energy of Building Materials in Houses, Master of Building Science Thesis, University of Adelaide, Adelaide, p. 184.

Schipper et al 1998, Energy Use in Australia in an International Perspective: Comparison of Trends through the early 1990's, by Lee Schipper, Fridtjof Unander, Celine Marie, Ian Walker, Roger Gorham — IEA and Michael Ting, Marta Khrushch, Tom Krackler — Lawrence Berkeley Laboratory, for DPIE.

SECWA 1991, Domestic Energy Use in Western Australia (an analysis of the 1986 ABS Household Energy Survey and Diary Data), State Electricity Commission of Western Australia, September 1991.

Seeman, P. 1984, Input-Output Analysis and Energy Consumption, Undergraduate Thesis, Bachelor of Engineering, University of Canterbury, New Zealand.

SMH, 1998, 'Tuned in But Not to Cable TV' Sydney Morning Herald, 3/11/98.

SOLARCH 1993, Cost/Benefit Study of Insulation of Residential buildings in NSW, The National Solar Architecture Research Unit, School of Architecture, University of NSW, Sydney, report for the NSW Office of Energy, November 1993.

SOLARCH 1995, "A Window Energy Rating Scheme for Australia", report to the Australasian Window Council by Unisearch (UNSW), Sydney, December 1995.

SRC 1993, Domestic Hot Water Efficiency Improvements Program Feasibility Study — Task 1: Audits of Current Water Heater Stock and Usage, Summary Report, SRC Australia, for Queensland Electricity Commission, October 1993.

Stein, R.G., Stein, C., Buckley, M. and Green, M. 1981, Handbook of Energy Use for Building Construction, U.S. Department of Energy, Washington, March, p. 171.

Test Research 1995, Appliance Use Survey, prepared for NAEEEC by Test Research (ACA), February 1995 (postal survey of 2,900 Australian Households).

Treloar, G.J. 1996, The Environmental Impact of Construction — A Case Study, Australia and New Zealand Architectural Science Association Monograph No. 001, Sydney, November, p. 95.

Treloar, G.J. 1997, Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input-Output-Based Hybrid Energy Analysis Method, Economic Systems Research, Vol. 9, No. 4, pp. 375–391.

Treloar, G.J. 1998, A Comprehensive Embodied Energy Analysis Framework, PhD Thesis, Deakin University, Geelong, June, p. 285.

Treloar, G.J. and Fay, M.R. 1998, Embodied Energy of Living, Environment Design Guide Practice Note GEN 20, Royal Australian Institute of Architects, Red Hill, August, p. 8.

Tucker, S.N., Salomonsson, G.D., Treloar, G.J., MacSporran, C.M. and Flood, J. 1993, The Environmental Impact of Energy Embodied in Construction, report prepared for RITE, Kyoto, (DBCE DOC 93/39M), CSIRO, Highett, p. 134.

Tucker, S.N., Salomonsson, G.D. and MacSporran, C. 1994, Environmental Impact of Energy Embodied in Construction, report prepared for the Research Institute for Innovative Technology for the Earth (RITE), Kyoto, (DBCE DOC 94/22), CSIRO, Highett, p. 79.

Tucker. S.N., Salomonsson, G.D., Ambrose, M.D., Treloar, G.J., Hunter, B., Edwards, P.J., Stewart, P.J., Anton, S., and Crutchley, G. 1996, Development of Analytical Models for Evaluating Energy Embodied in Construction, report prepared for the Energy Research and Development Corporation, (DBCE DOC 96/84M), CSIRO, Highett, p. 56.

WSA 1998, personal communication with John Hughes, Water Services Association of Australia, Melbourne (through Standards Committee EL15/4).

Watt, M. 1996., Photovoltaic Power application in Australia. Report for the IEA.

Wilkenfeld, G.L. 1989, The Electrification of the Sydney Energy System, Thesis for the degree of Doctor of Philosophy, Centre for Environmental and Urban Studies, Macquarie University, Sydney, February 1989.

Worth, D.T. 1992, Pilot Study: Input-Output Analysis of the Embodied Energy in Building Materials, (DBCE DOC 92/40M), CSIRO, Highett.

Williamson TR, 1991, Report on the Costs and Benefits of Thermal Insulation in New Dwellings in South Australia, University of Adelaide.

Wilrath H 1998, “Thermal Star Ratings for Queensland Houses”, unpublished report for Queensland Department of Public Works and Housing, Brisbane, 1998.

Yann Campbell Hoare and Wheeler., 1990, Water Efficient Shower Roses, Project Proposal for Sydney Water Board.