Residential Energy Baseline Study: Australia

Prepared for

***Department of Industry and Science** on behalf of the trans-Tasman Equipment Energy Efficiency (E3) Program*

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Executive Summary

The Department of the Industry and Science (the Department), on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, engaged EnergyConsult to undertake an update of the Residential Baseline Study (RBS), a study into energy use in the Australian residential sector which was previously undertaken in 1999 and 2008. The study was extended to include New Zealand and covers the period 2000 - 2030. This report only focuses on Australia and a separate report has been prepared for New Zealand.

Objectives and Limitations

The prime objectives for the RBS were to develop a model of energy consumption that covers all categories of residential appliances/equipment and that provides projections of energy consumption until 2030. The study examined energy use in total, by end-use and by fuel. It also examined and modelled potential maximum residential electricity peak demand during extreme weather events. The RBS model was designed so Department users can input appliance, building and energy data as this becomes available, and be able to alter modelling factors in order to undertake policy research.

The key limitations of the RBS modelling and report are due to gaps and limitations in the data/information concerning residential appliances and equipment and their use, which require the need to make assumptions or estimations to address these gaps. For the modelling of projections of future energy use, such projections are largely based on existing product trends and current usage behaviour but in some cases further assumptions had to be made. For example, a conservative assumption is used that only current regulatory settings will impact on a product's efficiency, i.e. current Minimum Energy Performance Standards (MEPS) and any other efficiency improvements are based on past trends. Another key assumption is that appliance use will remain unchanged, unless existing trends clearly indicate otherwise.

There are further limitations regarding the modelling of peak power demand as there is less known about the use and operation of appliances and equipment during extreme weather events, when peak residential power demand occurs. This meant additional assumptions were required to fill data gaps.

Approach

This study is an attempt to model total energy use and demand from thousands of individual pieces of data on the hundreds of different types and models of residential appliances and equipment installed in Australian and New Zealand homes. The modelling tool, the RBS model, is a bottom-up, end-use energy model of the residential sector in Australia and New Zealand. The resulting RBS modelling enables the contribution of individual end-uses, product groups and products to national energy use to be examined and understood.

The RBS model incorporates data from a wide variety of sources and takes into account the following major factors:

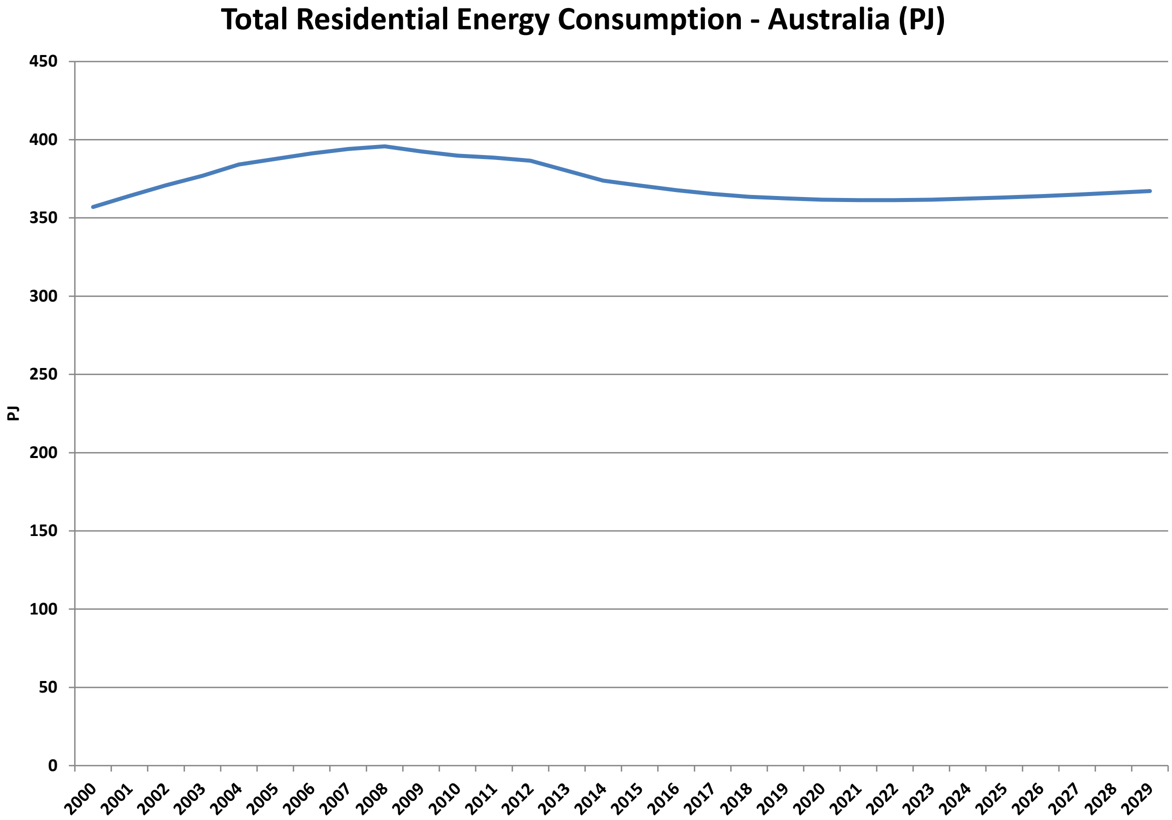
- Sales and stock of all residential appliances
- The energy usage, demand and efficiency of all appliances, which varies by appliance type, technology, size and year sold
- Usage patterns and user behaviour regarding all appliance use, varied by locality where relevant
- Building type, insulation and thermal efficiency varied by locality and over time
- The impact of climate on space conditioning requirements and usage
- The impact of locality on PV generation.

The RBS modelling used a consistent engineering algorithm and calculation methodology that focuses on determining the Unit Energy Consumption and Unit Energy Demand in each year for all of the 125 residential products modelled. This approach allows data on product efficiency, sales and stock over time to be separately incorporated into the model, as well as projections of these factors for future years to be separately developed, assessed and incorporated into the model. The result is that the RBS model is based on a consistent methodology which permits the examination of the drivers of energy and demand trends.

The potential impacts of improvements in building shell efficiency over time were also incorporated into the RBS model. Using existing AccuRate research, and research conducted specifically for this study, estimates of the average building shell efficiency and space conditioning energy requirements for all dwellings in each year of the study period covered by the RBS (i.e. 2000-2030) were determined. These estimates were then used to modify the engineering algorithm (i.e. product information based) estimates of space conditioning energy consumption and demand.

National Results

The most important result is that the current study predicts that national residential energy consumption, after peaking at 385 petajoules (PJ) in 2008, has fallen for five years and will remain at current levels until around 2021. Only after 2021 is total energy consumption predicted to start to slowly rise.[1] This trend is conservative in that the model does not anticipate further energy efficiency regulatory requirements or new energy efficiency programs being introduced, unless the regulation has already been announced.



This decline in total consumption and then only gradual resumption in the trend to increased consumption is a consumption trend that differs from the decades of growth seen leading up to 2008.

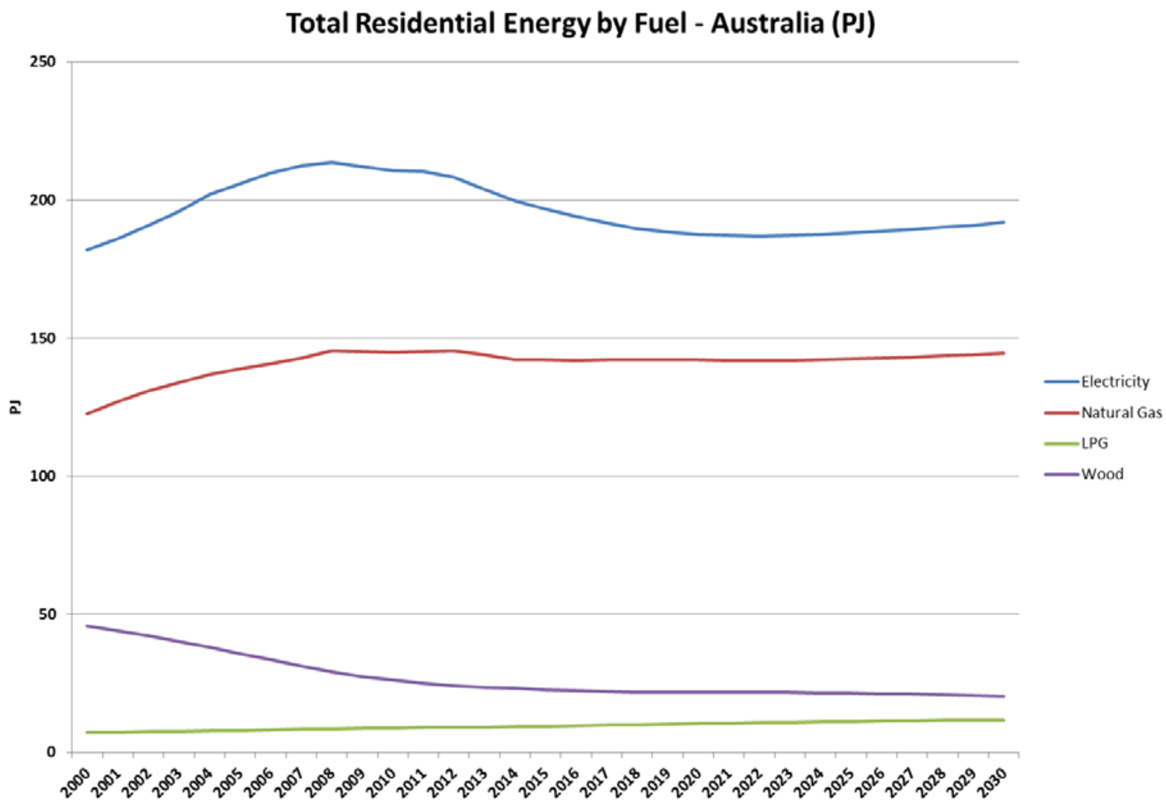
As will be further discussed later in this report, the main reason for the rises and falls in total energy consumption over the study period is due to changes in energy use per dwelling. Average energy use per dwelling, has being falling since the year 2004 and is expected to continue to decline to 2030, though less rapidly in the 2020s, based on projected trends. Since 2008 the saving in energy due to the decreased use per dwelling has exceeded the growth in energy use due to increasing numbers of dwellings, so there is

[1] Note: All results are reporting gross energy consumption or gross demand, excluding the impacts of PV generation, which is reported separately

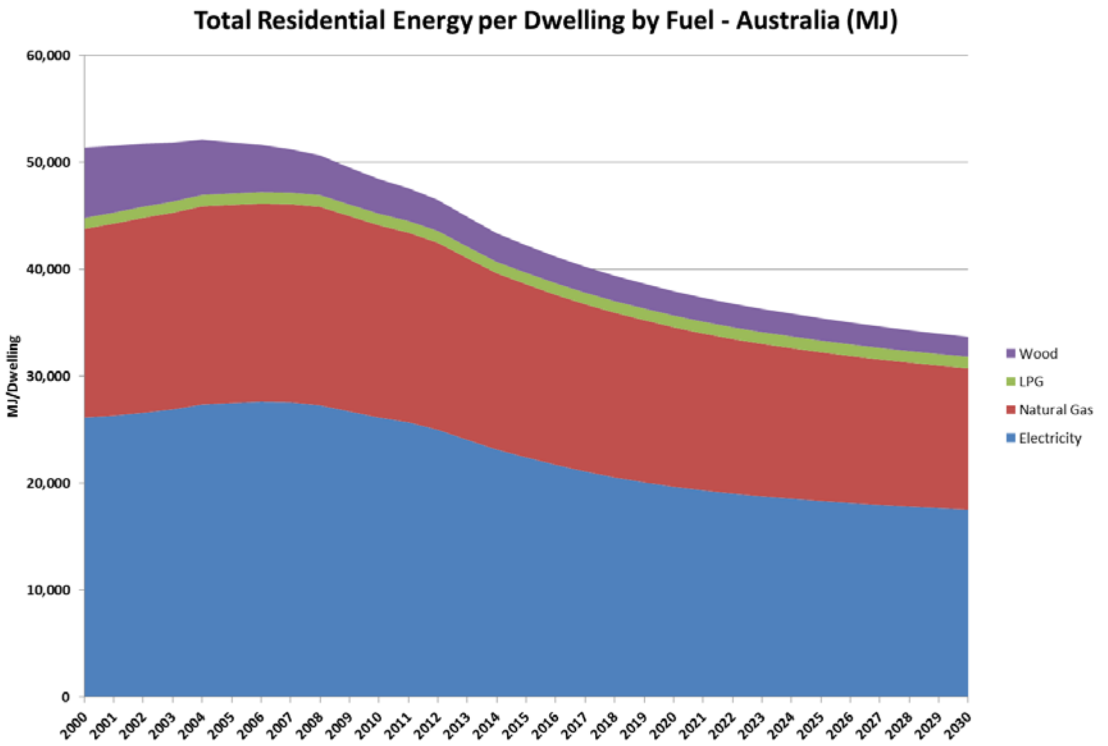
a net reduction in total energy use. Later in the 2020s, the increased energy use due to increasing housing numbers is expected to exceed the savings in energy from decreased use per dwelling, so total energy use is expected to start to slowly grow again. This increase in the 2020s follows from the model using a conservative assumption that no new regulatory driven changes will occur to drive further significant energy efficiency improvements.

Space conditioning contributes the greatest amount to the decline in total energy use per dwelling, followed by lighting and then appliances and water heating. These energy reductions are due to improvements in product energy efficiency, changes in the technologies being used and fuel switching. These changes are further discussed in the body of this report.

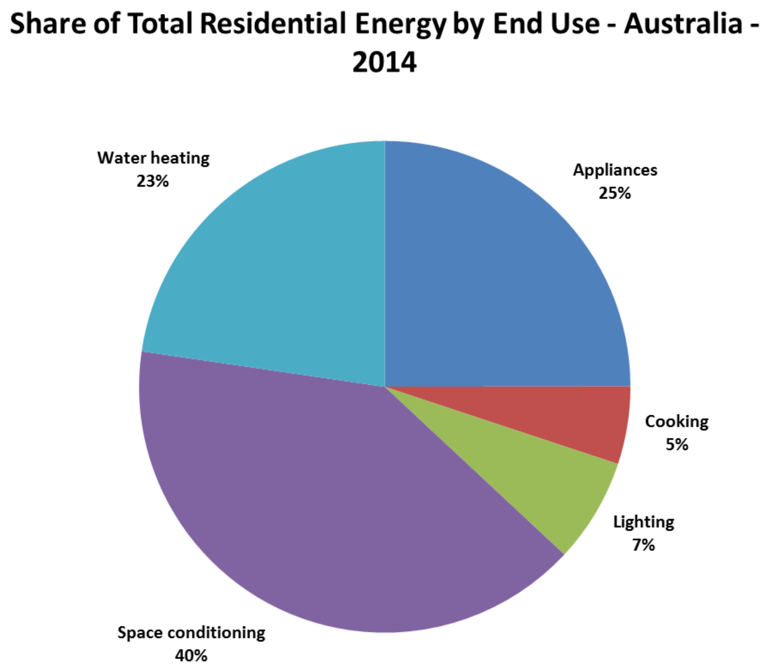
The national residential results show usage trends differing by fuel, as shown below. Electricity is the dominant form of energy used, followed by natural gas. Natural gas and Liquid Petroleum Gas (LPG) use are increasing but electricity and wood use are currently declining. Wood use is expected to continue to decline but electricity use is projected to begin to grow again in the 2020s. These declines are occurring despite ongoing population growth throughout the study period.



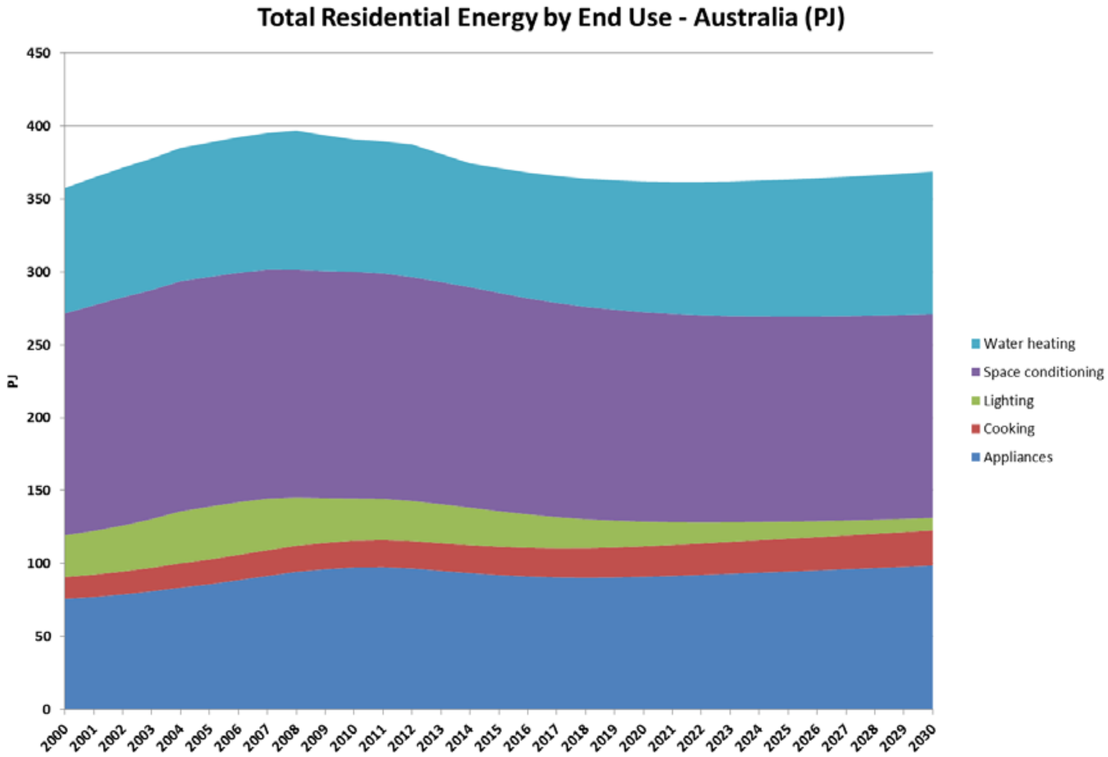
The driver of this trend is declining energy use per household since 2008 for all fuels except LPG, as shown in the following figure.



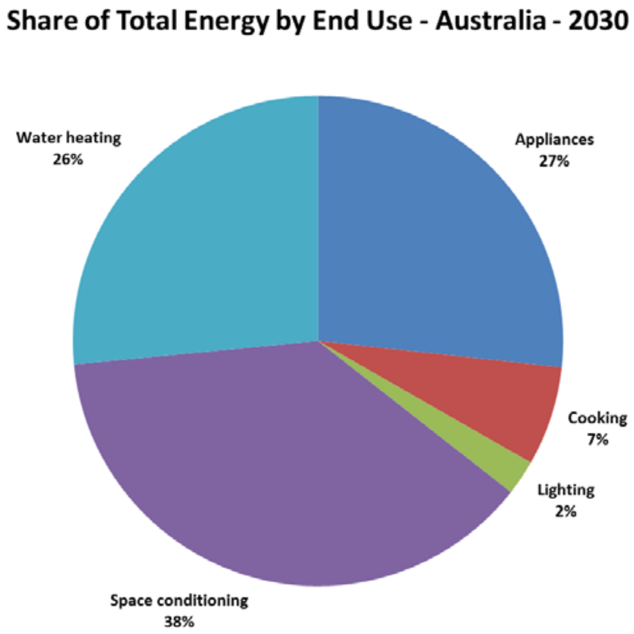
In terms of the contribution of the different energy end-uses to overall residential consumption, in 2014 space conditioning was the dominant end-use, followed by water heating and appliances. Lighting and cooking were minor energy users.



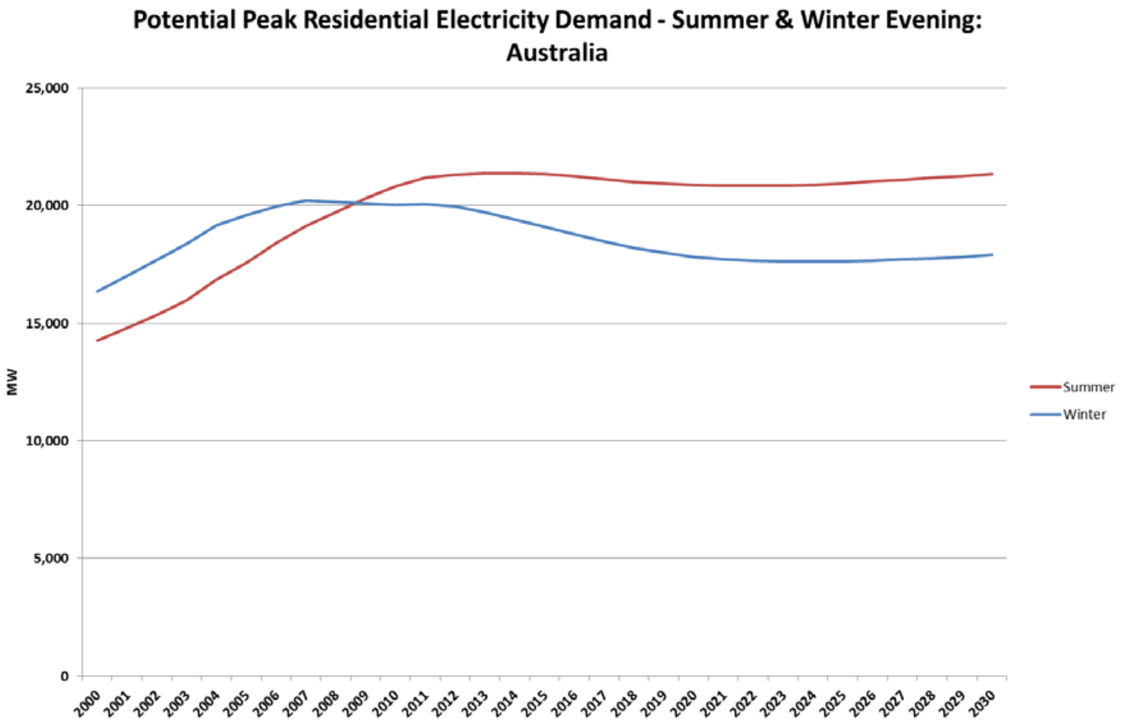
There are also changes in the contribution of different end-uses over time. The RBS projections indicate total energy use by both space conditioning and lighting declining through to 2030, but water heating and cooking energy use is increasing. Appliance energy use is in decline but is expected to start to increase from 2020.



The results of these changes are that the proportion of total energy used by end-uses is projected to be as shown in the following chart.



Potential peak demand was calculated for an extreme[2] summer evening and an extreme winter evening. The results are illustrated in the chart below. The trends in peak demand are similar to that of total energy consumption, which is rapidly rising in the 2000's, peaking and then declining or stabilising after approximately 2010.

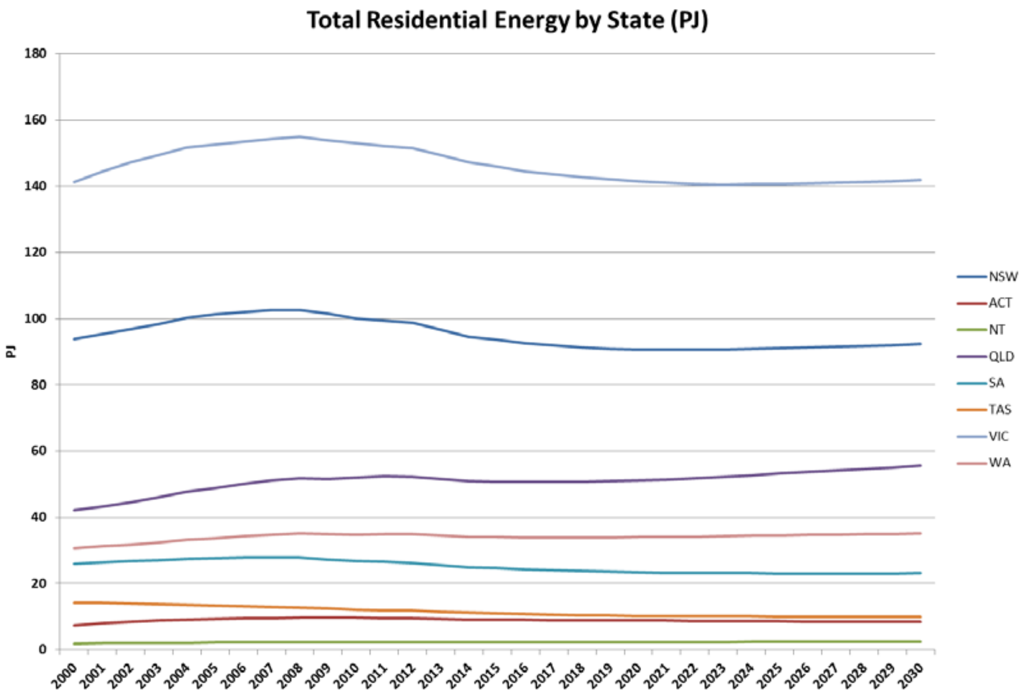


State Results

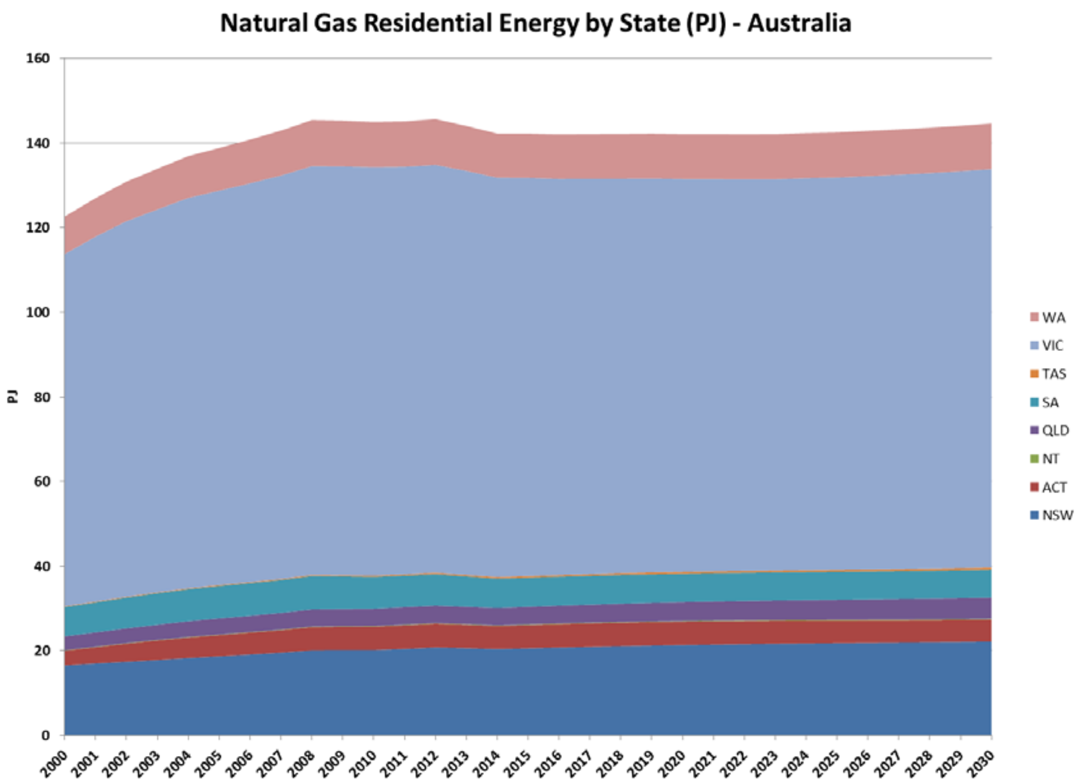
The total energy consumption of States is shown in the following chart. This chart shows:

- Projections for all States, with the exception of Western Australia and Queensland, show declines in their total energy consumption in 2030 compared to 2014
- State total energy consumption largely reflects their population/dwelling numbers. However Victoria has a higher consumption than NSW, and the largest energy consumption of any State, due to much higher space heating load.

[2] What constitutes an extreme summer or winter evening will vary with locality, but they are the evenings when the maximum proportion of dwellings are operating their space conditioning and coincide with very hot or cold weather.

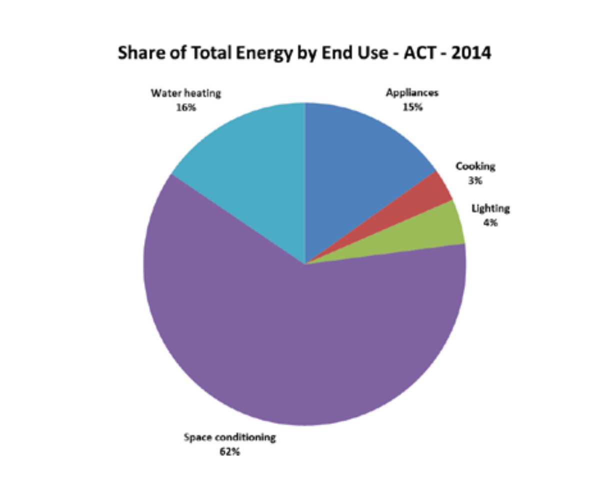


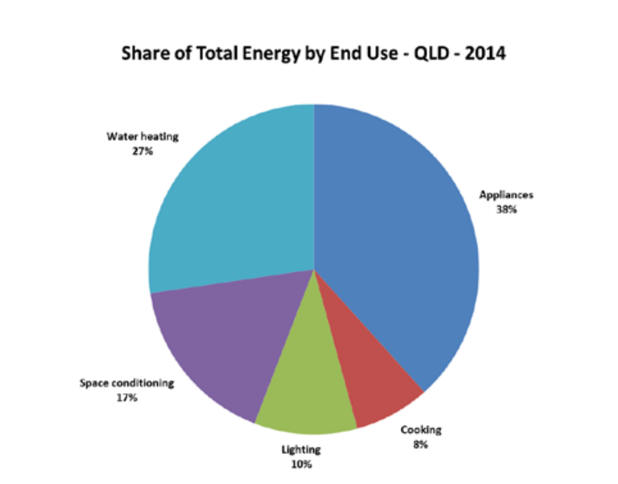
The differences between States in their use of different fuels are most noticeable for natural gas, as shown below.



The natural gas chart shows Victoria dominates the use of this fuel in Australia, and in 2014 contributed approximately 65% of total consumption despite having around 25% of the population. This reflects both Victorian households' greater access to natural gas and higher space heating needs.

Other significant differences between States reflect the extent that space conditioning dominates their total energy use, which in turn is a reflection of their climates. Generally the colder the climate, the more dominant space conditioning is in energy use. Two extremes in its influence in 2014 are shown below, with space conditioning making up 62% of consumption in the colder ACT but only 17% of consumption in the warmer Queensland.





Energy Use by End Use

The trend lines for energy consumption by end use in the following chart show both the contribution of each end use to the overall energy consumption and how energy use by end-use is changing. By analysing the contribution of individual products and product groups to the energy consumption of each end-use, further insight into the drivers of the end-use trends can be gained, which has been done in the main report. This chart, combined with the analysis shows:

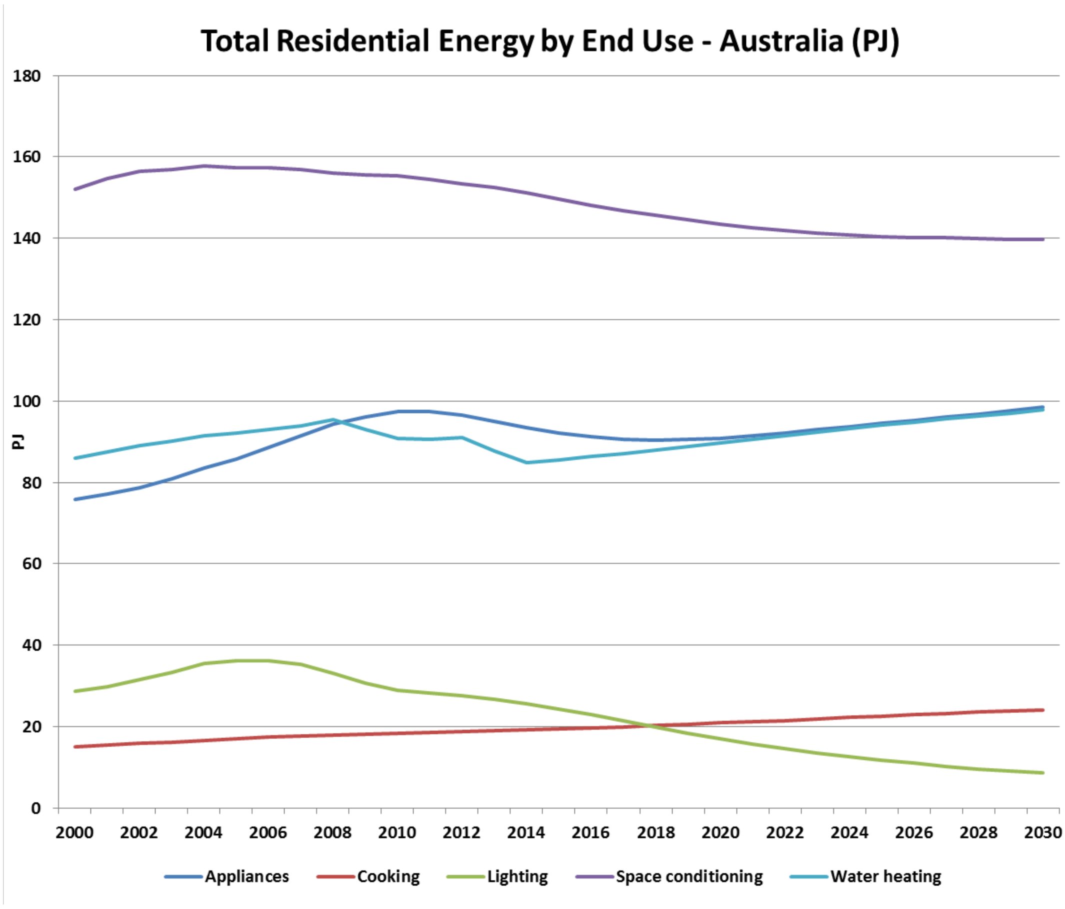
- Space conditioning energy use has been in decline since 2004 and is expected to continue to decline throughout the projection period. Improvements in the energy efficiency of products is a major contributor to this decline, and the trend for householders to use more efficient air conditioners for heating, instead of electric resistive heaters, gas heaters or wood heaters, is adding to the decline.
- Water heating energy use has been in decline since 2009, but is expected to increase from 2014 onwards. Reductions in hot water use have been a major contributor to the decline in the energy use of water heating over the last five years, probably due to the introduction of water efficiency measures, but ongoing reductions in water use are not expected to occur, so reductions in water heating energy use are also

expected to cease. This will mean water heating energy use will again start to increase as dwelling numbers, and therefore water heater numbers, increase.

- Appliance energy use has been declining since 2010 but is expected to start to increase from 2020. Improvements in the energy efficiency of appliance products, especially of televisions, has been the main driver of the recent decline in appliance energy use but, unless new improvements in appliance energy efficiency occur, increasing appliance numbers will lead to increases in total appliance energy use in the 2020s.

- Lighting energy use has been in decline since 2007 and is expected to continue to decline throughout the projection period. Improvements in the overall energy efficiency of the mix of lighting technologies used in the home are the major contributor to the decline in the energy use of lighting products. Householders have changed from using inefficient incandescent lamps to more efficient compact fluorescent lamps and halogens, and increasingly are using even more efficient light emitting diode lamps.

- Cooking energy use has been increasing for fifteen years and projections indicate energy use will continue to increase, but at a relatively low rate of increase driven by increased cooking appliance numbers, due to increasing dwelling numbers.

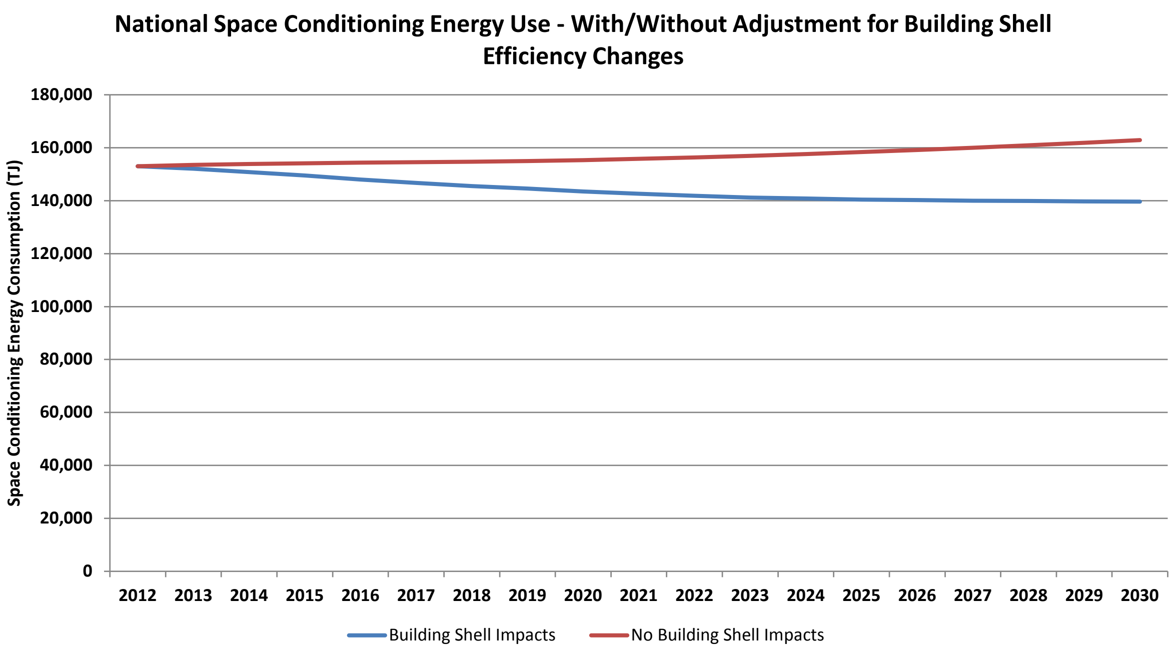


Impact of Building Shell Efficiency Improvements

The RBS model was developed in a way that enables the impact of residential building shell efficiency improvements on space conditioning energy use to be examined. AccuRate based estimates of the average building shell efficiency of dwellings in each year, in each State, were obtained, and input into the RBS model. The changes in average building shell efficiency compared to a base year were then used to calculate the potential impact of building shell changes on space conditioning energy use.

However, the only comprehensive study of whether AccuRate estimates of building shell efficiency actually correspond to 'real life' energy use was a CSIRO study (Ambrose et al, 2013) of energy use in 414 homes in Adelaide, Melbourne and Brisbane, with star ratings ranging from 3.5 to 6.5 stars. The results of this study found that improvements in the building shell efficiency of the dwellings, in the study, as estimated by AccuRate, did not relate to savings in space conditioning energy use in Brisbane or Adelaide, and only related to heating energy use in Melbourne homes. CSIRO notes that there was a range of factors that impacted on the conduct of the study that make it difficult to draw robust conclusions about differences in lower and higher rated houses that could be applied across Australia. Nevertheless, this suggests AccuRate based estimates of building shell efficiency improvements are more clearly applicable to space heating energy use in colder climates.

Consequently the RBS model settings were adjusted so the impact of building shell efficiency improvements on space conditioning energy use would only be included in the energy modelling for the space heating of dwellings in the ACT, Victoria and Tasmania. The resulting modelled national space conditioning energy use, with and without the impacts of adjustments for improvements in building shell efficiency, is shown below.



These results suggest as much as 23 PJ of energy, 14% of total consumption, may be saved in 2030 from projected improvements in the building shell efficiency of the average dwelling in 2012 compared to 2030. Also, these predictions are conservative in that they do not include any potential cooling energy savings from building shell efficiency.

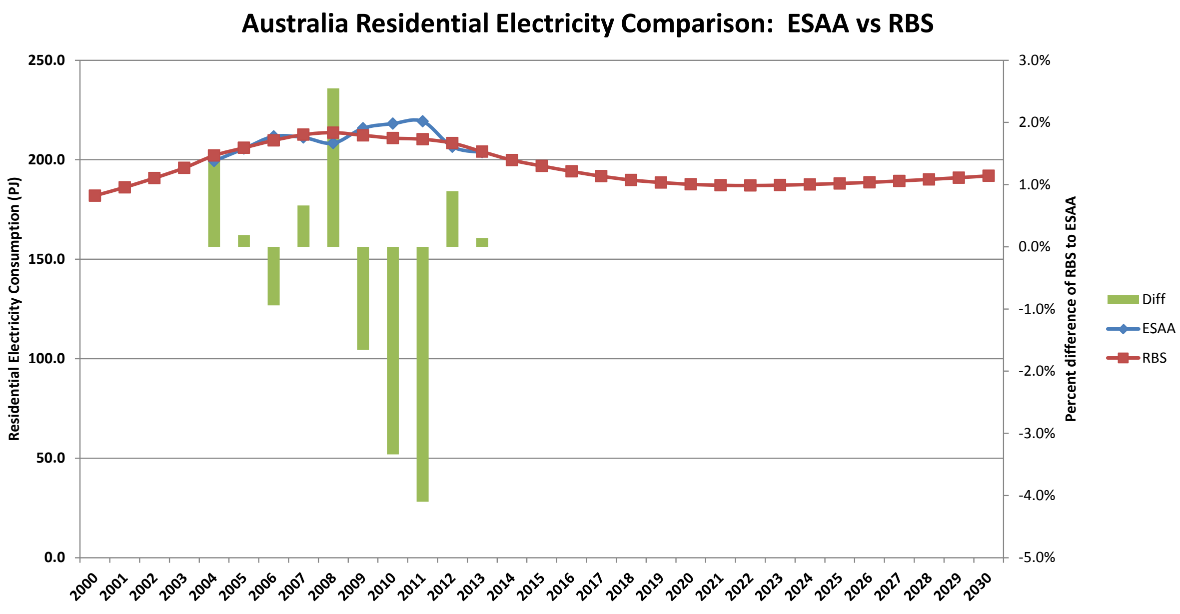
The impact of these building shell improvements on peak demand were also modelled but indicated these might result in an impact of only 1.8% on winter peak by 2030, and due to other factors the impact probably would be even less.

RBS Model Accuracy and Comparison to Top-down Data

The results of the RBS modelling were compared to other sources of estimates of residential energy use, including:

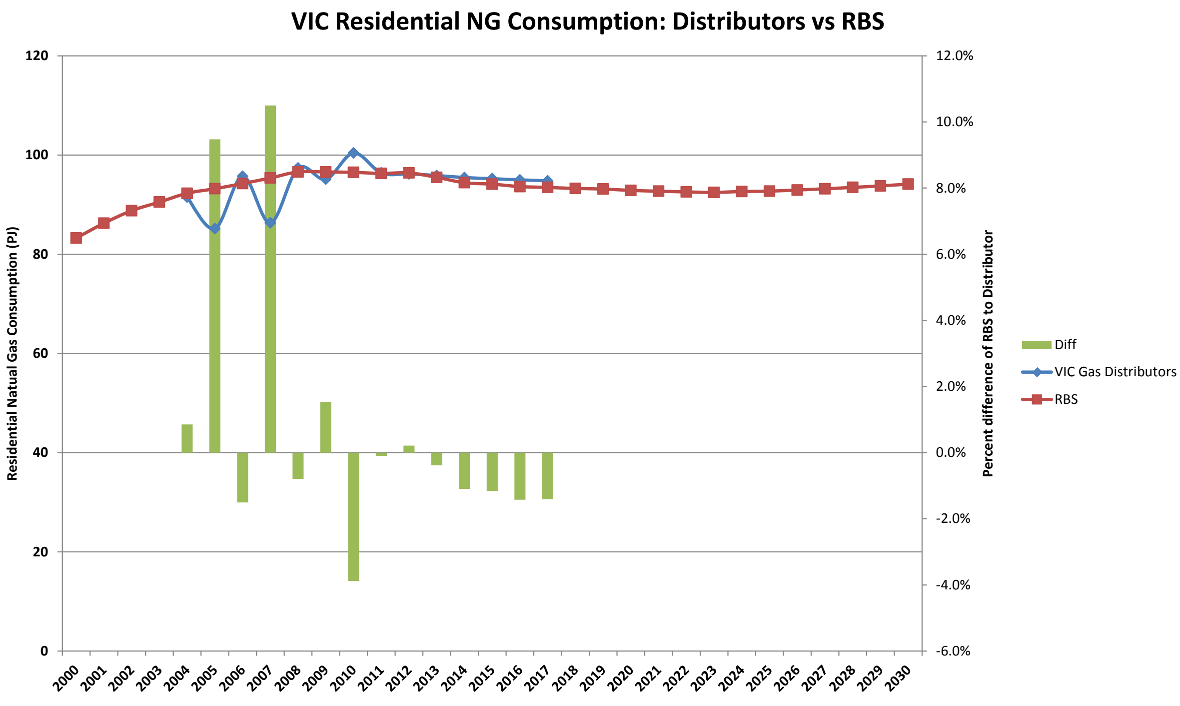
- Office of the Chief Economist (OCE)
- Energy Supply Association of Australia (ESAA)
- Various electricity and gas distributors.

The OCE estimates are based on aggregated data from market operators for Australia's electricity networks, who provide estimates and projections of residential consumption. In comparison, the ESAA residential energy measurements were closely aligned with distributor data, which is based on actual metered consumption data. This meant the ESAA measurements were more appropriate for assessing how the RBS estimates compared to actual residential consumption, and the figure below shows the comparison for national electricity consumption. The results show that for all the years compared there was an acceptable difference of less than 5% in the electricity estimates, and for most years a difference of 2% or less was found. In addition, the ESAA figures for recent years support the RBS's identification of a downward trend in energy consumption.



Comparisons of electricity consumption estimates were also done at the State level and, not surprisingly given the poorer appliance and use data available for the States, the results showed a lower level of consistency between the RBS results and the ESAA estimates. However, the maximum variation between the estimates was still under 10%, except for some outlier results for South Australia and Northern Territory, and the variation was under 5% for most years and States.

An effective comparison between the RBS national gas consumption estimates and OCE or ESAA estimates was not possible as the OCE or ESAA estimates both do not appear to be based on, or to be consistent with, State gas distributor consumption data. Consequently comparisons with State distributor estimates of gas consumption were undertaken and revealed that RBS results were within a maximum of 10% of the distributors' estimates. This is a satisfactory result given gas consumption is so strongly influenced by annual weather variations. The comparison for Victoria, the largest natural gas consumer, is shown below, which also shows the distributors projecting declining gas consumption as does the RBS results.



Note: Using distributors' projection data from 2011-2017

Conclusion

The RBS modelling has produced extensive insights into the current and future Australian residential energy consumption trends and drivers of these trends. The RBS predicts a decline in total national energy consumption before a gradual increase in consumption in the 2020s, which is consistent with energy distributor data over recent years and with their more recent predictions. This is a significant divergence from the rapid increases in consumption witnessed during the 2000s.

The RBS modelling has shown the extent that improvements in the energy efficiency of appliances, as well as consumers changing the fuel type for their space conditioning, have led to a decline in energy use per dwelling and that this trend is expected to continue throughout the study period. Since 2008 the rate of decline in energy use per dwelling has exceeded the rate of increase in dwelling numbers, so total energy use has declined. However, in the 2020s, projections indicate the rate of decline in energy use per dwelling reduces, so the increasing dwelling numbers start to drive an increase in total energy use. This trend follows from the model conservatively assuming no future regulatory will occur to drive further significant energy efficiency improvements, which may or may not prove to be the case.

1. Introduction and Background

The Department has commissioned EnergyConsult to undertake an update of the Residential Baseline Study (RBS), a study into energy use in the Australian and New Zealand Residential Sectors. A similar study 'Energy Use in the Australian Residential Sector' covering just Australia was last published in 2008 and prior to that in 1999. The Department now wishes to extend the study to both Australia and New Zealand. This report only focuses on Australia. A separate report has been prepared for New Zealand.

Objectives and Scope

There were a number of objectives for the RBS but prime requirements for the study include:

- Developing a model of energy consumption that covers all categories of residential appliances/equipment and that enables projection until 2030.
- Modelling potential residential electricity peak demand during extreme weather events
- Ensuring that alterations to appliance efficiency can be undertaken separately to building shell efficiency, so the impact of policy changes on building efficiency can be undertaken with the model
- Provide facilities so Department users can input appliance, building and energy data as this becomes available, and be able to alter modelling factors in order to undertake policy research.

The model and report are to encompass:

- In Australia, the building classifications of Class 1a- detached dwellings, Class 1b- attached dwellings and Class 2- buildings containing two or more occupancy units
- Residential energy use of electricity, natural gas, liquid petroleum gas, and wood, and solar photovoltaic electricity generation
- The ten grouped climate zones, as used in the 2008 study (EES 2008)
- Results and modelling at the jurisdictional level of Australian States and Territories, and at the national level.

The report describes the research, modelling and results obtained from undertaking the Residential Baseline Study. It covers the following topics:

- RBS Methodology chosen, the underlying calculation approaches and modelling architecture
- Overall national results, the total energy consumed, the main end-uses contributing to that consumption, and the energy consumption and peak demand by States

- Details of energy consumption at the end-use level and the main drivers of such consumption
- Data sources and the data processing used to populate the RBS model.

The key outputs of this study are a new version of the 'Energy Use in the Australian Residential Sector' report and provision of the RBS model which was used to provide the outputs required to prepare this report.

Limitations

The key limitations of the RBS modelling and report are due to data/information limitations concerning residential appliances and equipment and their use, and due to the assumptions required when making projections about future residential energy use.

Generally there is considerable information available on the numbers, nature, characteristics and use of residential appliances and equipment, but there are gaps and limitations on the information available for some products which resulted in the need to make assumptions and estimations. The nature of the information used and its limitations are described in Data Sources and Input Processing, and also in more detail in the Technical Appendix.

For the modelling of projections of future energy use, such projections are largely based on existing product trends and current usage behaviour but in some cases further assumptions had to be made. For example, a conservative assumption is used that only current regulatory settings will impact on a product's efficiency, i.e. current Minimum Energy Performance Standards (MEPS) and any other efficiency improvements are based on past trends. Another assumption is that appliance use will remain unchanged, unless existing trends clearly indicate otherwise.

There is less known about the use of appliances and equipment during extreme weather events, when peak residential power demand occurs, or about how space conditioning equipment operates during extreme weather events. This limitation on the data available means additional assumptions were required to fill data gaps and there is a lower level of confidence in the peak demand results of the RBS.

Project Team and Acknowledgements

This report was prepared by Paul Ryan and Murray Pavia of EnergyConsult Pty Ltd.

The authors would like to acknowledge the contribution of Glenn Seymour of Strategic Energy Ltd (N.Z.), who assisted in researching and analysing New Zealand residential appliances and energy use data, and in the reviewing of this report. We would like to thank Richard Collins of Punchline Energy for his analysis and input regarding appliances.

We would also like to acknowledge the contribution of Sustainability House who were commissioned to provide the AccuRate estimates of the space conditioning energy loads of New Zealand housing.

Finally, we would like to thank the Department of Industry and Science, the Energy Efficiency and Conservation Authority, and all the people whose research we have drawn on to prepare this report and to develop the RBS model.

2. Methodology

Introduction

This report presents the main output and results of the RBS model developed for this study. The RBS model is a bottom-up, end-use energy model of the residential sector in Australia and New Zealand. This chapter describes the methods and approach used to estimate the energy use and demand of the different residential energy end-uses in the RBS model, and the overall architecture of the RBS model.

The RBS model incorporates data from a wide variety of sources and takes into account the following major factors:

- Sales and stock of all residential appliances
- The energy usage, demand and efficiency of all appliances, which varies by appliance type, technology, size and year sold
- Usage patterns and user behaviour regarding all appliance use, varied by locality where relevant
- Building type, insulation and thermal efficiency varied by locality and over time
- The impact of climate on space conditioning requirements and usage
- The impact of locality on PV generation.

In total 129 different appliances and products were modelled. The main aspects of the RBS modelling methodology is presented in the following sections:

- Underlying Method
- Space Conditioning Method
- Peak Load Method
- Model Architecture.

Underlying Method

The underlying method on which the residential energy end-use model and study is based is classified as a bottom-up engineering model (Yuning Ou, 2012). It involves calculating the energy end-use consumption at the household end-use level and aggregating these consumptions to estimate the total locality or national consumption.[3] More specifically this involves estimating the energy use at the appliance (unit) level and then aggregating the energy use across all appliances and households to get the total energy use.

[3] It should be noted that this approach will provide reasonable estimates of average consumption levels across the population of all dwellings but is not intended to be used as an estimate of the energy use of any specific, individual dwelling, as the consumption of individual dwellings will vary considerably.

This approach is summarised in the calculation that for each energy end use:

*Annual Energy Consumed (AEC) = Stock Numbers * Unit Energy Consumption (UEC).*

Likewise for energy demand in principle:

*Total Power Demand = Stock Numbers * Unit Power Demand (UPD)*[4].

The RBS model determines total energy consumed or demanded through the use of a Stock Model, and through the Calculation of Energy Impacts, both aspects of the model that are described below.

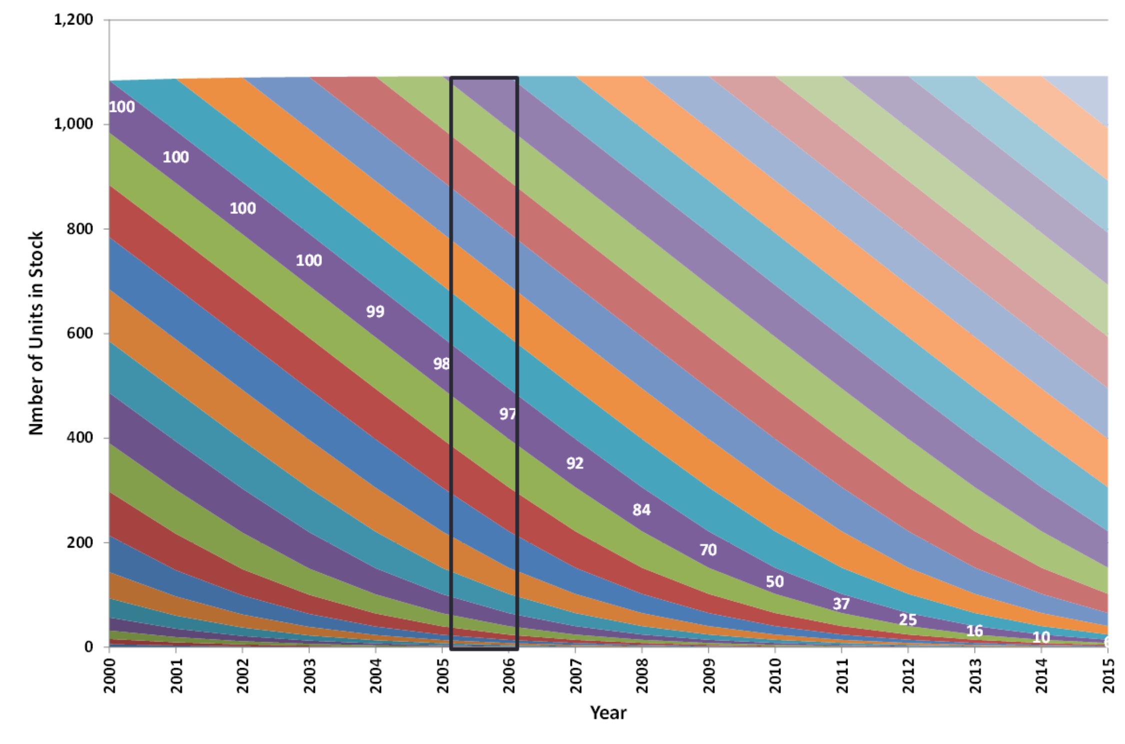
Stock Model

The energy consumption and power demand of particular appliance and equipment products are calculated using the characteristics of the products obtained from stock models. The stock models are effectively databases that keep a running tally of the numbers of each product in the residential market in any year, and the average characteristics of each product in any year. The stock in any year will be the sum of all past stock sales, less retirements of equipment.

Figure 1 shows that stock is added to by the sales in each year, and these products remain part of the stock into the future, but gradually reduce in number as they are retired (i.e. shown as going from 100 to 10 over time in the diagram). In any given year, (e.g., the year 2005 shown within the black rectangle in the diagram), the stock will consist of a mixture of the units sold in all previous years. Importantly, this means that equipment characteristics of the stock in any given year will also reflect the equipment characteristics of the stock of all previous year.

[4] For solar PV systems, similar equations are used for determining energy generation and power demand. These gross amounts are calculated and also combined with other model outputs to determine net generation when required. Impacts on locality of PV arrays on output and seasonal variations will be considered as required.

Figure 1: Stock Composite of Sales from Previous Years



The stock models of the RBS model therefore collect data on the required equipment characteristics of the products sold in every year, e.g. the average size, power, and efficiency of the units in any given year. These are the equipment characteristics which are used to calculate average energy consumption and power demand for the product. The stock model then keeps track of the data needed to calculate these average characteristics for each year, based on the characteristics and number of the new equipment sold in the year, as well as that of all previous years. This stock modelling is done at the national level and at the State/Territory level.

Calculating Unit Energy Impacts

The next aspect of the energy modelling is determining the value of the Unit Energy Consumption (UEC) for each end-use in the residential energy end-use model. At its most basic level, UEC is determined by:

*UEC = Hours of usage * Unit Energy Input,* or

UEC = Hours of usage[5] ** Unit Capacity * Unit Efficiency.*

The energy use of residential equipment can be calculated from these formulae, or from a variation of these formulae for more complex products operating in different modes or

[5] Operating hours for appliances are hours the appliance is used, and efficiency and capacity are changed in more complex equipment that can operate at part loads.

different measurement and usage metrics (such as wet appliances where UEC is a function of the use per cycle). For products with multiple modes (e.g., products which have a standby energy consumption element), energy consumption while in operating mode must be separately calculated and added to obtain the total energy consumption in all modes.

Unit Power Demand (UPD) is determined in a similar way to UEC, but the focus is on the proportion of equipment operating at a given time which is mainly derived from their usage profile, and can be expressed as:

*UPD = Proportion of equipment operating * Unit Power Input.*

Consequently UPD is determined for particular time periods, e.g. time of day or specific peak demand periods during a year. This means information on the usage behaviour for the equipment during the periods of interest, and on the operating power input requirements of the equipment, are essential for determining UPD in any period. The calculation of estimated peak demand is further explained in the section Peak Electricity Demand Method.

Space Conditioning Method

Though there are plenty of complexities and challenges in determining UEC and UPD for all types of appliances, one of the main challenges in the calculations comes when considering space conditioning equipment. For space conditioning equipment the use will vary with the locality, weather, building shell efficiency, building size, zoning, equipment type and occupant usage behaviours, plus through the interaction of these variables. As space conditioning is typically a large driver of energy consumption, some additional complexity is required in the methodology for modelling space conditioning in order to obtain reasonable model accuracy.

There are many methods for estimating space conditioning energy use and demand, but broadly they can be divided into three approaches as identified by Stern (2013):

- measurement/metering based approaches (billing, metered data, hours of use analysis)
- engineering algorithm models
- building thermal modelling.

In Australia and New Zealand there appears to be insufficient data to use measurement/metering based approaches, whereas the building thermal modelling, using AccuRate software developed by CSIRO, and engineering algorithm approaches have both been used to predict energy use and demand.

Thermal modelling involves the modelling of the energy requirements of a building to achieve specified internal thermal comfort conditions, such as temperature ranges, with the modelling being based on the specific design, construction and orientation of the building. Such modelling is conducted by programs such as AccuRate and other software tools accredited by the Nationwide House Energy Rating Scheme (NatHERS) (NatHERS 2015) to model the building shell efficiency of residential dwellings and can be used to estimate the heating and cooling energy demanded by the dwelling design in different climate zones to meet specified interior comfort conditions.

However, on its own, thermal modelling cannot meet the requirements of the RBS to determine the energy used in Australia for space conditioning. Information on the heating/cooling demand (i.e. the output of thermal modelling) needs to be combined with information on what actual space conditioning equipment is installed and usage behaviour in order to estimate actual energy use. In other words, thermal modelling on its own cannot be used to determine energy use unless it is combined in an engineering algorithm model that incorporates equipment and use data.

This combined thermal modelling/engineering algorithm approach is what was used in the previous RBS (EES 2008) and a combined approach will again be used in the current RBS, though the details of the approach differ from that used in the previous RBS[6]. The two key components of the current modelling approach are:

- Engineering algorithm modelling that uses data on space conditioning stock numbers, equipment efficiency and usage behaviour to determine the energy use of space conditioning equipment. This modelling is fundamentally the same as that used for all other products in the RBS model and is driven by stock models and calculation of Unit Energy Consumption (UEC) as previously described.

- Thermal modelling used to estimate the potential impact of changes in building shell efficiency over time on space conditioning energy demand. The RBS approach uses a stock model of housing stock to determine the changes in average thermal efficiency in States over time, with building shell thermal efficiency determined through AccuRate modelling. These changes in estimated energy requirements are then expressed as a ‘Usage Adjustment Factor- Building Shell’, which is a percentage increase or decrease in estimated energy required compared to a base year[7]. The Usage Adjustment Factor- Building Shell could then be fed into the engineering algorithm component of the model and impacts on energy use directly determined.

The RBS space conditioning method therefore starts with the engineering algorithm approach, hence with Unit Energy Consumption. UEC in its relevant form is stated as:

*UEC = Hours of usage * Unit Capacity * Unit Efficiency*

[6] Details of the differences with the previous approach and justification of the present method are contained in the Technical Appendix.

[7] The base year was 2012, chosen as it was the year where the most recent and accurate space conditioning usage data was available.

There was extensive information available on the Unit Capacity and Unit Efficiency of space conditioning equipment, so the information was obtained to enable this part of the modelling method to be implemented. There was also information available on the operating hours of space conditioning equipment across different types of equipment and States in Australia (e.g. ABS HEC 2014).

A further complication for the model was that Hours of Usage[8] does not directly equate to the number of hours that each unit is operating at its Unit Capacity (i.e. registered capacity). Issues affecting the calculation of a relevant Hours of Usage variable include:

- **Duty Cycle**: Most space heating equipment is thermostatically controlled and is automatically switched on and off, or its output up or down, according to the temperature requirements of the space being conditioned. The proportion of the Hours of Usage that the equipment operates depends on its duty cycle[9].
- **Reverse Cycle Use**: Reverse cycle air conditioning equipment introduces another modelling issue in that the proportion of equipment used for heating and/or cooling varies between climate zones. So only 5% of AC units may be used for heating in the Northern Territory, but 95% may be in Tasmania.
- **Saturation**: When a dwelling has multiple heaters or air conditioners, they will not all be used equally, with the second and third unit generally being used less. So allowance needs to be made for the saturation of equipment.
- **Housing Occupancy**: Approximately 10% of dwellings are unoccupied at any given time, so use of equipment needs to account for this. This applies to space heating and all other equipment, to varying degrees, too.

To accommodate all of these factors that influence Hours of Use a series of Usage Adjustment Factors (UAF) have been developed and included in the model, which correspond to the factors listed above. So there is a Usage Adjustment Factor- Duty Cycle, a Usage Adjustment Factor- Reverse Cycle, etc. as well as the Usage Adjustment Factor- Building Shell previously mentioned. The total impact of these factors is calculated in the model by multiplying the different factors together to determine the overall *Usage Adjustment Factor*.

The *Usage Adjustment Factor* is included in the *UEC* formula and expressed in its revised form as:

*UEC = Hours of usage * Usage Adjustment Factor * Unit Capacity * Unit Efficiency*

[8] The "hours of usage" is defined as the operating hours, i.e., the time that the user has switched the unit on. When relevant, standby hours will be calculated using the non-operating hours.

[9] For air conditioners/heat pumps, their efficiency is calculated using a seasonal energy efficiency ratio (SEER) value which takes into account variations in duty cycle or partial load use, so duty cycle was not relevant for this equipment.

The resulting approach means space conditioning energy use can be calculated in a manner consistent with that used for other residential equipment but the modelling approach can still incorporate all the complexities of space conditioning and the impact of building shell efficiency on its energy use.

Peak Electricity Demand Method

The peak demand modelling of the RBS is aimed at facilitating the development of measures to address peak load as well as general energy efficiency. The model was designed to estimate the trends in potential maximum peak demand in each State, during winter evenings and summer evenings, in response to changes in appliance and building shell efficiency over time. Winter and summer evenings were the time period modelled as this is when the residential maximum electricity demand occurs in response to extreme weather events.

The peak load of space conditioning equipment is calculated using a variation of the 'Combined Approach', one of the six peak demand savings estimation approaches identified by the US National Renewable Energy Laboratory, Stern (2013). This approach was defined to estimate the demand savings from energy efficiency actions, but has been varied to simply estimate residential peak demand. The Combined Approach is an engineering algorithm approach to calculating maximum potential demand, with the impact of building shell efficiency also integrated into the model, which is a similar combination of methods to that used for modelling space conditioning energy use.

TecMarket Works (2004, cited Stern, 2013) summarises the relevant engineering algorithm for estimating demand savings from equipment, and a variation of this for estimating demand is presented as follows:

$$kWDemand = units * kW/unit * RLF * DF * CF$$

Where:

- kW Demand = demand from relevant equipment that contributes to the system peak
- Units = units of relevant equipment
- kW/unit = unit demand of equipment (for space conditioning the maximum input power rating)
- RLF = rated load factor (the ratio between non-coincident peak and theoretical peak)
- DF = diversity factor
- CF = coincidence factor.[10]

[10] Further explanation of the calculation of potential maximum demand and of these terms is provided in the Technical Appendix.

Implementing the engineering algorithm approach has involved obtaining data on the number and characteristics of all residential appliances and equipment potentially operating during system peaks, and the development of programs to execute the demand equation specified above. The potential contribution of all products modelled is calculated and the results summed to estimate the aggregate potential maximum demand for each State and nationally for each year of the study period.

The impact of building shell efficiency changes was integrated into the demand model in a similar way to the manner used to integrate building shell efficiency changes into the modelling of space conditioning energy use. Research was conducted using AccuRate modelling to determine how building shell efficiency has changed over time and the resulting changes were then incorporated into the Demand Diversity Factor, via multiplying this by "Demand Adjustment Factor". The model allows the user the option of using or not using the Demand Adjustment Factor when calculating peak demand.

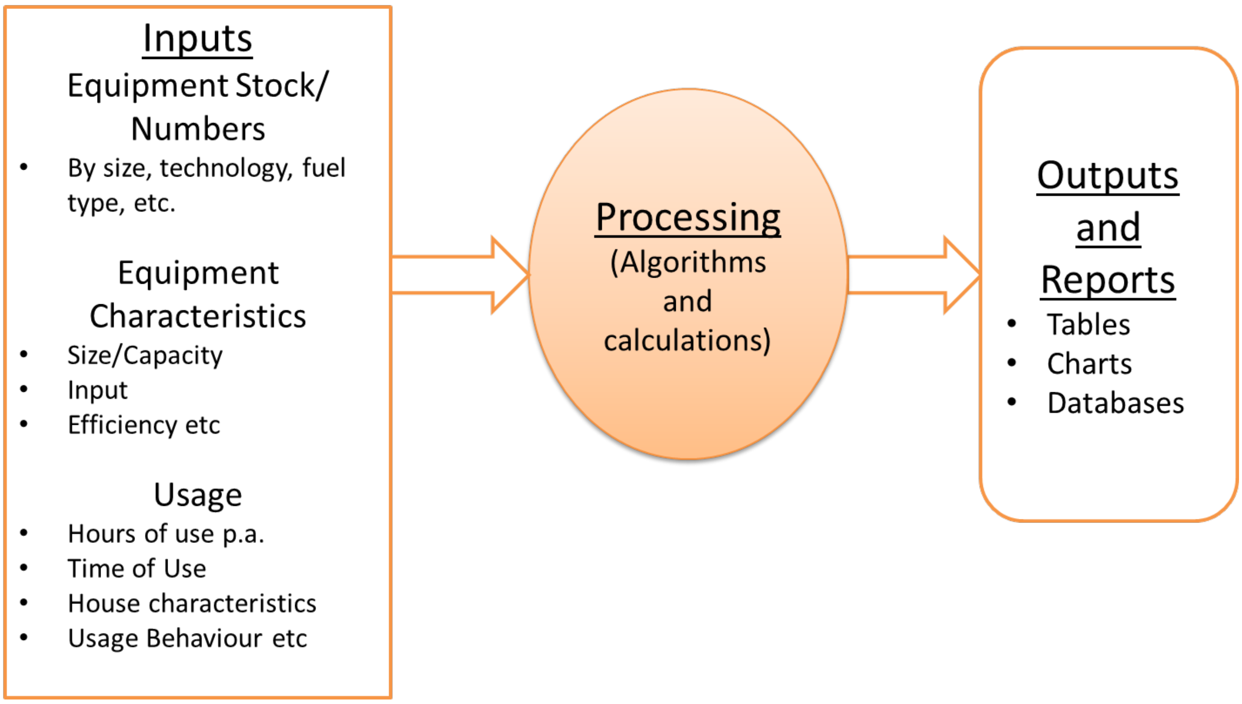
Research (such as that of Home Energy Rating (2007)) suggests there is a strong and quantifiable link between AccuRate theoretical predictions of space conditioning peak demand and NatHERS building star ratings. Likewise, the AccuRate modelling for dwellings with a range of efficiency undertaken for this RBS found a very high degree of correlation between modelled peak energy load in the coldest week and modelled overall annual energy consumption (i.e. 0.92 for detached housing and 0.94 for semi-detached). The results imply that the changes in AccuRate estimated energy efficiency of dwelling stock in a given year, compared to the base year, will strongly correspond to changes in Accurate estimated peak energy loads. Consequently the Usage Adjustment Factor- Building Shell previously discussed, was used as a Demand Adjustment Factor reflecting the impact of building shell changes on estimated power demand. So if the Usage Adjustment Factor- Building Shell for a year indicated energy use was 25% less than the base year energy usage, energy demand would also be 25% less.

However, it should be noted that there is limited research on the relationship of AccuRate ratings to real peak demand, so results will be reported for the modelling of maximum potential peak demand with and without adjustment for the estimated impact of building efficiency changes. The RBS model can also be used by the Department to model the potential impacts of building efficiency on peak demand over time.

Model Architecture

A new RBS energy end-use model had to be developed to meet the requirements of the current study of residential energy use. An overview of the architecture of the RBS model developed to meet the requirements of the RBS, in terms of the information flows and main processes represented, is shown in Figure 2. Examples of the types of input data are also shown.

Figure 2: Overview of Model Architecture: Information flows

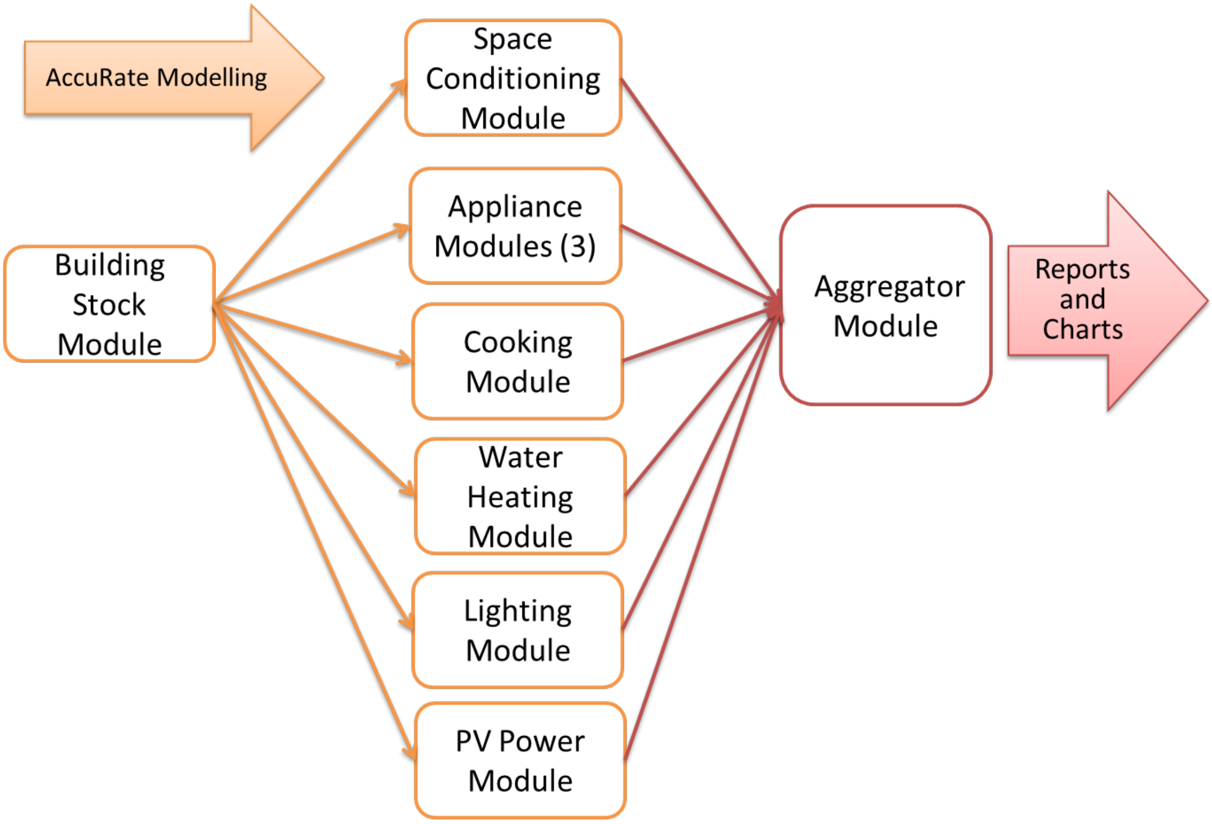


A modular approach was used to develop the model, with each module focused on either an energy end-use or a specific input/output of the model. The main modules of the model are:

- Water heating
- Space conditioning
- Lighting
- Cooking
- Appliances – White Goods
- Appliances – Information Technology and Home Entertainment
- Appliances – Other Equipment
- PV Power
- Building Stock (including thermal demand requirements)
- Aggregator (which includes Peak Demand aggregation).

A schematic of the end-use model is provided in Figure 3 below.

Figure 3: Schematic of Energy End-use Model Modules and Linkages



Within each end-use module, calculations were undertaken on each individual product for each year of the study period to determine UEC and UPD, and then these were aggregated by product group, product category and end-use as appropriate. The calculations were undertaken on a jurisdictional basis (state/territory/country) and by relevant climate zone where this was applicable (space conditioning, water heating, PV). The results were then produced as tables and charts within each module, as well as exported to the Aggregator. The nature of the different calculations used is described further in the Technical Appendix.

The model processed data and provided results on the energy end-uses, product categories and product groups that are listed in Table 1.

Table 1: List of Product Groups included in RBS Model

End Use	Category	Group
Space conditioning	Combined space heating and space cooling equipment	AC ducted
	Combined space heating and space cooling equipment	AC non-ducted (split and WW)
	Space cooling equipment	Evaporative (mostly central)
	Heating Equipment	Electric resistive
	Heating Equipment	Mains gas non-ducted
	Heating Equipment	Mains gas ducted
	Heating Equipment	LPG non-ducted
	Heating Equipment	Wood Heaters
	Space cooling equipment	Fans
Appliances	White goods	Refrigerators
	White goods	Freezers
	White goods	Dishwashers
	White goods	Clothes washers
	White goods	Clothes dryers
Appliances	Other Equipment	Pool Equipment - Elec
	Other Equipment	Pool Equipment - NG
	Other Equipment	Pumps
	Other Equipment	Battery chargers
	Other Equipment	Miscellaneous
	Other Equipment	Class 2 Common Areas
Appliances	IT&HE	Television - composite average
	IT&HE	Set-top box - free-to-air
	IT&HE	Set-top box - subscription
	IT&HE	Video players and media recorders
	IT&HE	Home entertainment - other (mostly audio equipment)
	IT&HE	Game consoles
	IT&HE	Computers - desktop
	IT&HE	Computers - laptop
	IT&HE	Monitors (used with desktop computers)
	IT&HE	Wireless/Wired networked device
	IT&HE	Miscellaneous IT equipment
Lighting	Lighting	MV incandescent
	Lighting	MV halogen
	Lighting	ELV halogen
	Lighting	CFL
	Lighting	Linear fluorescent
	Lighting	LED
Cooking	Cooking Products	Uprights

End Use	Category	Group
	Cooking Products	Cooktops
	Cooking Products	Ovens
	Cooking Products	Microwave
Water heating	Hot water heaters	Electric Water - Small
	Hot water heaters	Electric Water - Med/Large
	Hot water heaters	Gas storage (mains)
	Hot water heaters	Gas storage (LPG)
	Hot water heaters	Gas instant (mains)
	Hot water heaters	Gas instant (LPG)
	Hot water heaters	Solar electric
	Hot water heaters	Heat pump
	Hot water heaters	Solar gas
	Hot water heaters	Wood
Generation	PV	PV 2kW
	PV	PV 4kW
	PV	PV 6kW
	PV	PV 10kW
	PV	PV NZ

Note: Groups are further divided into 129 products, which are listed in the Technical Appendix

3. Overall Results: National and State

Introduction

Estimates of Australian residential energy use and photovoltaic (PV) generation are presented in this section. These are the top-level results of the RBS modelling and will be presented first at the national level and then for Australian States[11]. Results at the end-use level are presented in section National Results by End-use. Detailed results, such as the tables of information that underlie the charts presented, are provided in Excel format in the Output Table sheets which are separate to this report.

The energy consumption estimates reported in the RBS represent the delivered energy to the households. Energy used to deliver, transmit, transport, generate, refine or extract the energy is not considered. The embodied energy used in creating appliances is also not considered. Energy used for transport is also not included, except for a very small amount of electricity used for recharging mobility devices. Greenhouse emissions are also provided (see Residential Greenhouse Emissions).

The PV generation is presented separately to consumption data. This separate presentation is for two reasons. , Firstly, so energy consumption trends can be examined independently from any generation effects and secondly because not all electricity generated by residential PV can be assumed to be consumed by the residential sector. This means providing net consumption data, gross energy consumption less PV generation, may be misleading.

All years relating to the RBS outputs in this report are calendar years. The 'study period' is used to refer to the entire period modelled, from 2000 to 2030, while the 'projection period' refers to results for 2015-2030, which rely on projection of product sales, efficiency, etc., while the 'modelled period' refers to period 2000-2014 where results are modelled mostly using actual data on products.

Naturally, the results for the modelled period can be interpreted with a greater level of confidence, as these rely on historic data, while results for the projection period ultimately are based on projections of product sales, efficiency, usage and other characteristics, and the accuracy of these figures remains unknown.

National Residential Results

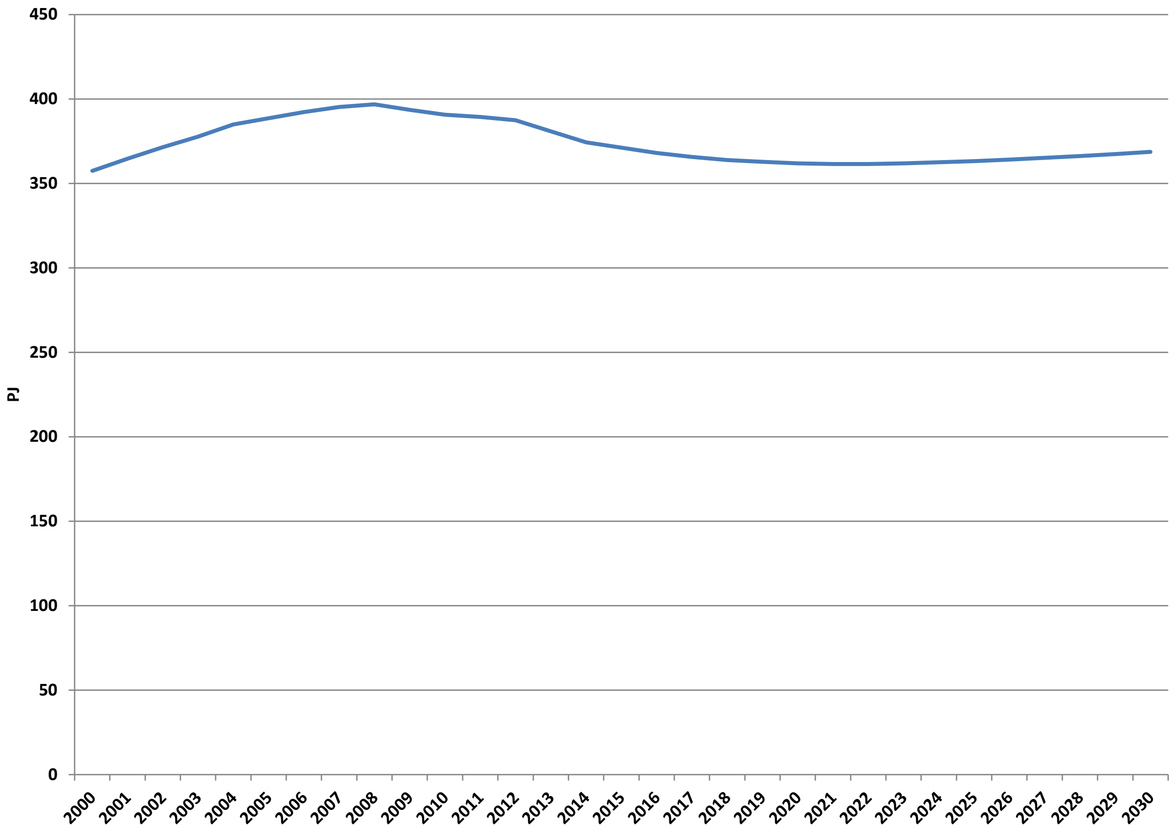
The overall national residential energy consumption results, aggregated across all households and end-uses, and the average energy consumption per household, also aggregated across end-uses, are the first two key results which provide insight into the current state of energy use in residential homes in Australia. Potential national peak demand results are also presented.

[11] For convenience, 'States' is used to refer to both States and Territories throughout the report.

Total Residential Energy Use

The total residential energy consumption is shown in Figure 4. This shows total energy consumption growing to around 395 PJ in 2008 but then decreasing slightly until 2021. Energy consumption then grows post 2022, but at a much lower rate than pre-2008, mainly as a result of population growth and the declining rate of efficiency improvement in the stock of appliances, as will be further discussed in later sections. The projections show total energy use will not reach the peak consumption of 2008 during the projection period. It is worth noting, this trend is conservative in that the model does not assume further energy efficiency regulatory requirements or new energy efficiency programs being introduced, unless the regulation has already been announced.

Figure 4: National Residential Energy Consumption Trends

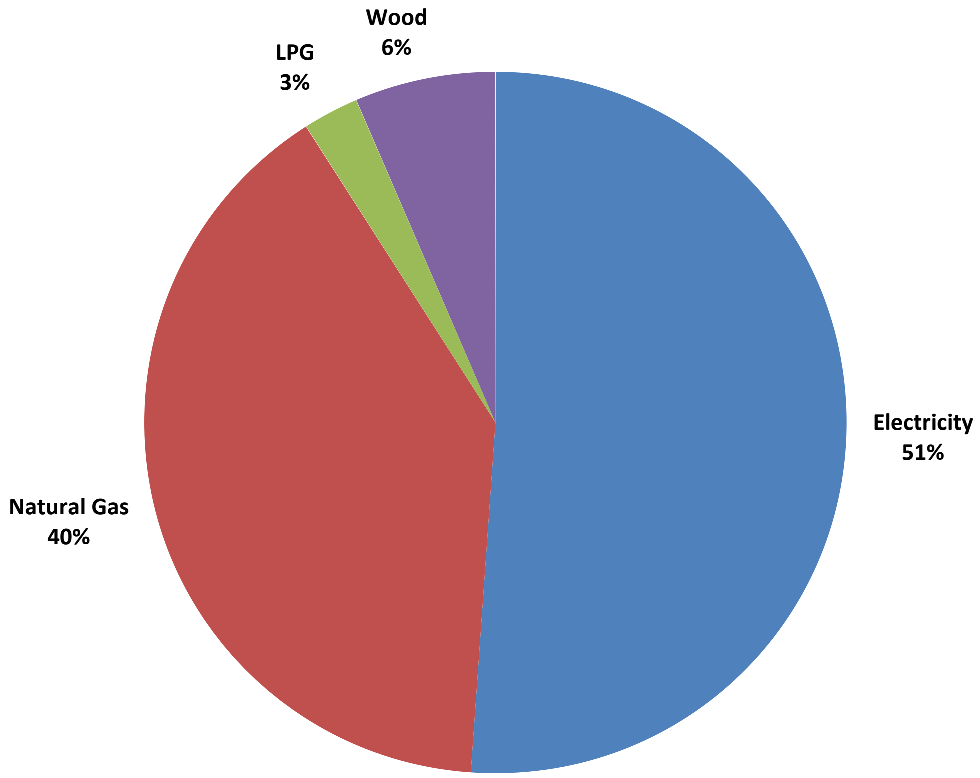


This decline in total consumption and then only gradual resumption in the trend to increased consumption is a consumption trend that differs from the decades of growth seen leading up to 2008. However, the RBS results are consistent with the measurement of actual total residential energy consumption over the last few years. Declines in electricity consumption have been reported by the Office of the Chief Economist (BREE 2014) and the Energy Supply Association of Australia since 2011 (ESAA 2005-2014).Declines in gas consumption have been reported by State natural gas distributors for the last three to five years (AER 2015), depending on the State. Gas distributors in Victoria and South Australia, and electricity distributors in Queensland are also all forecasting declines in residential consumption consistent with the RBS projected declines.

As will be shown later in this report, after 2008 total energy consumption has been declining, despite the ever increasing Australian population, and is a result of households becoming more energy efficient. This trend in turn is due to fuel switching by households and the improved energy efficiency of buildings and appliances, especially space conditioning and lighting.

Total residential energy consumption is the sum of the consumption of energy from electricity, natural gas, LPG and wood. The chart below shows the relative proportion of energy used by different fuels in 2014. It indicates that electricity use dominates residential energy use, followed by natural gas.

Figure 5: Proportions of Total Residential Consumption by Fuel



The contribution of the different fuels to total residential energy use over time is shown in Figure 6 and underlying trends by fuel type are shown in Figure 7.

Figure 6: Total Residential Consumption by Fuel

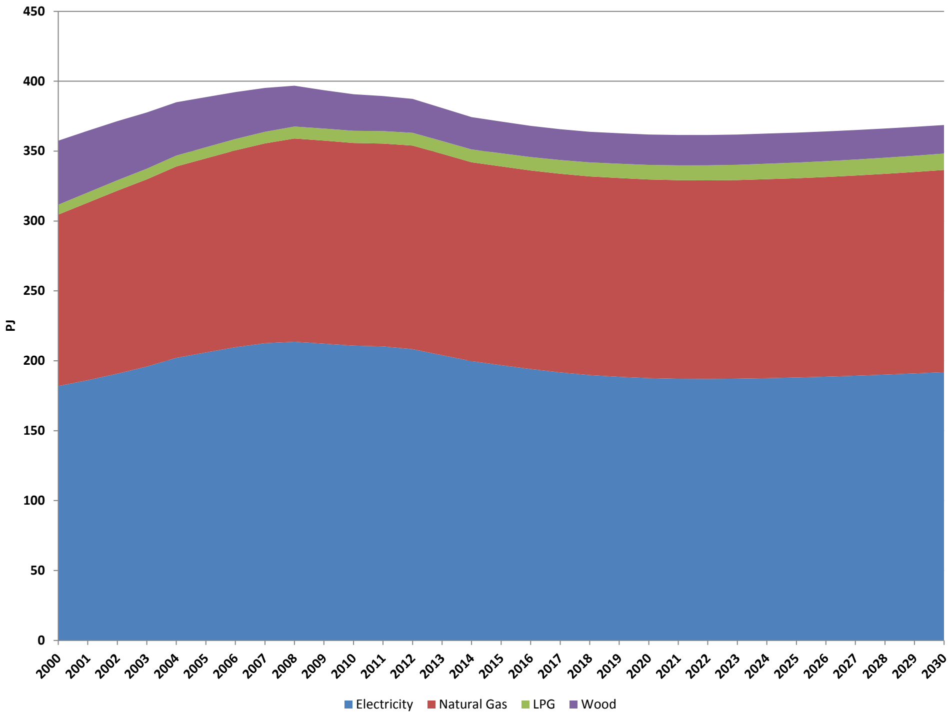
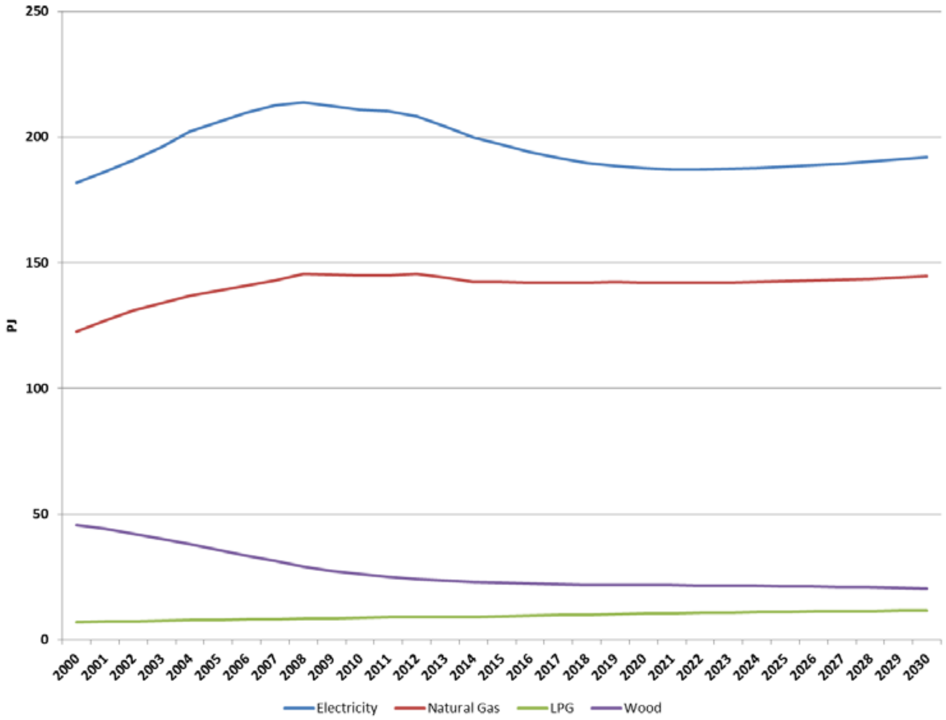


Figure 7: Trend Lines for Residential Consumption by Fuel

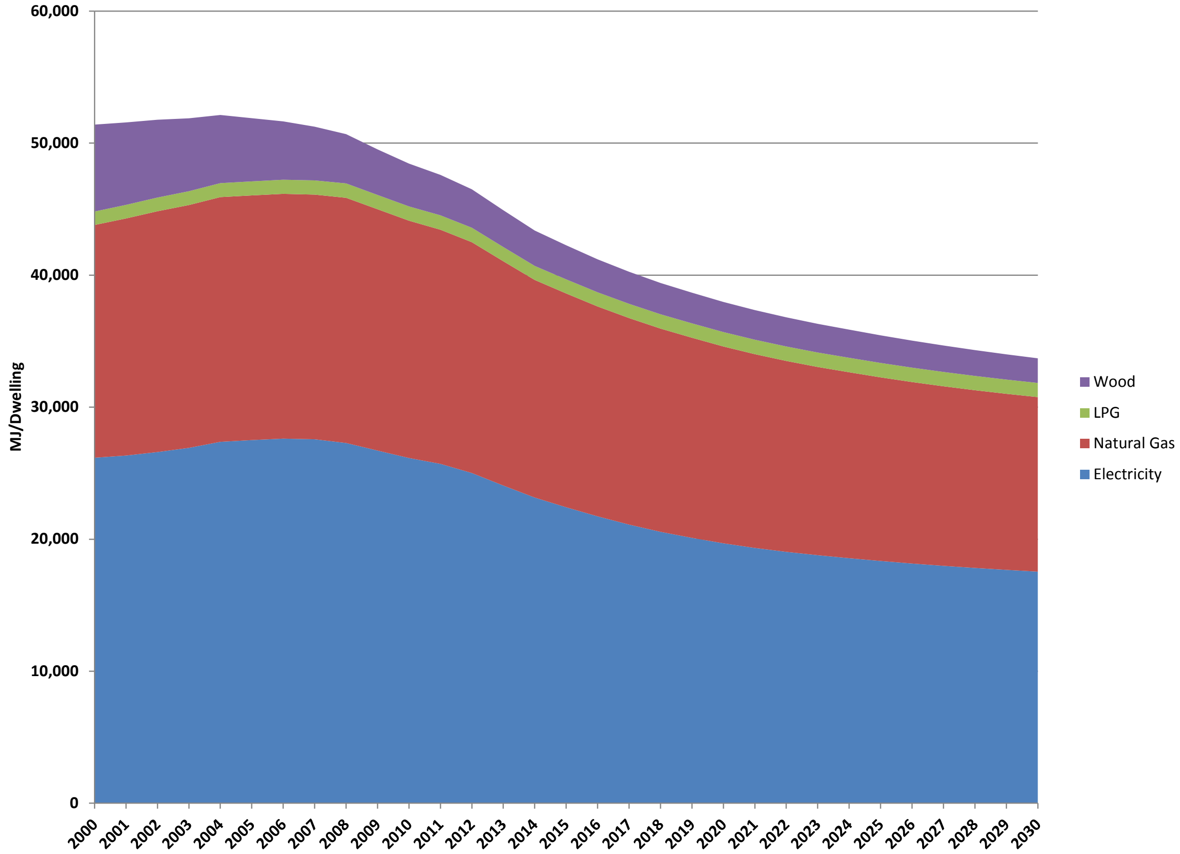


These trend lines show that the total energy use trend (i.e. peaking in 2008, declining then gradual increase in the 2020s) is largely the result of the underlying trend in electricity consumption, as electricity consumption follows a similar but slightly more exaggerated trend. Electricity use peaked in 2008, is currently in decline and is not expected to increase until after 2021. In comparison, natural gas use is expected to remain relatively stable post 2008, while wood use has declined and will continue to do so. LPG use is the only fuel expected to increase throughout the study period.

Background and Causes of Trends

The main reason for the rises and falls in total energy consumption over the study period is due to changes in energy use per dwelling. Average energy use per dwelling, as shown in Figure 8 has being falling since 2004 and the energy efficiency of the average dwelling is expected to continue to improve to 2030, based on projected trends. The average energy use was 51 GJ in 2000 but in 2014 was 43 GJ.

Figure 8: Total Residential Consumption per Dwelling by Fuel

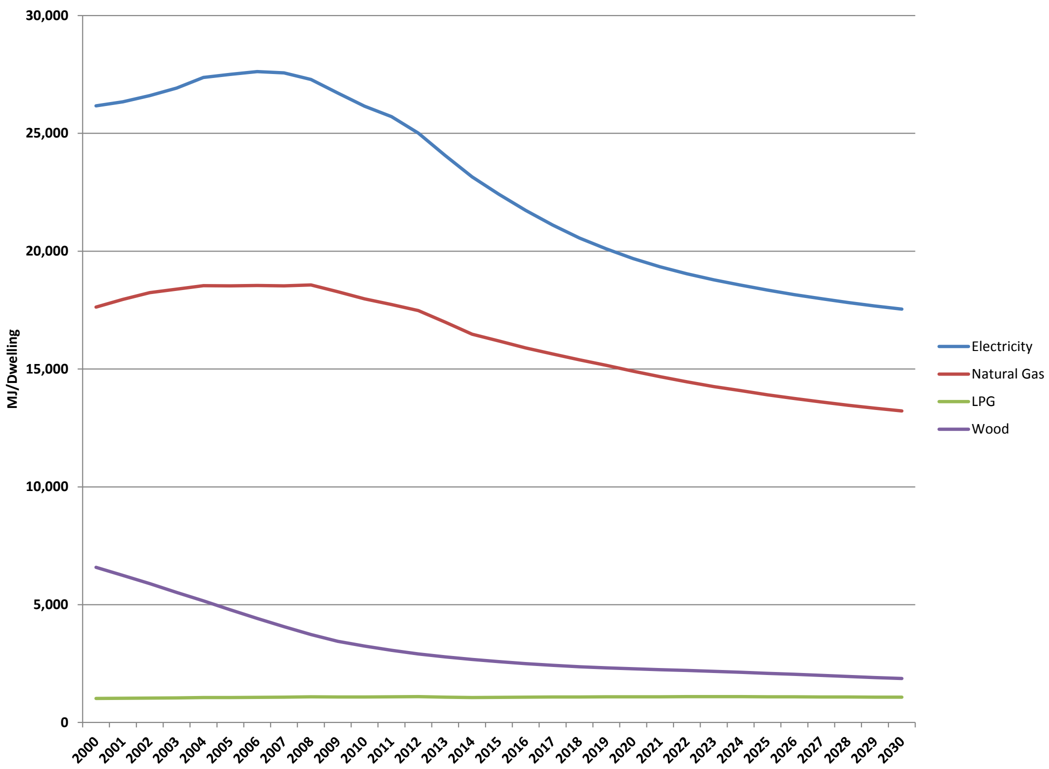


Initially the rate of decline in consumption in the early 2000s was less than the rate that dwelling numbers increased, so total energy consumption increased, but by 2009 the pace of decline in energy consumption per dwelling started to exceed the increase in dwelling numbers, so total consumption began to fall. Only when the rate of decline in average energy use starts to slow in the 2020s is it predicted that increases in dwelling numbers will lead to a new increase in total energy consumption. These efficiency trends, and the growth in dwelling numbers, are expected to be the trends that drive energy consumption in the near future.

It should be noted that these predictions of future energy use are based both on sales of future products leading to the integration of more efficient product into the appliance stock, and on there being some ongoing improvement in the efficiency of most products. However, these predictions are conservative in so far as they do not anticipate the introduction of any further energy efficiency regulatory requirements or energy efficiency programs being introduced, unless the regulation has already been announced. If further energy efficiency initiatives are introduced, then the energy use per dwelling may further decline and the projected growth in energy use during the 2020s may not occur.

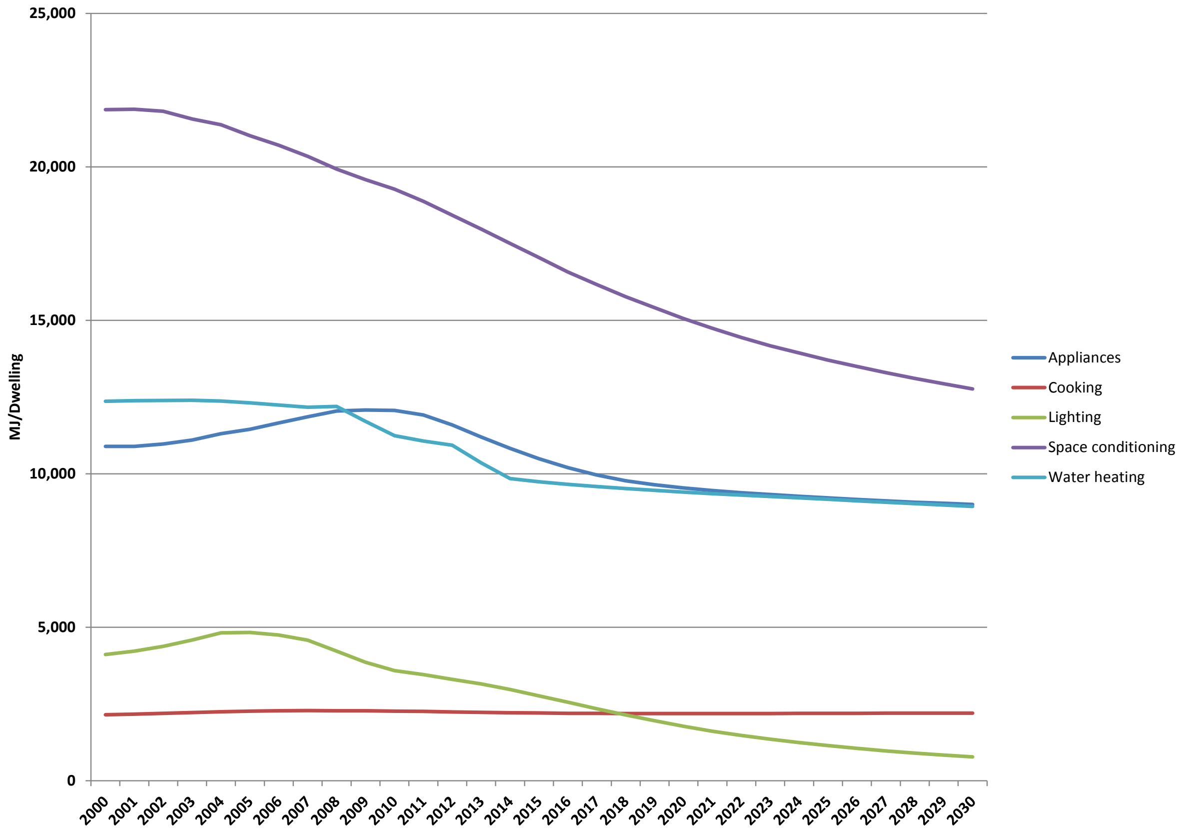
An examination of the trend lines for energy consumption by fuel per dwelling, shown in Figure 9, reveals that the decline in energy use is driven by a decline in the average use of all fuels, except LPG use which remains constant. The decline is most pronounced in electricity, but also strong in natural gas and wood use. The decline in total energy use per dwelling has accelerated since 2008 as the use of electricity stopped growing and then started to quite rapidly decline. Projections suggest this trend in electricity use will be one of the main drivers of future decreases in total energy use.

Figure 9: Trend Lines for Total Residential Consumption per Dwelling by Fuel



Further insight into the drivers of the current reduction in total energy use can be obtained by examining the energy consumption per dwelling for the individual end-uses, as shown in Figure 10. This chart shows that the energy used by each end-use, for the average dwelling, started declining from the mid to late 2000s and continues to decline throughout the study period. Space conditioning contributes the greatest amount to the decline in total energy use per dwelling, followed by lighting and then appliances and water heating. Cooking energy use also declines but only very slightly. The reasons for the declines in energy consumption for each end use are discussed later in this report, but are largely due to appliance efficiency improvements, changes in the technologies being used and fuel switching.

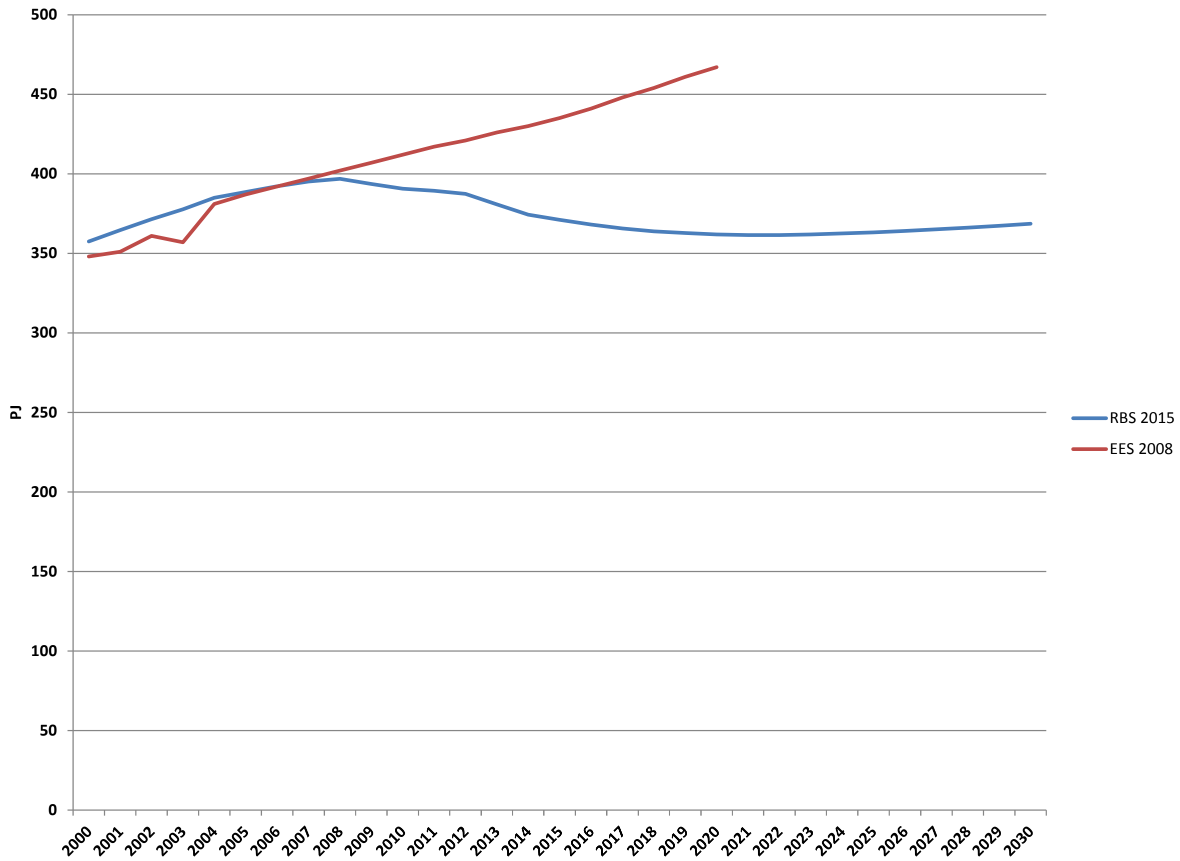
Figure 10: Trend Lines for Total Residential Consumption per Dwelling by End Use



Comparison to Previous RBS Trends

The present decline in total consumption is a consumption trend that differs from the decades of growth seen leading up to 2008 and was not anticipated in the forecasts of the previous RBS report (EES 2008). The figure below compares the total national energy consumption estimates of the two studies and shows the two sets of results are broadly consistent until 2008 after which their results start to diverge.

Figure 11: National Residential Energy Consumption: Trends in Current RBS and Previous Study



The earlier study predicted a steady, ongoing increase in energy consumption and total energy consumption as being 15% greater in 2014 than has proven to be the case. It is not surprising the earlier RBS did not anticipate the downturn in energy consumption as the trend only started to emerge after that report was published. In addition, other significant energy efficiency initiatives, such as the effective ban on general purpose incandescent lamps, were not introduced until after the 2008 RBS was published.

Total Residential Energy Use by End Use

The relative contribution of the different end uses to total consumption in 2014 is shown in Figure 12 and how these proportions change over time, as is shown in Figure 13.

Figure 12: Proportions of Total Residential Consumption by End Use in 2014

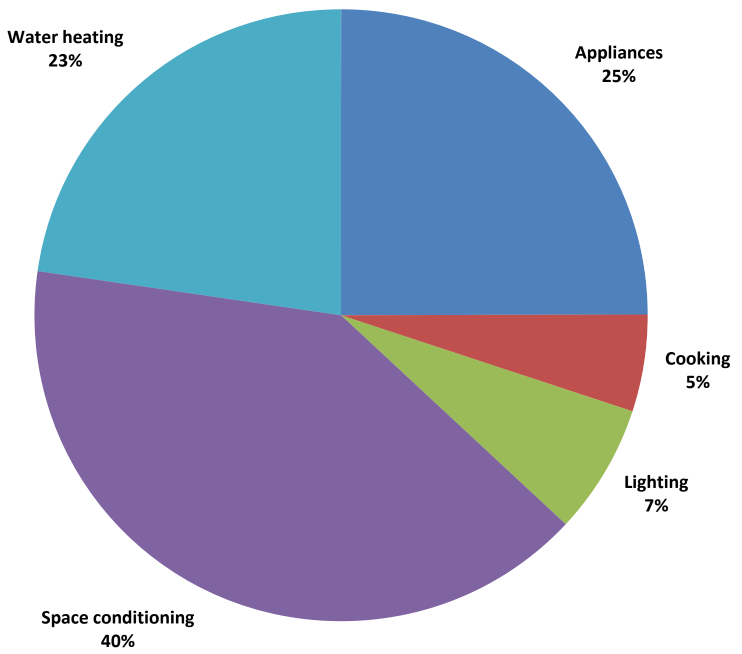


Figure 13: Total Residential Consumption by End Use

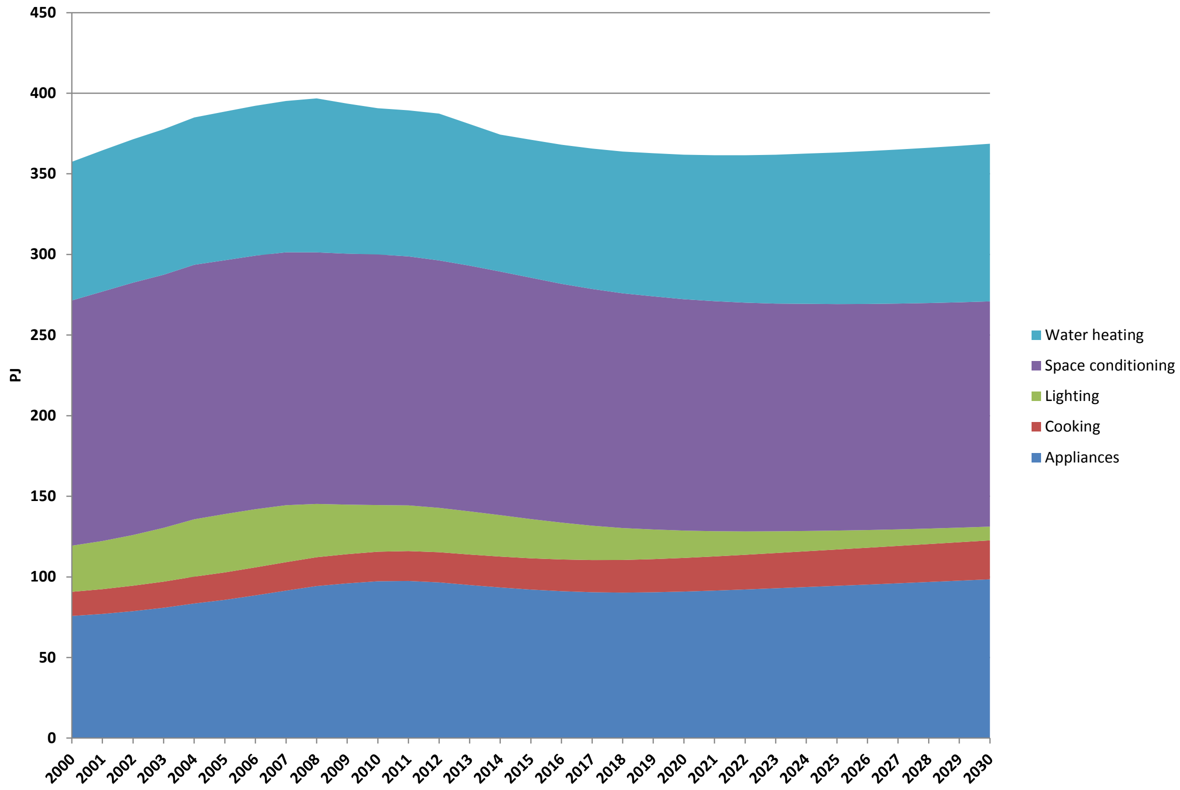
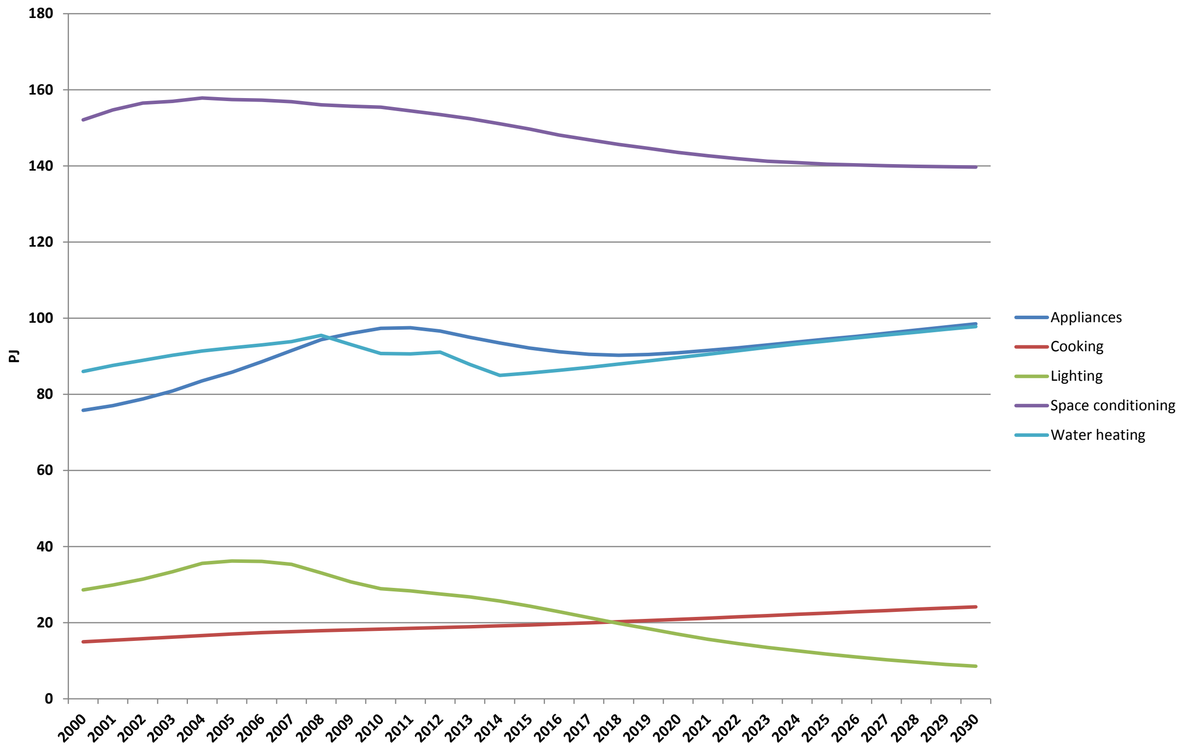


Figure 12 above show that in 2014 the largest share of total energy consumed is by space conditioning (40%), while roughly a quarter is used by water heating (23%) and appliances (25%). The remainder is used by Lighting (7%) and Cooking (5%).

The dominance of space conditioning to energy consumption is again clearly shown in Figure 13, as is the large contributions made by water heating and appliances to total energy use. However, this chart also shows the trend for the energy use of water heating and appliances to make up an increasing proportion of the overall energy consumption. The decline in energy use by lighting since 2005 has also added significantly to the overall decline in total energy use and is expected to continue to do so throughout the projection period.

Examining the trend lines for energy consumption by end-use in Figure 14 shows the contribution of each end use to the overall energy consumption trend. This chart shows consumption by space conditioning has been in decline since 2004, and is expected to continue to decline throughout the projection period. Likewise consumption by lighting has been in decline since 2006, and is expected to continue. Energy use by water heating has also been in decline since 2008, but is expected to increase from 2014 onwards. A similar trend is expected for appliances, with appliance energy use declining since 2010 but is expected to start to increase from 2020. Only cooking is expected to increase uninterrupted throughout the study period, but at a relatively low rate of increase.

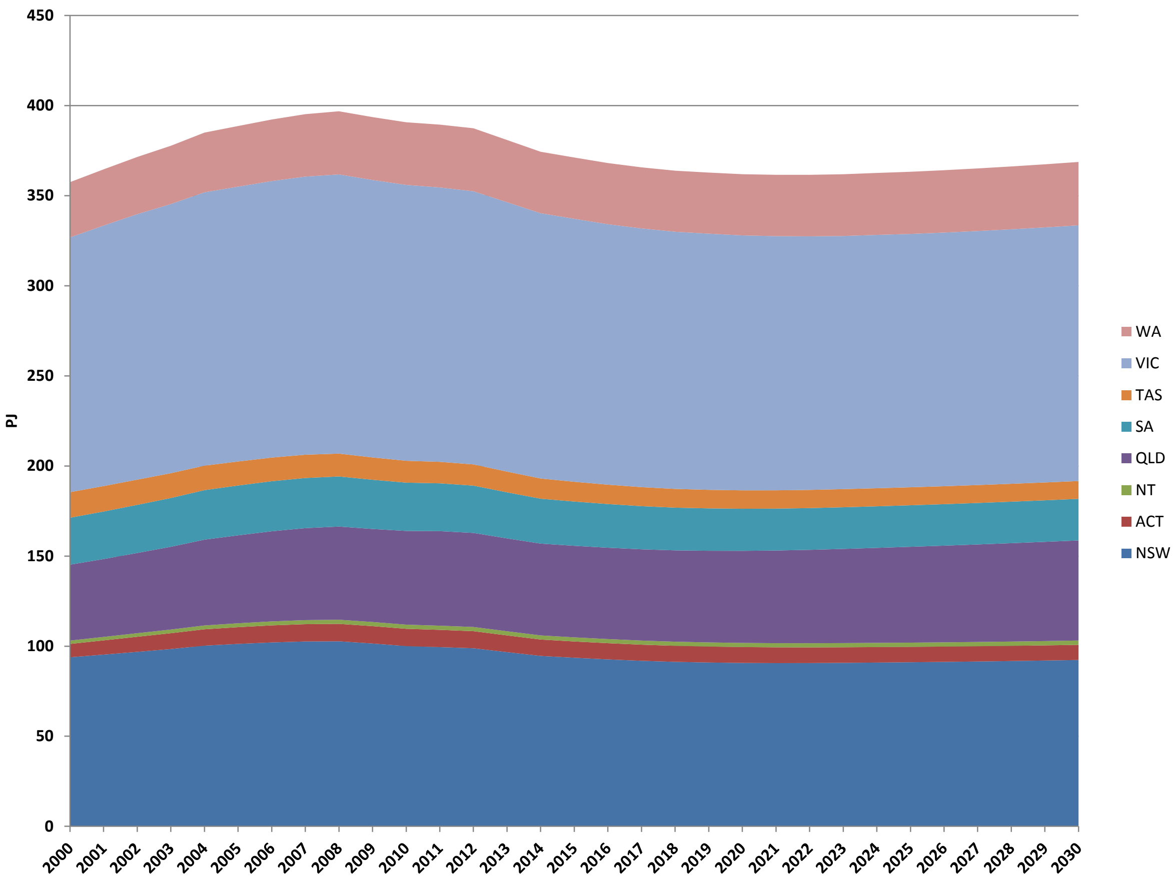
Figure 14: Trend Lines for Total Residential Consumption by End Use



State Energy Use

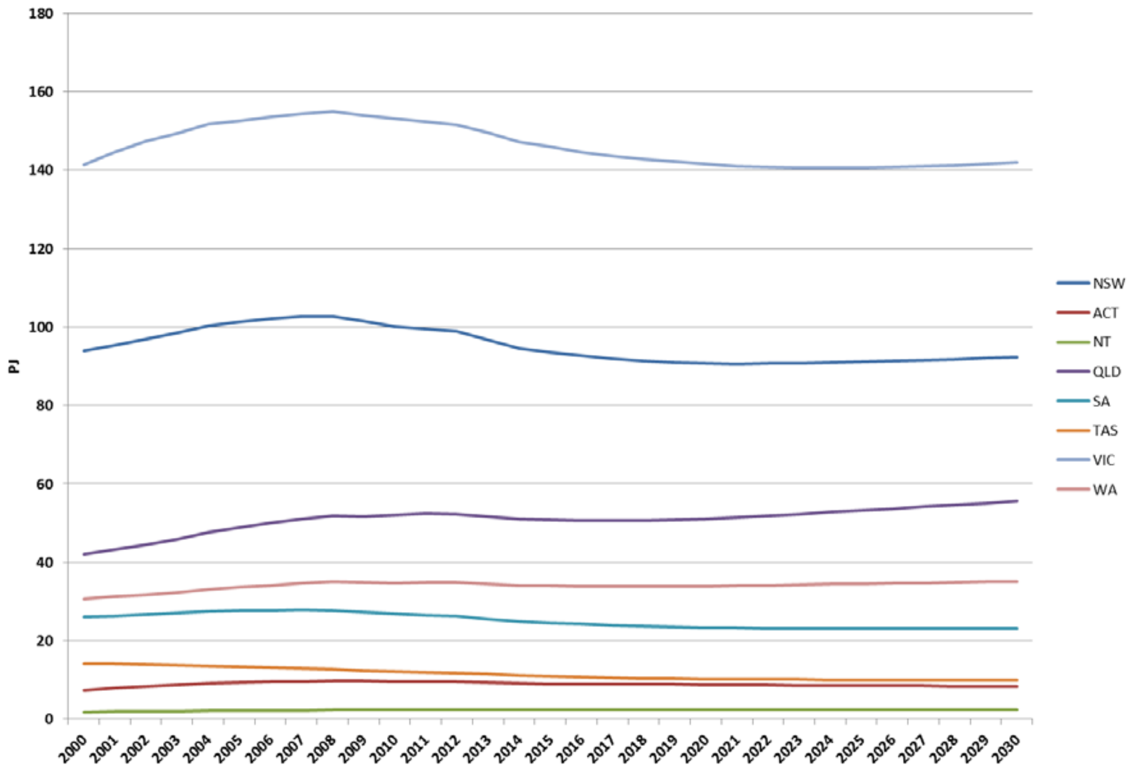
The national residential energy consumption can be broken down into the energy use of the underlying States. Figure 15 shows the contribution of each of the States over time to the national energy consumption. Victoria, with approximately a quarter of the national dwellings and relatively high energy use due to its colder climate, is the biggest contributor to the national energy consumption. It is followed by the next largest state, NSW, and then by Queensland, followed by Western Australia then South Australia.

Figure 15: Total Residential Consumption by State



The underlying trends in energy consumption by State are shown the Figure 16. These trend lines show that the national trend of a peak in consumption in the late 2000s, followed by a decline in energy use until at least the 2020s, is a trend also occurring in the two biggest States of Victoria and New South Wales. The smaller States also tended to show a similar trend, but the peak and decline is less pronounced.

Figure 16: Trend Lines for Total Residential Consumption by State



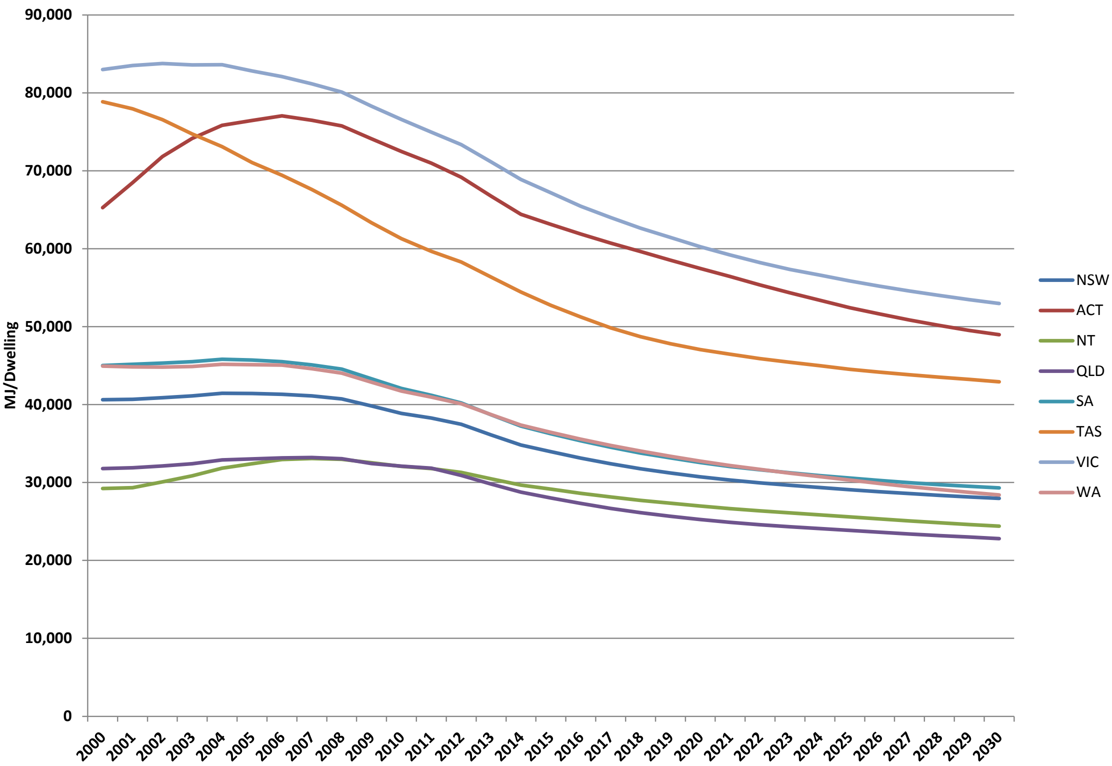
Household Total Energy Use by State

Examining the energy use per household across the States is another useful way of considering what is driving State energy use, as the impact of population/dwelling numbers are removed. Figure 17 shows the total energy consumption per household by State. A few trends of note in this chart are:

- Space conditioning energy consumption drives the relative energy use per dwelling in the States, so the colder States of Australian Capital Territory, Victoria and Tasmania all have much greater energy consumption per dwelling then the temperate States of New South Wales, Western Australia and South Australia, while the warmer States (Northern Territory and Queensland) have the lowest energy use

- From the mid-2000s energy use per dwelling has been declining in all States, especially in the colder States of Australian Capital Territory, Victoria and Tasmania.

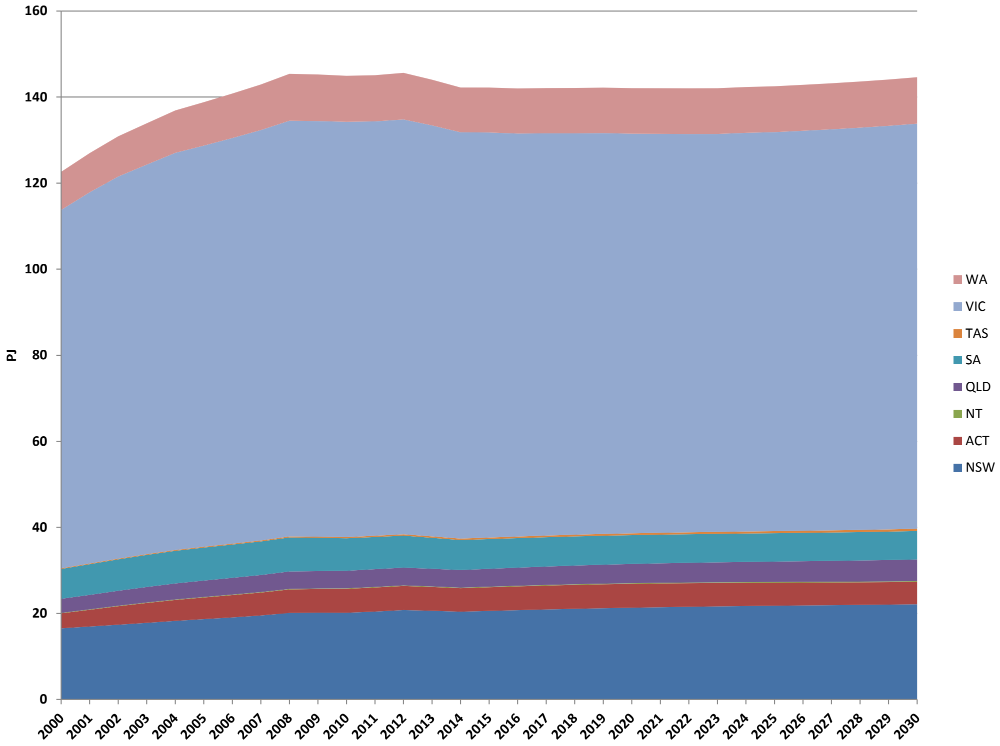
Figure 17: Total Energy Consumption per Dwelling by State



State Residential Energy Use by Fuel

The use of natural gas by States is shown in Figure 18.

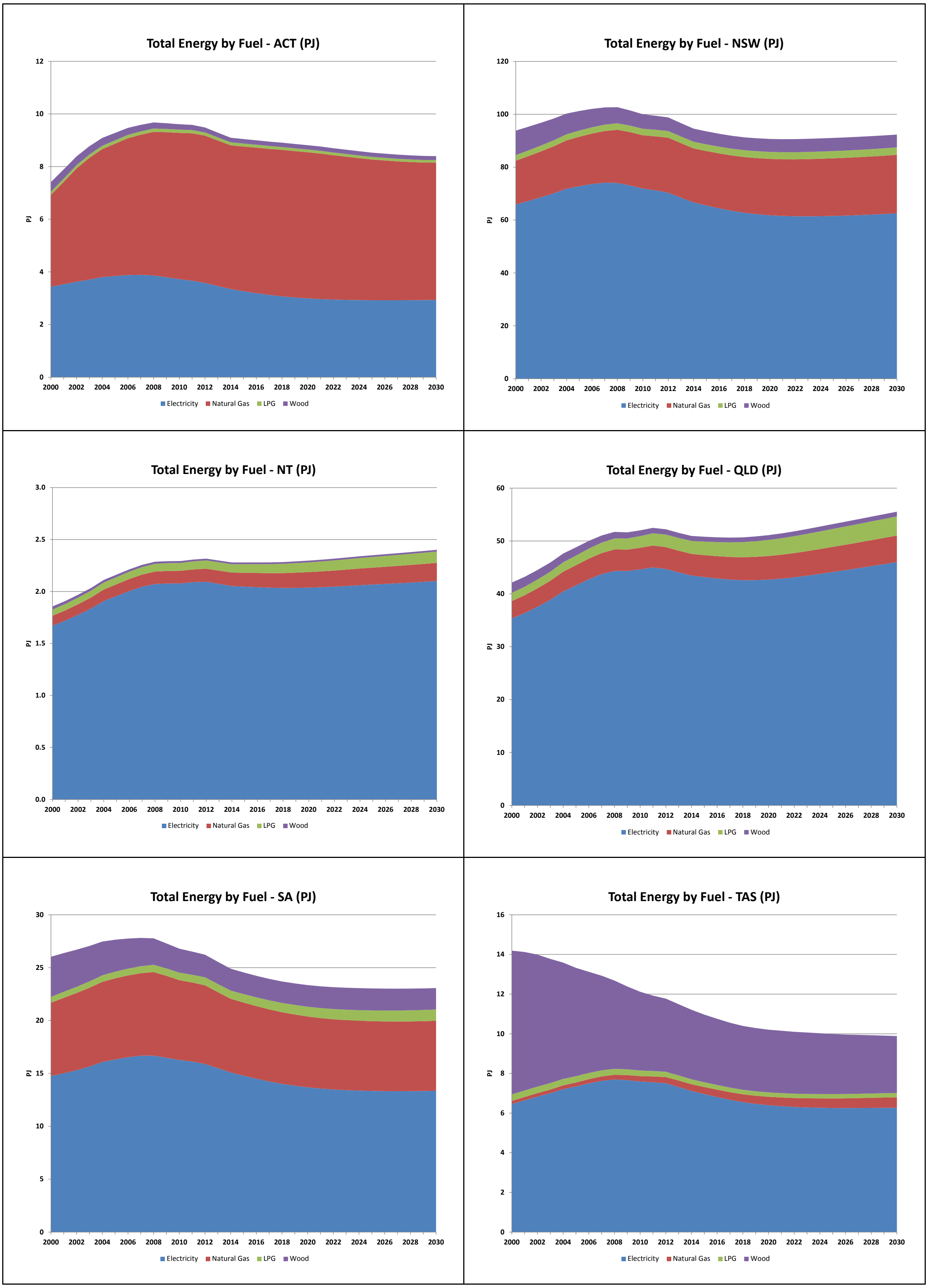
Figure 18: Natural Gas Residential Consumption by State

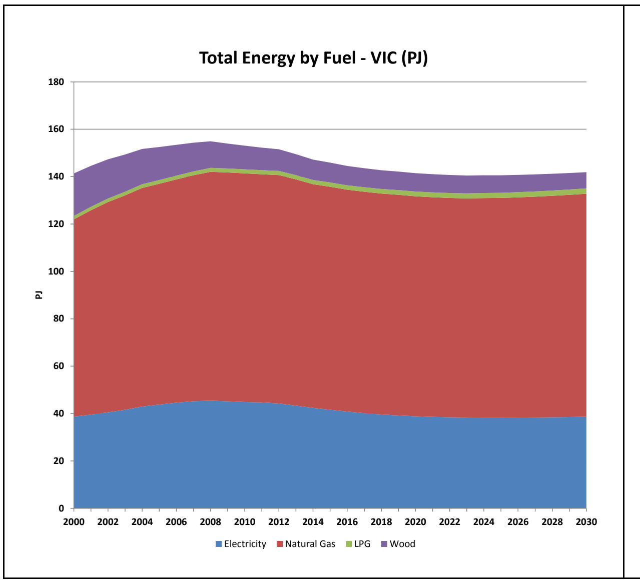


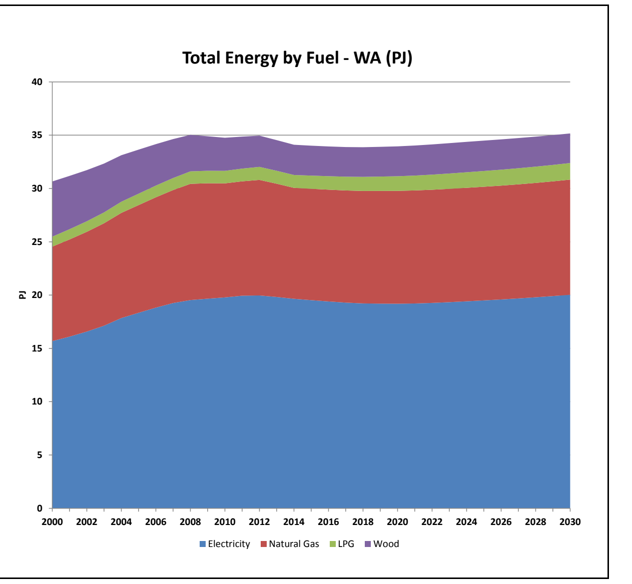
This chart clearly shows Victoria contributes the majority, approximately 65% in 2014, to the total national consumption, despite having only about 25% of the total national population. This reflects both Victoria's high penetration of natural gas and its high space heating load.

Differences in the mix of fuels used by different States are shown in the Figure 19. The charts illustrate the contribution over time of the different fuels to the energy consumption of each State.

Figure 19: Total Residential Consumption per State by Fuel







There is considerable variation in the relative contribution of the different fuels in each State. In the ACT and Victoria the majority of energy use is from natural gas, reflecting the importance of this fuel for winter heating in these States. Tasmania also has a high winter heating load but it has limited access to natural gas and in the past many dwellings have relied on wood for heating. This appears to be changing though as the use of wood is steadily declining while use of natural gas increases.

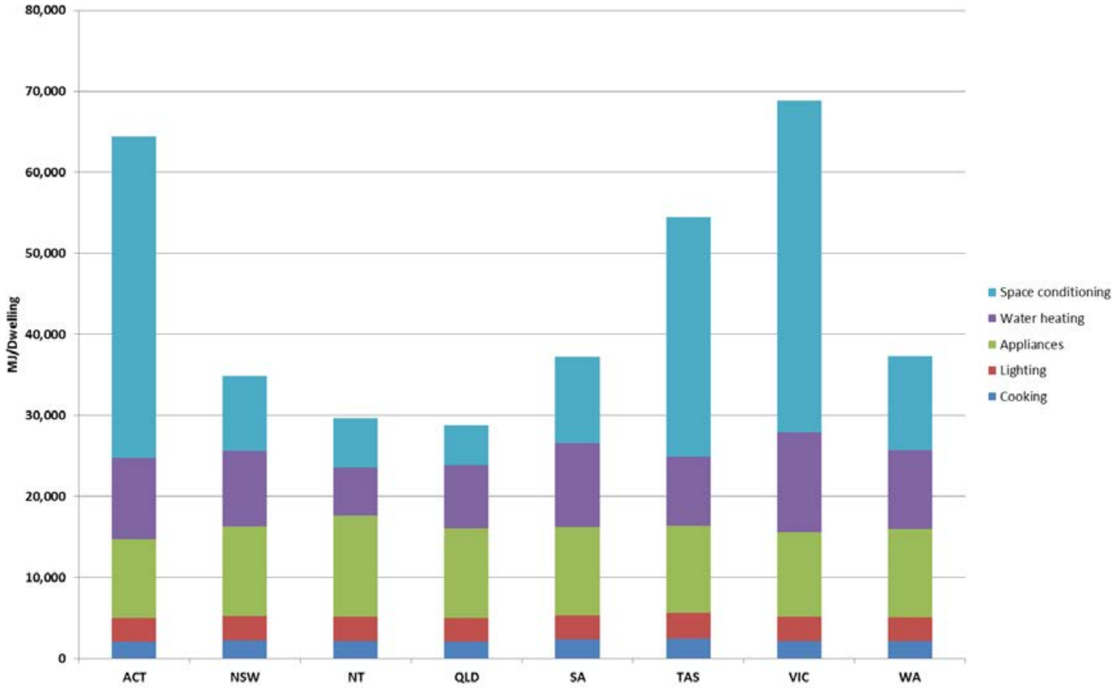
In South Australia, Western Australia and NSW, the use of electricity dominates energy consumption in these States, though natural gas also contributes a significant amount to total energy use. These three States have a more temperate climate; hence they have a reduced need for winter heating compared to Victoria, Tasmania and the ACT, which appears to be reflected in their lower use of natural gas.

Electricity use makes up the vast majority of energy use of the northern States of Queensland and Northern Territory. These States have had some use of wood in the past but its use is declining. The States have access to natural gas and their use of natural gas is slowly growing, but it makes up only a small minority of the total energy use.

State Residential Energy Use by End-Use

There are significant differences between States in the amount of energy consumed by specific end-uses by dwellings. The following charts show the energy used per dwelling by end-use for each State in 2014.

Figure 20: Proportions of Total Residential Consumption by End Use per State in 2014



A comparison of the energy used per dwelling in 2014 for the different end uses reveals:

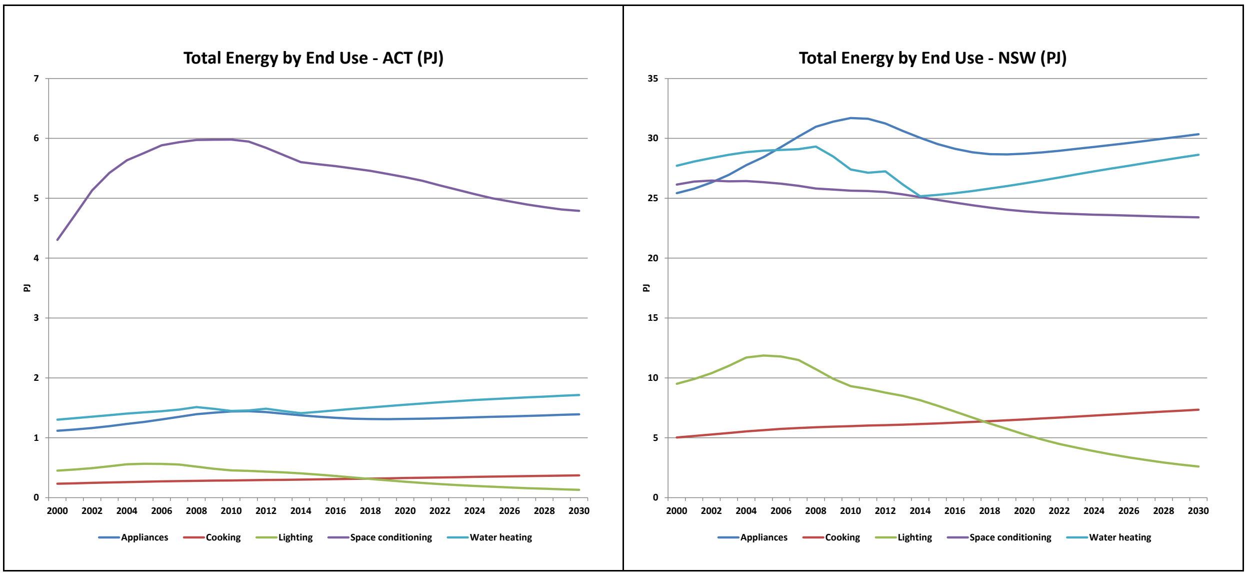
- Cooking and lighting is consistent across all states
- Appliances show some variation in the energy use, with New South Wales, Queensland and the Northern Territory all using slightly more energy, which may be due to higher use of swimming pools and spas in those states
- Water heating energy use varies considerably, e.g. with Victorian dwellings using over twice the energy of Northern Territory dwellings, which will largely be a result of differences in the type of water heating technologies predominantly used in the different states, as these vary in efficiency
- Space conditioning energy use varies enormously, with the colder states of Victoria, Tasmania and the Australian Capital Territory using much more energy than the other states due to their higher heating demand.

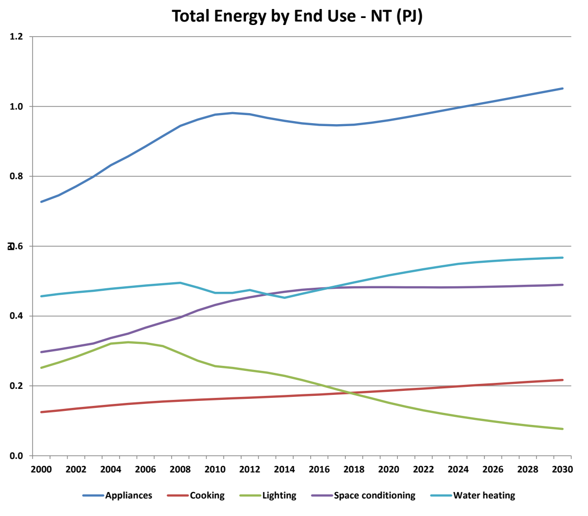
Figure 21 shows the total energy consumption by end-use for each state over time. These charts reveal there are ongoing changes in the energy use for different end-uses and trends that are consistent across the states, such as:

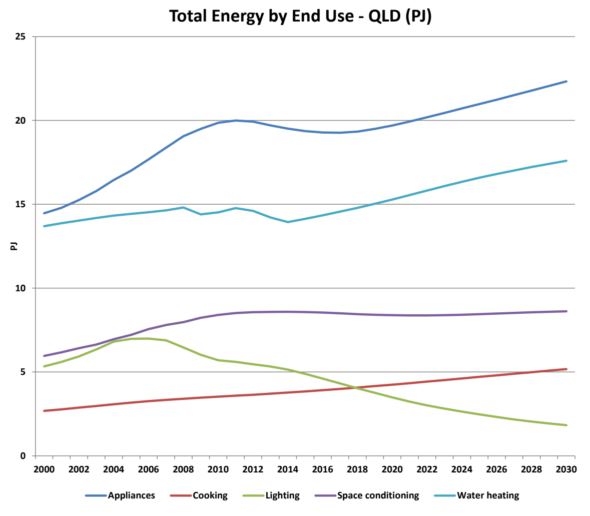
- Lighting energy consumption is falling in all States, while cooking energy use steadily rises
- Water heating energy use rose in the 2000s, has declined for the last five years, but is expected to increase for the next fifteen years
- Appliance energy use also rose in the 2000s, has declined for the last five years, and in most States is now expected to start to increase or will by the 2020s
- Space conditioning energy use is declining in all States, except in the Northern territory and Queensland where it is expected to stabilise or slowly increase.

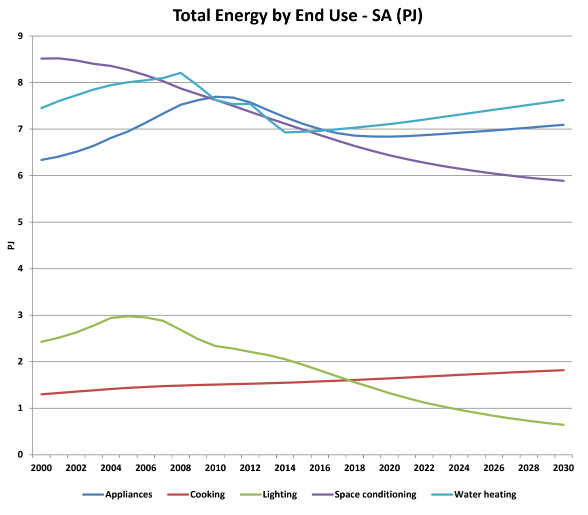
Understanding these trends in end-use consumption requires a more detailed analysis which is undertaken in the next chapter.

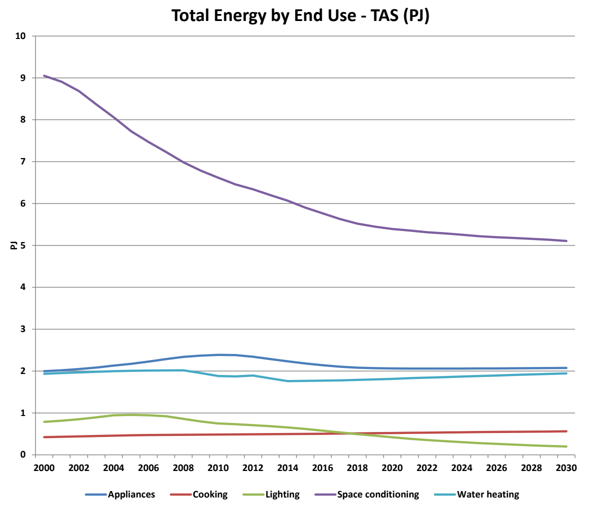
Figure 21: Trend Lines for Total Residential Consumption by End-use per State

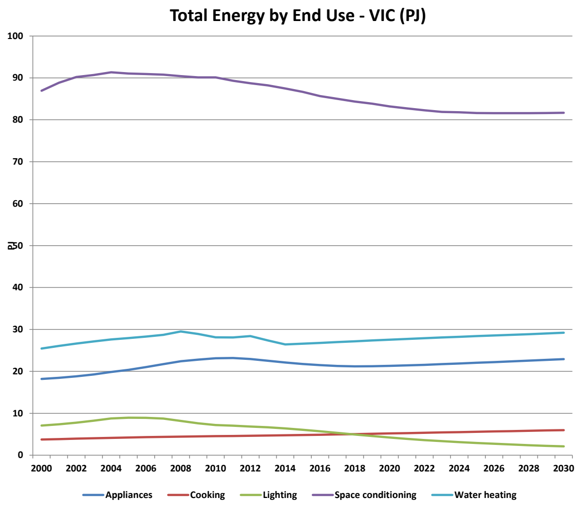


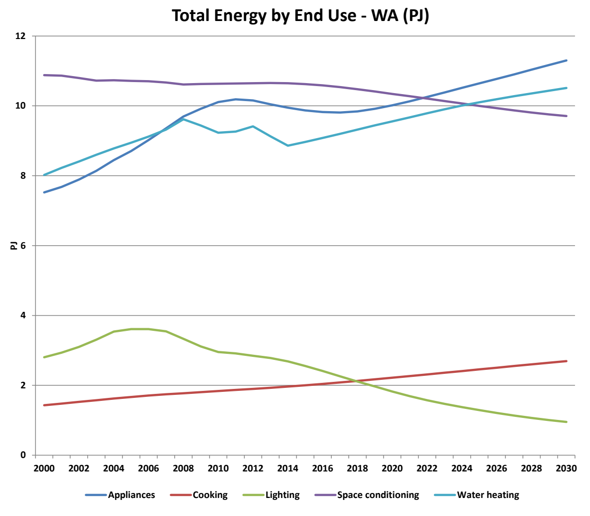

Total Energy by End Use - NT (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating


Total Energy by End Use - QLD (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating


Total Energy by End Use - SA (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating


Total Energy by End Use - TAS (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating


Total Energy by End Use - VIC (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating


Total Energy by End Use - WA (PJ)
PJ
Appliances
Cooking
Lighting
Space conditioning
Water heating

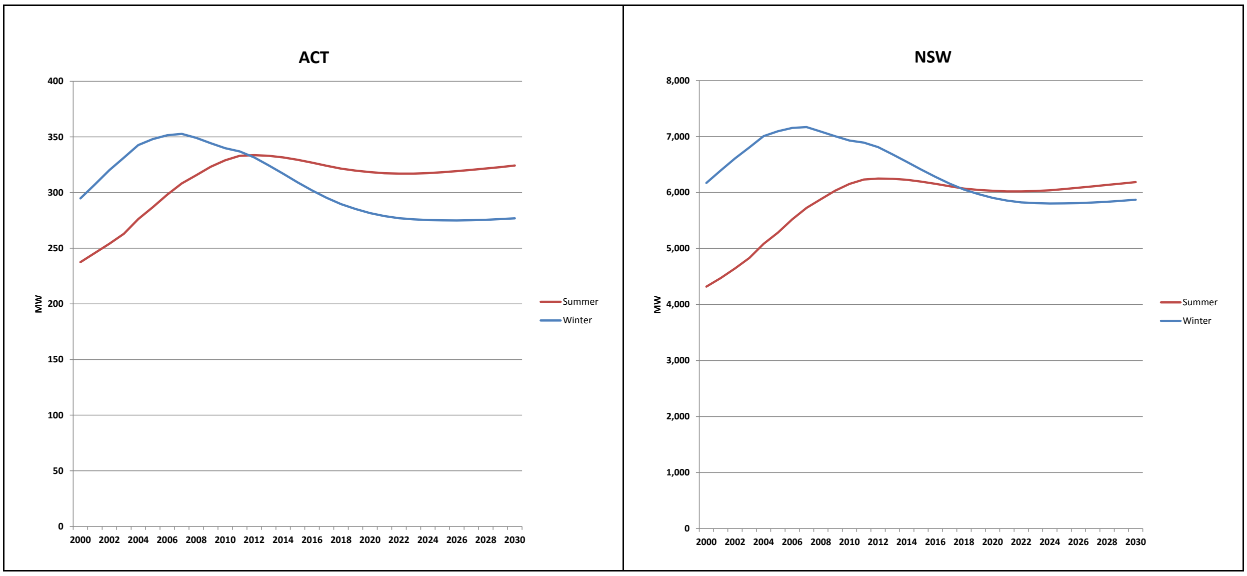
State Peak Demand

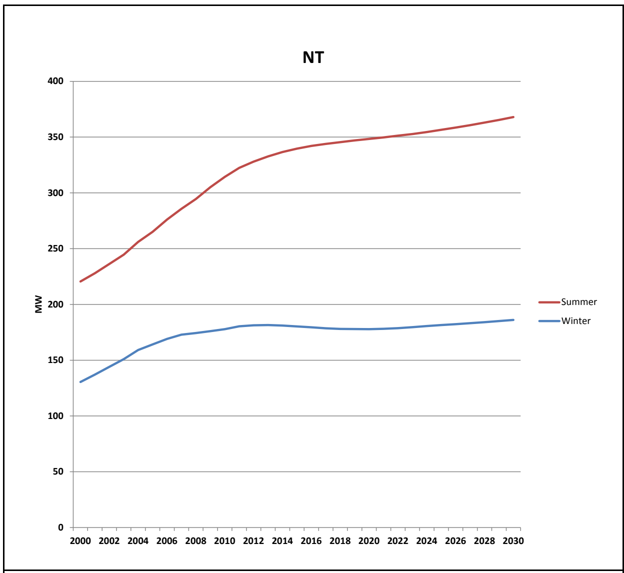
Before presenting the peak demand results, it should be noted that these results are unlikely to be as accurate as the energy consumption model results due to the poor quality and relative shortage of data on the factors that are used to estimate maximum potential peak demand. Though data on stock numbers and equipment characteristics is generally as good as that used for energy consumption calculations, the data on the use of equipment in extreme weather events, when residential peak load events occur, is poorer. There is also limited data on how equipment, especially space conditioning equipment, operates in these extreme conditions. Consequently there is a lower degree of confidence in the peak demand modelling results.

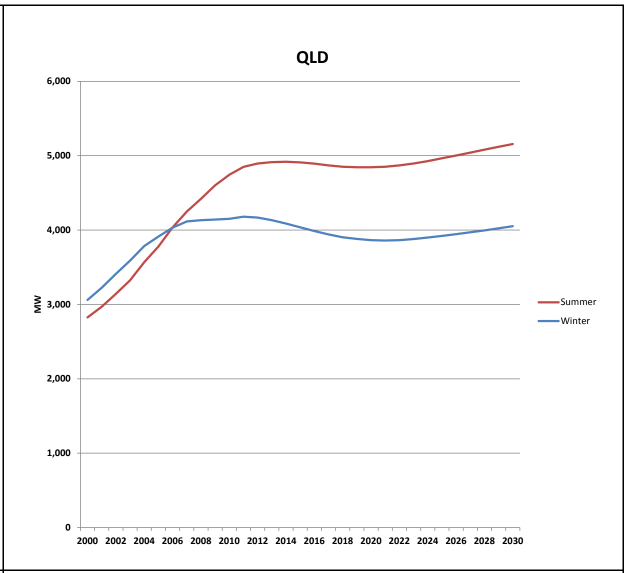
It also should be noted that the maximum potential peak demand discussed is an estimate of the potential maximum demand that could occur if extreme weather were to lead to the maximum use of electrical space conditioning devices during a summer/winter evening. It is not an estimate of past actual demand or correlated to past actual extreme weather events.

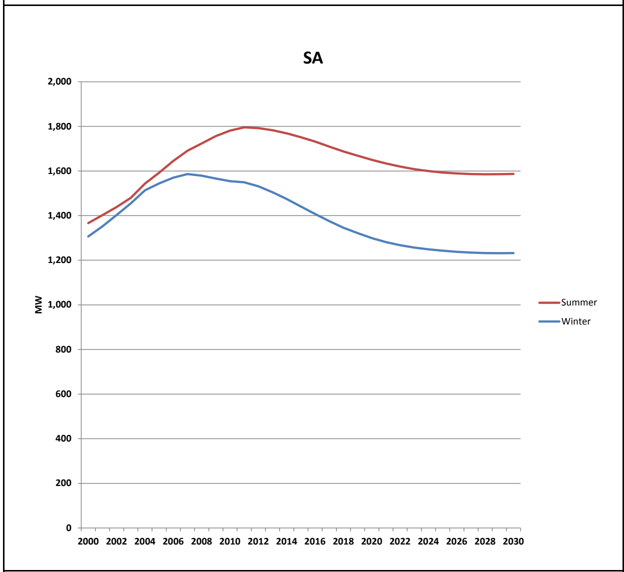
The maximum potential peak demand for electricity for each state is presented for each State in the charts below. The locality dependent nature of peak demand is confirmed by the differences between the potential peak demand charts of the States, with some States having a higher peak demand in summer, some in winter, and for some the peak has changed from being a winter to summer peak during the study period.

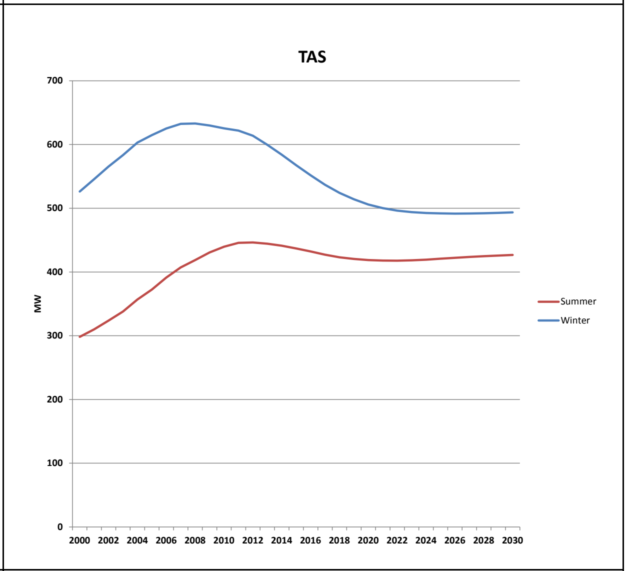
Figure 22: Trend Lines for Potential Maximum Summer and Winter Evening Peak Demand per State

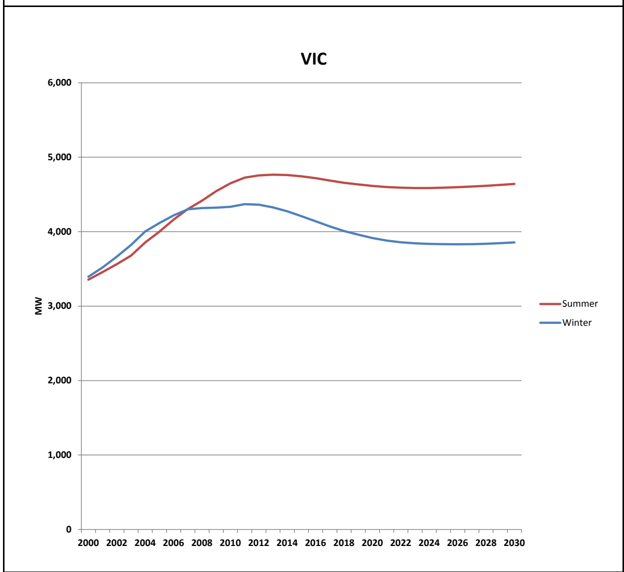


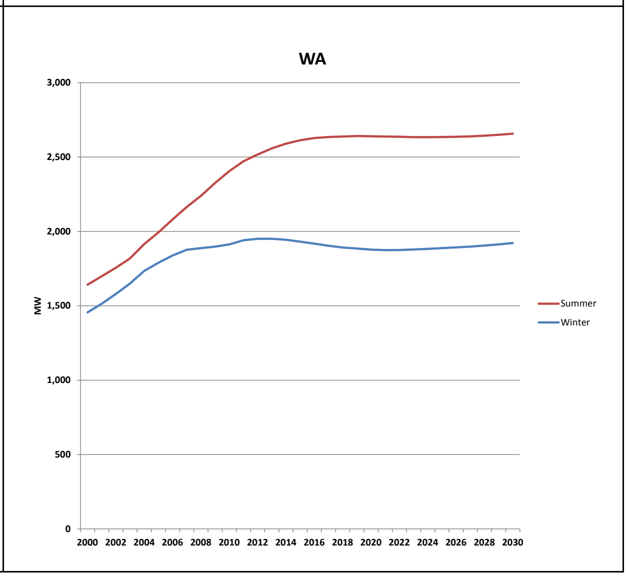

NT
MW
400
350
300
250
200
150
100
50
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter


QLD
MW
6,000
5,000
4,000
3,000
2,000
1,000
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter


SA
MW
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter


TAS
MW
700
600
500
400
300
200
100
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter


VIC
MW
6,000
5,000
4,000
3,000
2,000
1,000
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter


WA
MW
3,000
2,500
2,000
1,500
1,000
500
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030
Summer
Winter

The trends across the States include:

- Summer peak demand is greater than winter peak demand now, and until 2030, in all States except New South Wales and Tasmania
- The rate of increase in the potential summer peak demand was greatest during the 2000s for all States except Western Australia, where peak demand grew rapidly until 2015
- For all States, except the Northern Territory, summer peak demand declined or stabilised during the 2010s, but then slowly increased in the 2020s.
- Northern Territory summer peak demand keeps rising throughout the study period but less rapidly after 2010.
- Winter peak demand increased rapidly during the 2000s but then declined or stabilised in all States after 2010.

The drivers in peak demand can be seen in Figure 23 and Figure 24 which show the end use contribution to total peak demand at a national level.

Figure 23: National Potential Maximum Summer Evening Peak Demand by End-use

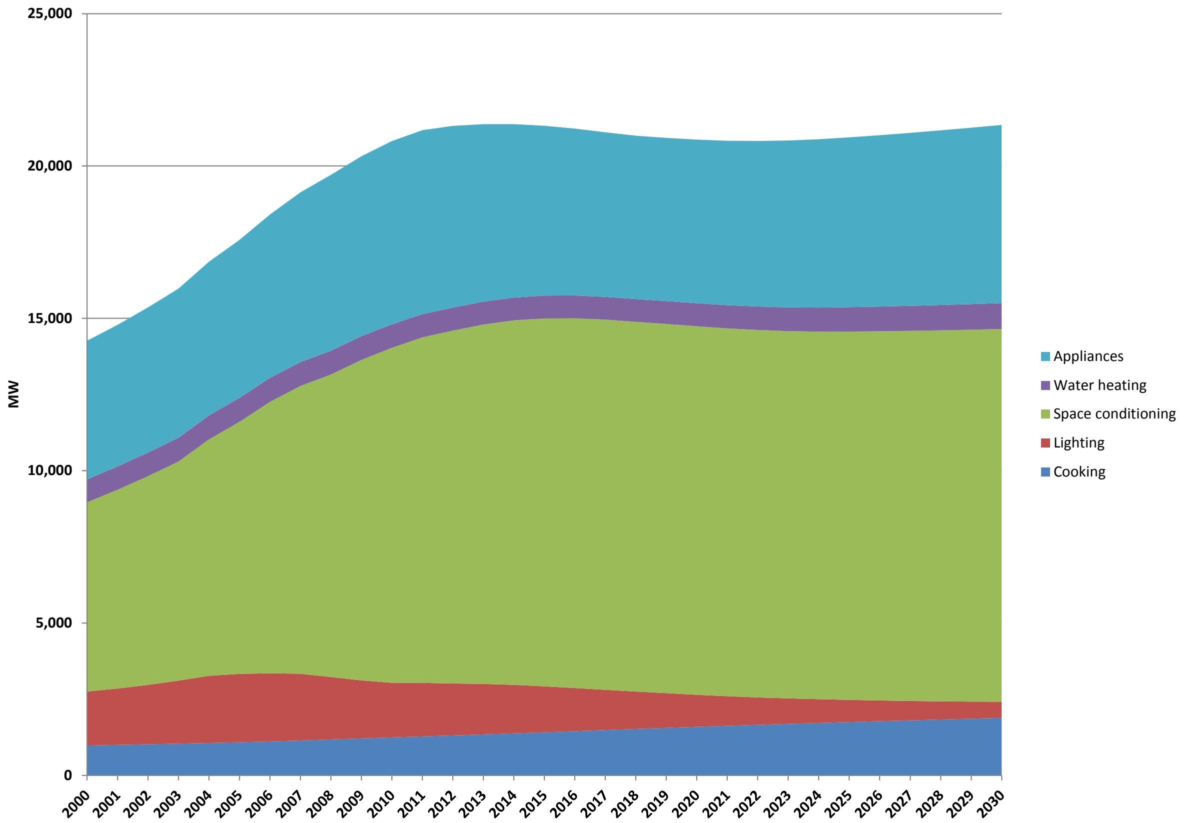
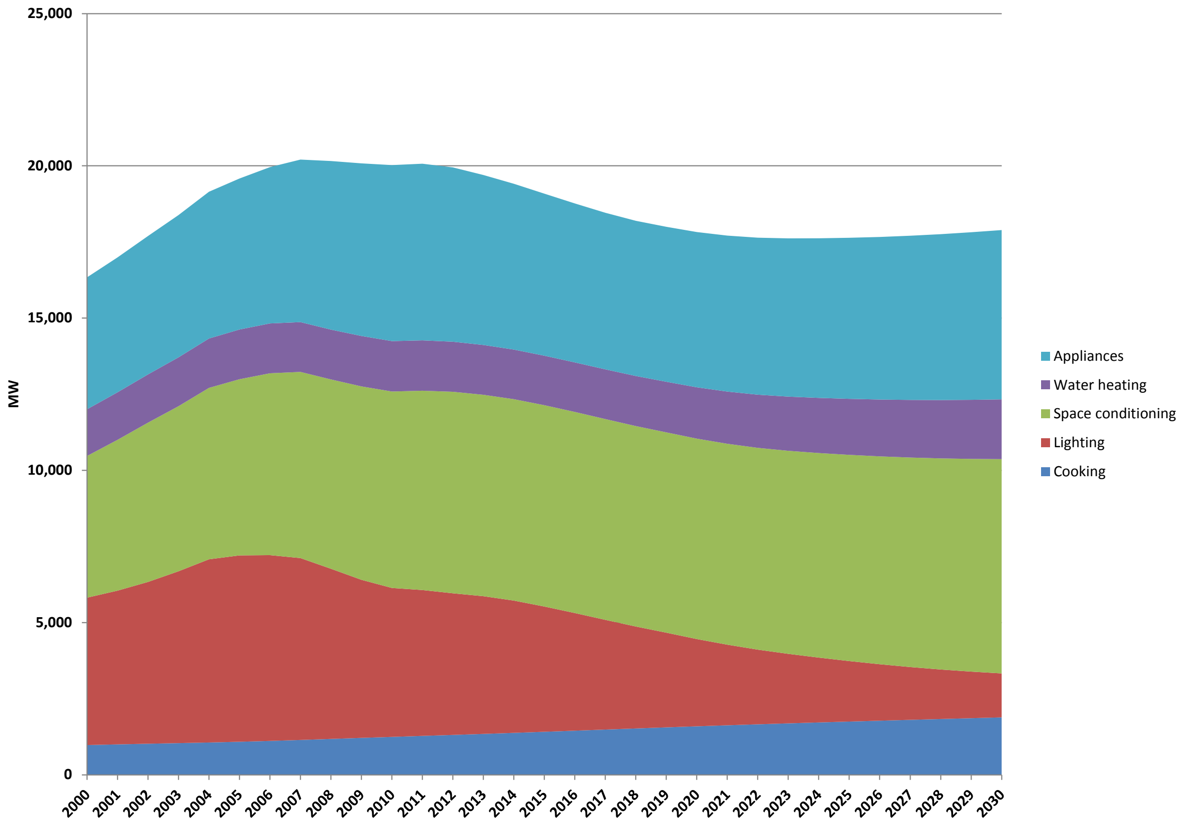


Figure 24: National Potential Maximum Winter Evening Peak Demand by End-use



Space conditioning is the end-use with the largest contribution to both summer and winter peak demand, currently followed by appliances then lighting. Other observations are:

- Projections show the contribution to the summer peak of space conditioning will stabilise post 2015, but continue to grow for the winter peak
- Appliance contribution to peak demand has declined since around 2012 but projections indicate it will increase again in the 2020s
- Lighting contributes significantly to the winter peak but power demand from lighting has been in decline since 2005.

The charts show the maximum value of the potential summer evening peak demand occurred in 2013, while the maximum value for the winter peak demand occurred in 2007. After these peaks, the maximum peak demand values decline and are not expected to start to rise again until the late 2020s.

The drivers of changes in the end-use peak demand include:

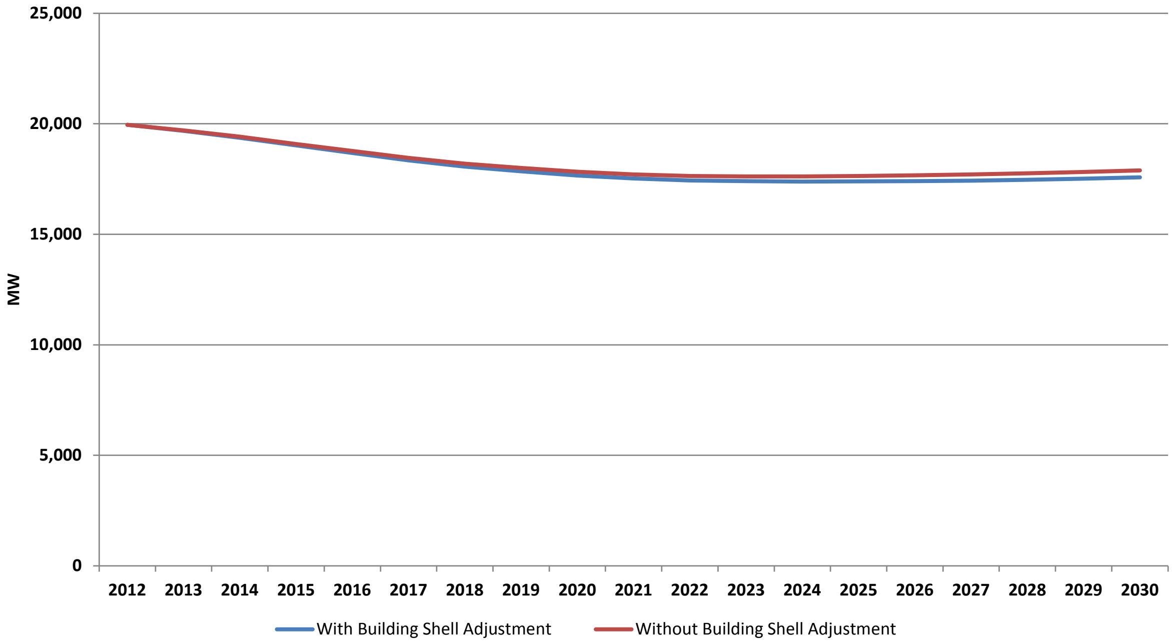
- Improved energy efficiency of air conditioners, largely due to the introduction of MEPS and labelling which have significantly improved their efficiency and rated power requirements

- A move away from electric resistive heating toward the use of more efficient and lower power rated air conditioners, plus a move towards gas heating
- Improvements to the efficiency of lighting, and hence lowering of power requirements, due to the replacement of many incandescent lamps since the mid-2000s by more efficient lamps.

Another factor possibly affecting maximum peak demand could be changes in building shell efficiency. However, the CSIRO study (Ambrose et al, 2013) results, discussed later in the Impact of Building Shell Efficiency Improvements section of Chapter 4, do not show a significant and consistent relationship between AccuRate estimates of building shell efficiency and cooling energy use. While this study was not definitive, the CSIRO report does suggest that at this stage it is unlikely to be possible to predict how summer peak demand will be affected by building shell efficiency, as measured by AccuRate. Consequently, estimates of potential maximum peak demand were not modified in the RBS to allow for changes in building shell efficiency.

However, a relationship between AccuRate measurements of building shell efficiency and heating energy use was found in Victoria, which may also be applicable to other cold climate areas. In addition, AccuRate modelled peak demand and modelled space conditioning energy requirements also appear to be strongly related, as discussed in Peak Electricity Demand Method. Together these findings support the idea that building shell efficiency improvements, as estimated by AccuRate would be related to the potential maximum peak demand on winter evenings. This possibility was modelled and the impact of building shell efficiency on heating power demand modelled for Victoria, Tasmania and the ACT. The resulting estimates of national potential peak demand were then compared against the model results based on the assumption that building shell improvements made no impact. As is shown in Figure 25 below, the RBS modelling suggests inclusion of the impacts of building shells on winter peak electricity demand made little impact on the estimated peak demand, and by 2030 the difference between the two estimates of demand was only 1.8%. The proportional impact of building shell improvements in the colder States should be larger but will remain relatively small.

Figure 25: National Potential Maximum Winter Evening Peak Demand With and Without Building Shell Efficiency Impacts[12]



It is worth noting that this estimate of the impact of building shell improvements on potential maximum winter peak demand assumes that the impact of building shell improvements on power demand will be equivalent to the impact on space heating energy use. However, it is quite possible building shell improvements will have a much smaller impact. This is because in extreme weather the space conditioning equipment may be functioning at full capacity in both lower and higher building shell performance homes, due to the equipment being undersized for the heating load demands that occur during extreme weather. Given there is some evidence of this occurring (e.g. observations in Ambrose et al, 2013), it is probable that the estimate of the impact of building shell improvements on potential maximum winter peak demand presented above is an over-estimate of the building shell impacts. Consequently the impacts of building shell efficiency on peak demand were not included in earlier estimates of peak demand presented in this report.

Residential Greenhouse Emissions

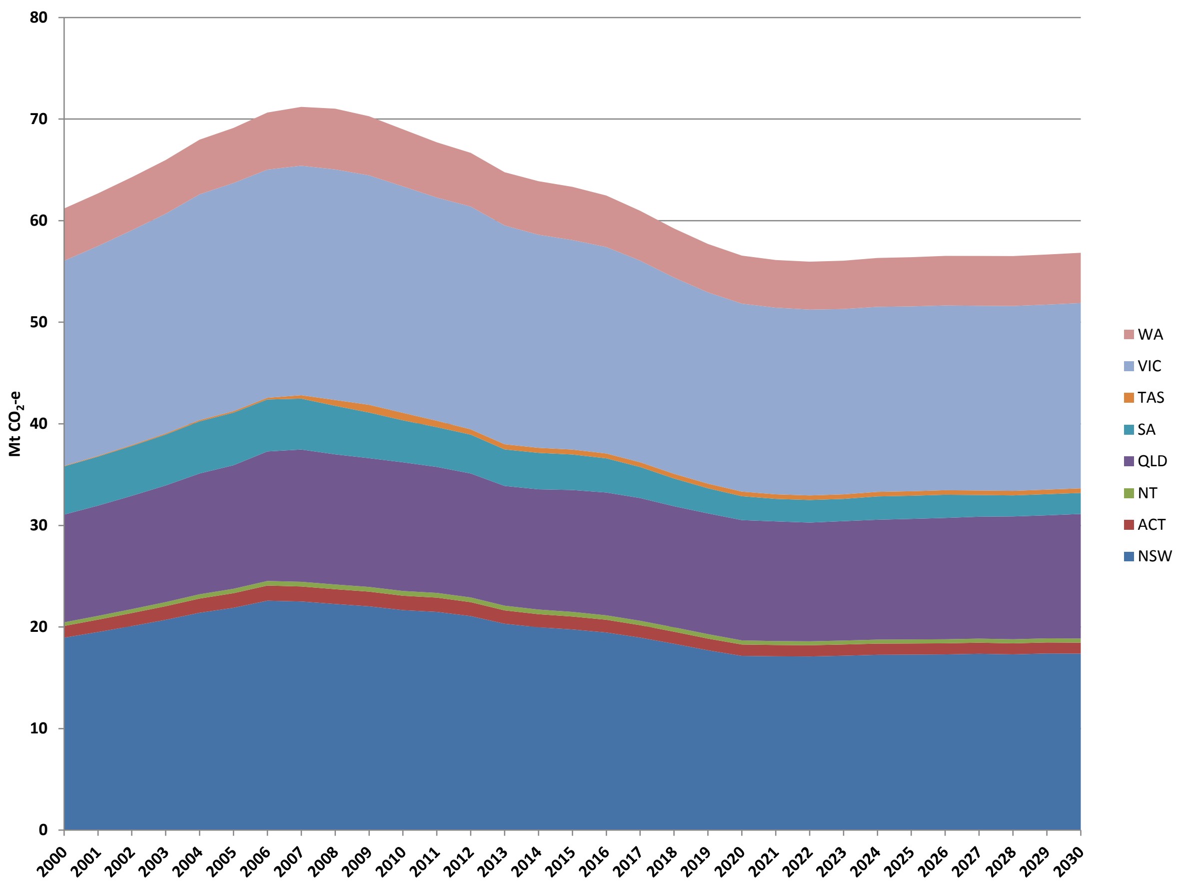
The national greenhouse emissions from residential energy use were calculated by multiplying the energy consumption by fuel for each State by the greenhouse emission factors for the fuels in each State. The results in Figure 26 show that the trend for greenhouse emissions largely mirrors the trend for energy use over the study period. Greenhouse emissions were 61 Mt CO_2-e in 2000 and rose rapidly until the mid-2000s,

[12] This chart shows national winter peak demand but the building shell adjustments have only been applied in three states, Victoria, Tasmania and Australian Capital Territory.

peaked, then declined to around 2020. Post 2020 greenhouse emissions remain largely constant until 2030. Emissions started at 61 Mt CO_2-e in 2000, the peak occurred in 2007 at 71 Mt CO_2-e, has dropped to 64 Mt CO_2-e in 2014 and is projected to be between 56-57 Mt CO_2-e from 2020 to 2030. In total, residential greenhouse emissions are projected to decline 7% from 2000 to 2030.

The breakdown of greenhouse emissions by State shows a very similar pattern to that shown by total energy use by State (see Figure 15). Each State contributes to national greenhouse emissions in a proportion roughly equivalent to their population size, though Victoria's and Australian Capital Territory's[13] contribution is increased due to their larger space heating energy needs, and Tasmania's contribution is reduced due to its extensive use of zero emissions hydropower. The State with the largest contribution to national greenhouse emissions is Victoria, followed by New South Wales and then Queensland.

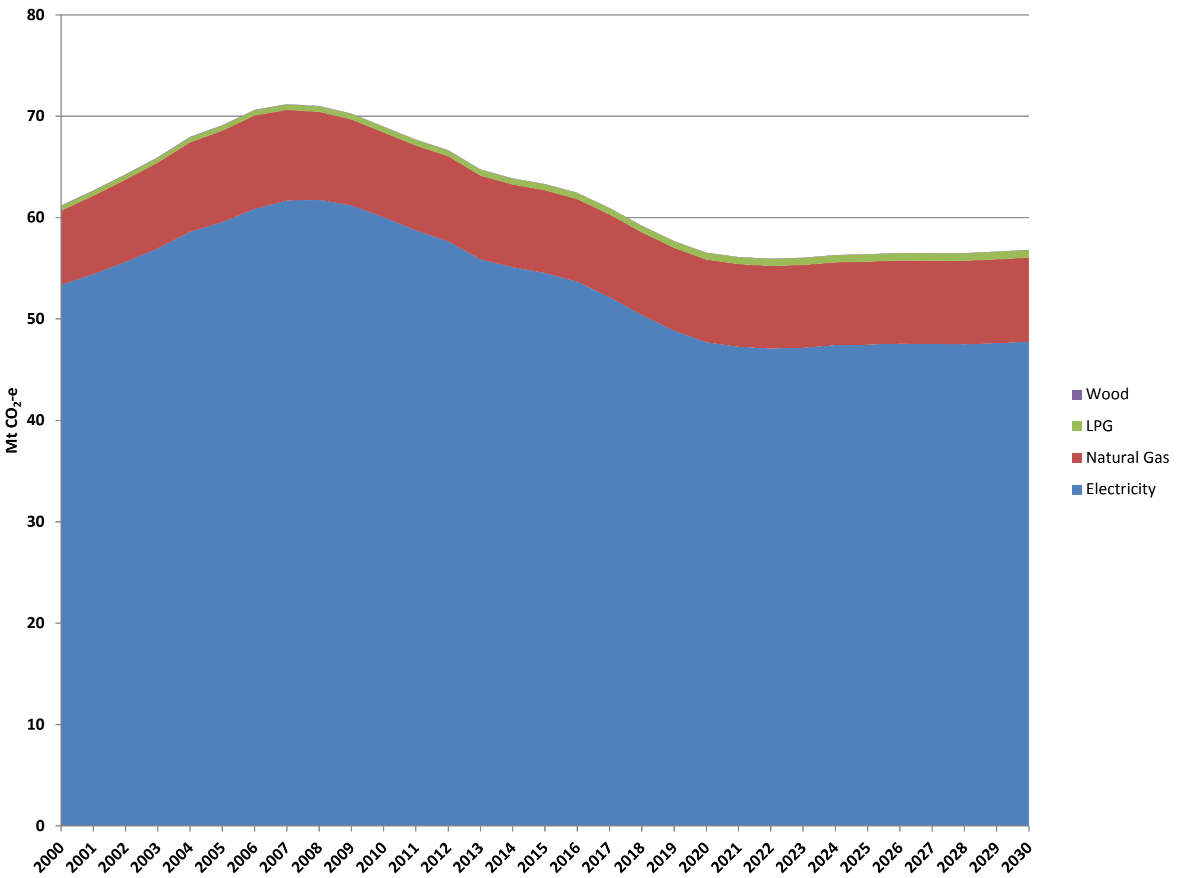
Figure 26: National Residential Greenhouse Emissions by State



[13] Note: The ACT has a policy to increase renewable electricity to 90% of all electricity used by 2020, which will significantly reduce its greenhouse emissions. This change will be incorporated into the RBS model in the near future through an updating of ACT greenhouse emission factors.

Figure 27 provides a breakdown of national greenhouse emissions by fuel, which shows electricity contributed 86% of residential greenhouse emissions in 2014.

Figure 27: National Residential Greenhouse Emissions by Fuel



4. National Results by End-use

The relative contribution of the different end-uses to the total energy consumption has been previously discussed (see Total Residential Energy Use by End Use in chapter 3). The earlier study predicted a steady, ongoing increase in energy consumption and total energy consumption as being 15% greater in 2014 than has proven to be the case. It is not surprising the earlier RBS did not anticipate the downturn in energy consumption as the trend only started to emerge after that report was published. In addition, other significant energy efficiency initiatives, such as the effective ban on general purpose incandescent lamps, were not introduced until after the 2008 RBS was published.

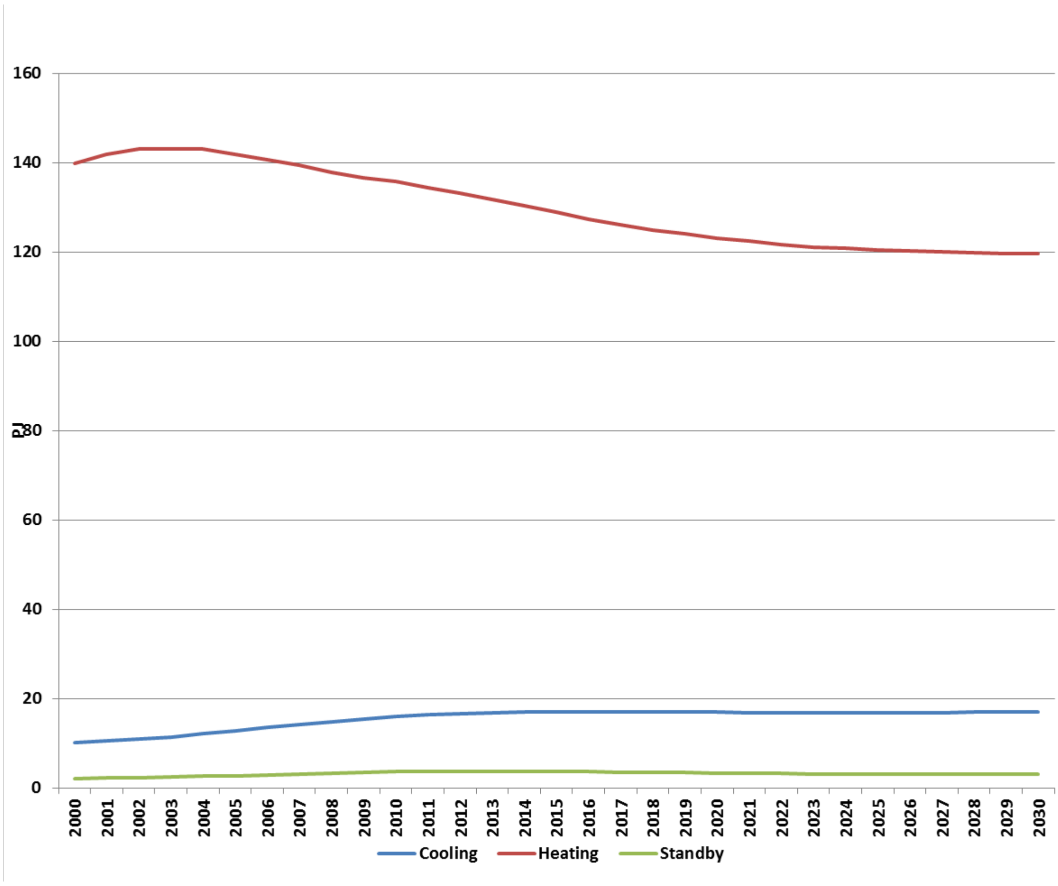
The following results provide greater detail on the underlying trends and drivers of energy use for each end-use.

Space Conditioning

Space conditioning energy use is a major component of residential energy consumption nationally, using 151 PJ in 2014, and is the dominant driver of energy use in the colder states. The overall energy use by space conditioning peaked around 2004 and since then is decreasing, and is expected to continue to decline to 140 PJ by 2030.

A breakdown of the use of the energy used by space conditioning for heating, cooling and standby operations is shown below. Heating energy use clearly dominates space conditioning, with approximately 86% of the total space conditioning energy being used for heating in 2014, 11% for cooling and 2% by standby operations.

Figure 28: National Space Conditioning Residential Energy Use per Operation



The dominance of heating in total space conditioning energy use is largely explained by the much larger population numbers living in colder regions, such as Victoria, Tasmania and Australian Capital Territory, compared to the numbers living in hotter regions, such as Northern Territory and northern Queensland. In addition, most heating appliances (e.g. gas heaters, wood heaters, and resistive electric heaters) are much less energy efficient than the air conditioners used for cooling, which means more energy will be used for heating. The chart also shows that energy used by heating is in decline, while that used for cooling is expected to remain relatively stable over the projection period.

Space conditioning is an end-use that can be satisfied with a variety of fuels and the chart below shows the mix of fuels, with natural gas the dominant fuel, followed by electricity then wood. Fuel use changes over the study period, with wood use declining throughout the period, natural gas growing until 2010 but then declining, and electricity growing until 2014 but then declining. LPG gas use provides a minimal contribution to the total space conditioning energy use and is declining.

Figure 29: National Space Conditioning Energy Use by Fuel

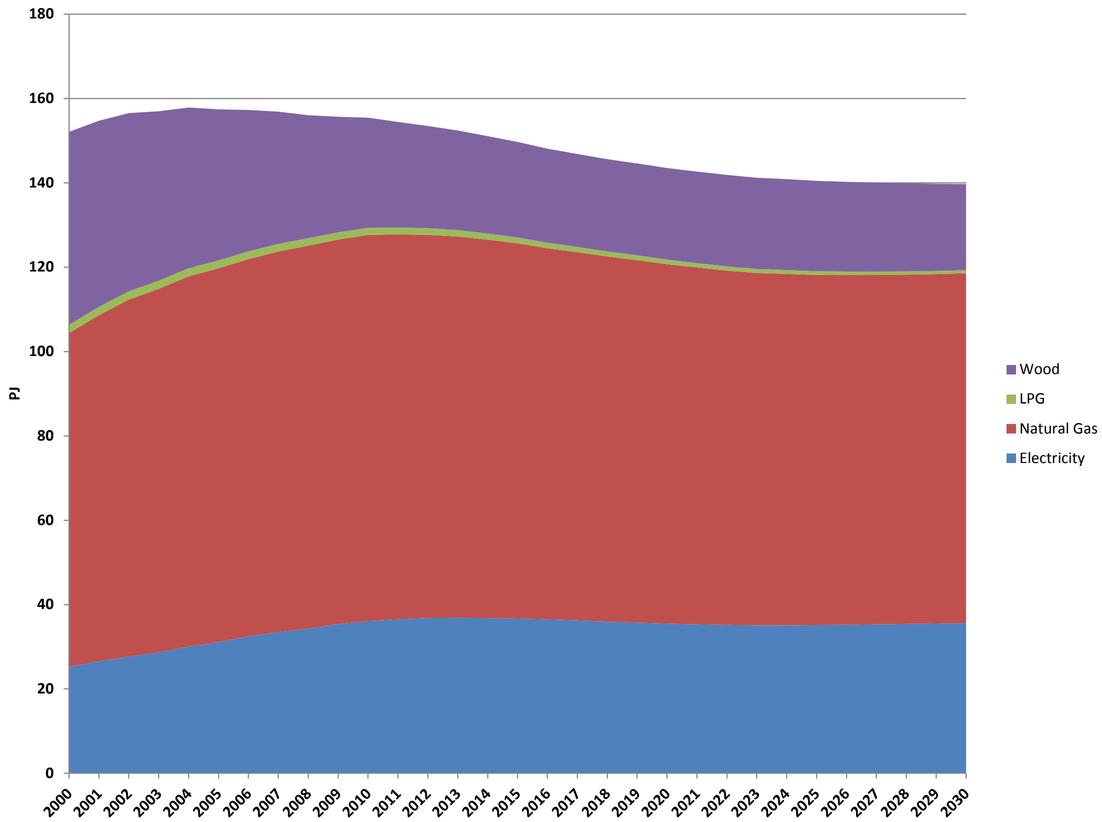
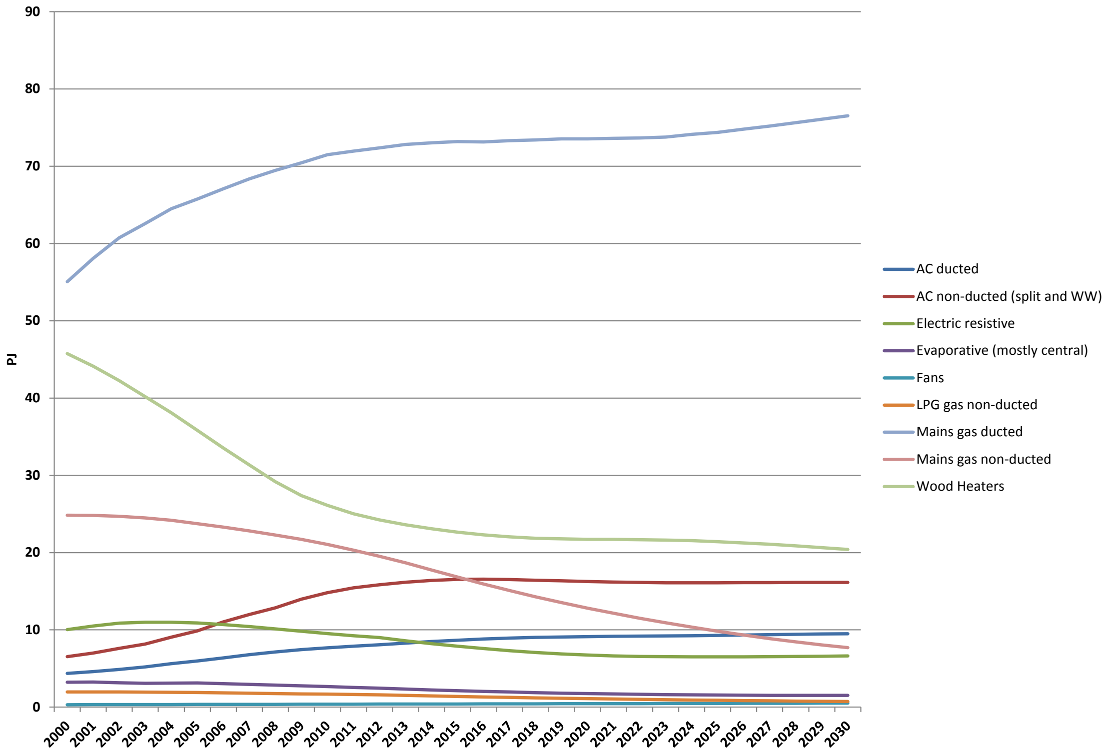


Figure 30 below shows the contribution of specific product types to space conditioning energy use. The major user of energy in this end use is natural gas ducted heaters, which currently use a total of three times more energy than the next biggest energy user. Other significant users of energy are wood heating, non-ducted gas heating and non-ducted air conditioners.

Figure 30: National Space Conditioning Energy Use per Product Group



Though total space conditioning energy use is declining, as the chart shows, this is not true for all products. Natural gas energy use rose rapidly in the 2000s and, though its growth has slowed, it is predicted to have continuing increasing energy use. Energy use by ducted air conditioners continues to increase over the study period. Non-ducted air conditioning energy use also rose rapidly during the 2000s and is projected to continue to rise till around 2017, but then is expected to slightly decline. Significantly, the energy use by wood heaters and by non-ducted gas heaters is declining quite rapidly, contributing to the overall reduction in space conditioning energy use. LPG heaters, resistive electric, evaporative coolers and fans energy use is stable or declining but these products add only a relatively small amount to the total space conditioning energy use.

The underlying drivers for the projected reduction in total space conditioning energy use appear to be:

- Fuel substitution: Households appear to be moving from using wood heaters or non-ducted gas space heaters to air conditioners, which are much more energy efficient than wood or gas heaters, so the energy consumption per dwelling declines.[14]

- Rapid improvements in the efficiency of new air conditioners which continue to flow through to improvements in the overall stock of air conditioners
- Most other products also slowly improving in their efficiency.
- Improvements in building shell efficiency, discussed below.

Impact of Building Shell Efficiency Improvements

The impact of building shell improvements over time on AccuRate estimates of the space conditioning energy loads of the average house in each State/Territory has been researched and modelled. The result is an annual Usage Adjustment Factor which is created for each State and can be used to adjust the energy use estimates and projections of the RBS so as to allow for the impact of building shell improvements.

However, before the Usage Adjustment Factor was used it was necessary to determine if there was evidence that improvement in the thermal performance of building shells, as estimated by AccuRate, resulted in reduced energy use for space conditioning. There appears to be only one study conducted in Australia to test this issue.

The CSIRO study (Ambrose et al, 2013), was of 414 homes built in the 2000s in Adelaide, Melbourne and Brisbane. The houses in each city were divided into older homes built to the 3.5-4 star standard in the 2003-2005 editions of the Building Code of Australia (BCA), and newer homes that were built to the BCA standard of 5 stars or more that was introduced in 2006. Star ratings are measured with NatHERS accredited software tools such as AccuRate. The study found:

- Dwellings' star rating was related to cooling energy use in Melbourne and Brisbane, but in an inverse manner to what was expected. The newer, higher rated homes used significantly more cooling energy in summer, instead of less as was expected. Cooling energy use in Adelaide also increased in the higher rated houses, but the difference was not statistically significant.

- Heating energy use was related to star rating in all cities if internal temperatures were normalised across higher and lower rated houses[15] and was related to actual energy savings Adelaide and Melbourne, but not in Brisbane. There was a 19% reduction in Adelaide, and a 50% reduction in Melbourne, in the actual energy used for heating in higher rated houses compared to the lower rated houses.

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[14] This and similar comparisons of the efficiency of gas or wood energy use, compared to electricity use, are comparisons of the efficiency of the use of delivered energy. They ignore the energy used and lost in generating and transmitting the electricity to the home.

[15] Higher rated houses in the study tended to have slightly higher temperatures in the main living area than lower rated houses, suggesting some of the potential energy savings was taken back by increasing internal temperatures.

- Annual combined heating and cooling energy consumption was 48% lower in high rated houses in Melbourne, but virtually unchanged in Adelaide. In Brisbane though it was 12% higher in the higher rated houses, so the opposite of what was expected.

It is also worth noting that, based on the energy use predicted by AccuRate, there should have been an approximately 65% space conditioning energy savings between the low rated versus high rated houses in each of the three cities. This was not found in the result, and the closest to it was the 48% annual savings in Melbourne, which was 70% of the predicted savings.[16]

While it is the only study of this issue, the CSIRO study results imply:

- Until further research is undertaken, AccuRate/star ratings are not an accurate guide to either annual heating or cooling energy use in Adelaide or Brisbane. The implication is that AccuRate/star ratings will also not be an accurate guide for Perth or Sydney which have the same climate zone as Adelaide, nor in more northern parts of Australia where there is a predominantly cooling load like Brisbane. Consequently for the RBS modelling, a conservative approach was taken that any impact of building shell changes on space conditioning energy use will not be included in the modelling for Western Australia, South Australia, Northern Territory, Queensland and New South Wales[17].

- AccuRate/star ratings appear to be a useful guide to heating energy use in cooler states, if they reflect the Melbourne findings, but not for cooling energy, where the results are the opposite to that expected and increased star ratings are associated with increased cooling energy use. In addition, the impacts appear to vary with the nature of the cooling systems.

Consequently for the RBS modelling, the impact of building shell changes on heating energy use were incorporated in the modelling for Victoria, Tasmania and Australian Capital Territory, though the impact of the changes will be reduced to 70% of AccuRate

[16] CSIRO notes that the findings of the study should be regarded as preliminary as research is ongoing and several factors made it difficult to draw robust conclusions about the differences in energy use between lower-rated and higher-rated houses that could be applied to other such houses in Australia. For example:

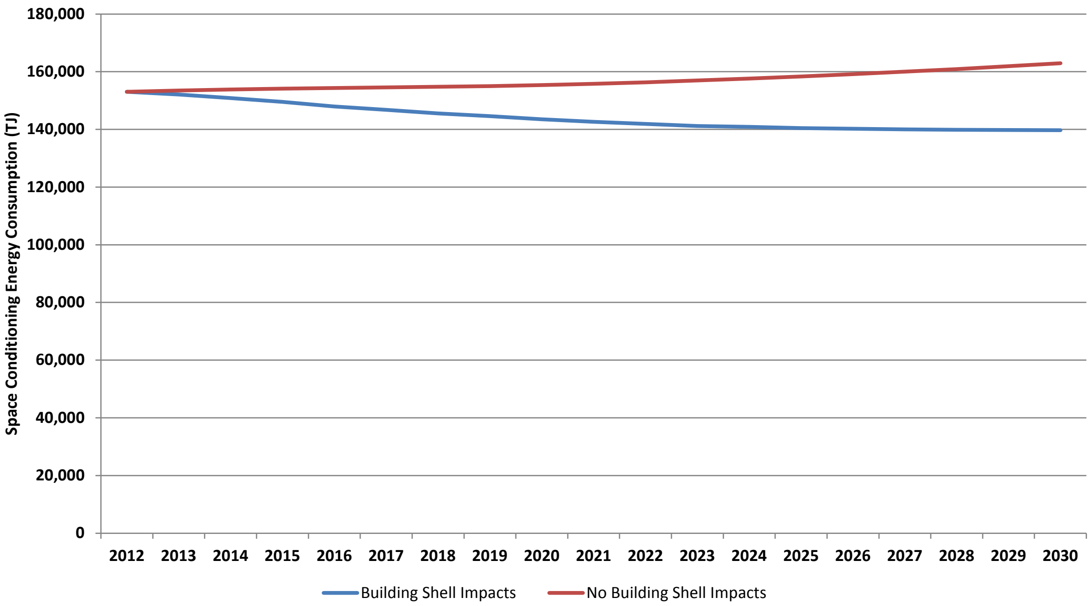
- The sample size was restricted and there was an uneven distribution of houses across star rating values in the three cities;
- There were above-average temperatures during the summer period monitored which made it likely that air-conditioning appliances were operating at full capacity, making it difficult to detect differences due to the star rating;
- The higher rated houses were generally constructed more recently than the lower rated houses , which may have caused some inherent bias, for example the newer houses were more likely to contain younger children and have someone home all day.

[17] The alternative to this approach was to continue to model impacts in these states but this would involve including negative impacts (increases) on cooling energy use from improvements in building shells. However, there was insufficient data to accurately quantify this effect.

predicted impacts. The impact of building shell changes on cooling energy use was not included for these States[18].

The modelled national space conditioning energy use, with and without the impacts of adjustments for improvements in building shell efficiency, is shown in Figure 31.

Figure 31: National Space Conditioning Energy Use- With/Without Adjustment for Building Shell Efficiency Changes[19]

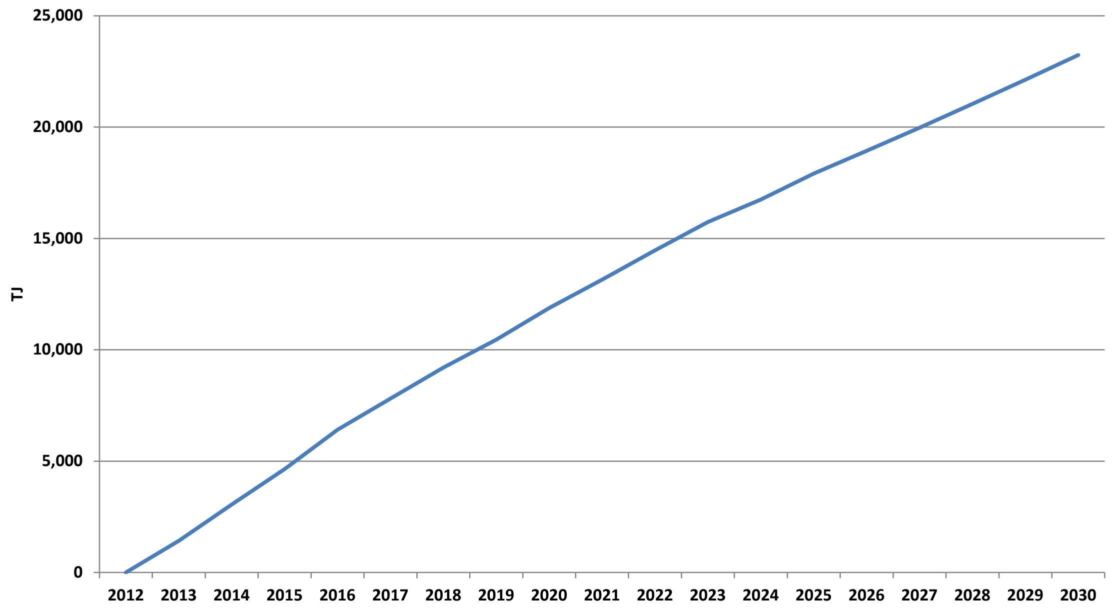


The projected energy savings from building shell efficiency improvements implemented from 2012 onwards are shown in Figure 32. These savings are equal to the difference between the trend lines with building shell improvements versus without building shell improvements after 2012.

[18] Again an alternative would be to model the inverse impact of negative impacts (increases) on cooling energy use from improvements in building shells, but again there was insufficient data to accurately quantify this effect, especially as it varied with cooling appliance type.

[19] This chart shows national space conditioning energy consumption, but the building shell efficiency adjustments are only applied to three states- Victoria, Tasmania and Australian Capital Territory.

Figure 32: National Energy Savings from Building Shell Efficiency Improvements: Post 2012



In Figure 32 above, the projections indicate that savings could be as much as 23 PJ of energy, or 14% of total energy consumption by 2030.

The savings from building shell improvements implemented before 2012 cannot be directly estimated from the RBS modelling, as such estimates will depend entirely on what improvements were being examined, hence what the "no improvement' base case was assumed to be. The base case scenario would need to be defined to address whether insulation retrofits have occurred, insulation in the ceiling of new homes occurred, a minimum of 3 star rating been required, etc. The RBS model is not designed for exploring such historic alternatives and scenarios, so estimating such savings is out of scope for this project, though the model could be modified to explore such questions.

Appliances

Appliances as a group lead to around a quarter (26%) of the overall residential energy consumption of all the end uses. Appliances all require electrical power and can be categorised into White Goods, Information Technology and Home Entertainment (IT&HE), and Other Equipment. Other Equipment includes large energy users such as swimming pools and spas (which can also use gas for water heating), pumps, battery chargers, and use from miscellaneous equipment (e.g. irons, personal care, cleaning equipment, fish tank heaters, etc.). It also includes the energy used for the shared facilities in Class 2 buildings, for example for building lifts, water pumping, common area air conditioning, car park ventilation, security and common area lighting.

Appliance energy use in 2014 was 94 PJ but, as shown in Figure 33, peaked in 2010 to 2011 at 98 PJ. Projections indicate appliance energy use will to continue to decline until the 2020s after which it will start to increase again.

Figure 33: National Appliance Energy Use per Category

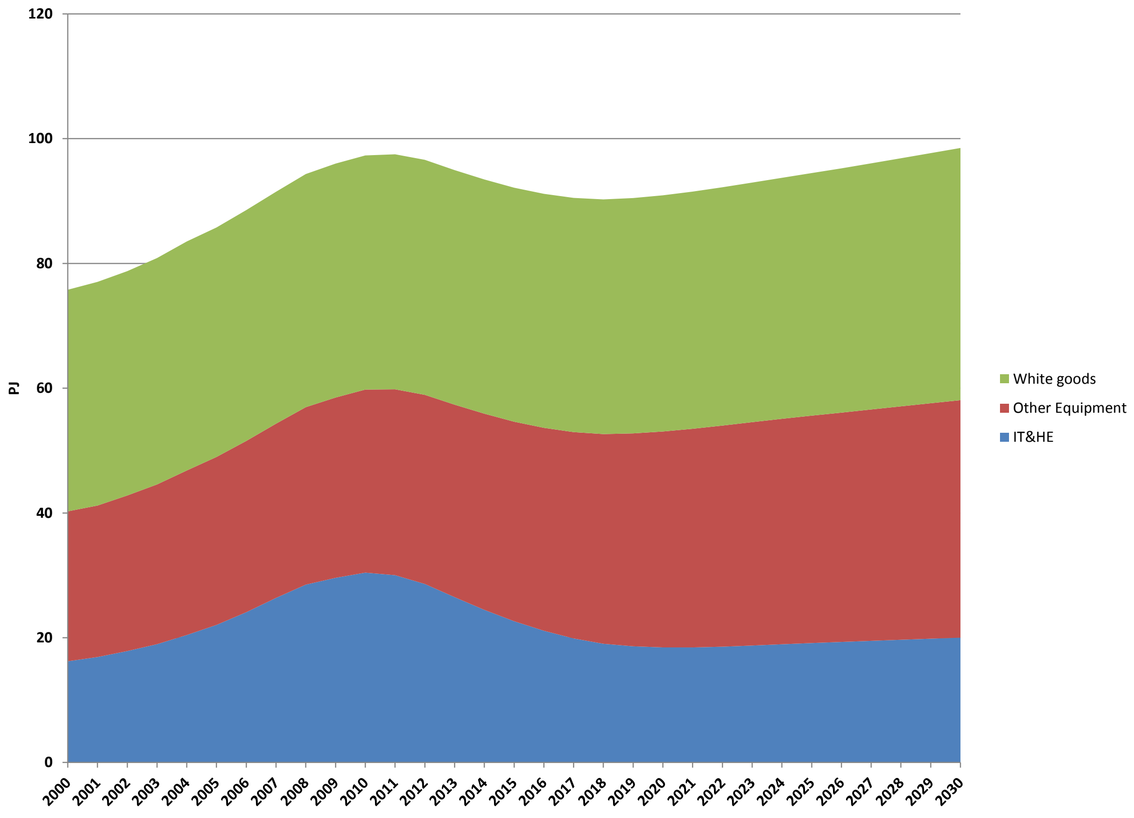
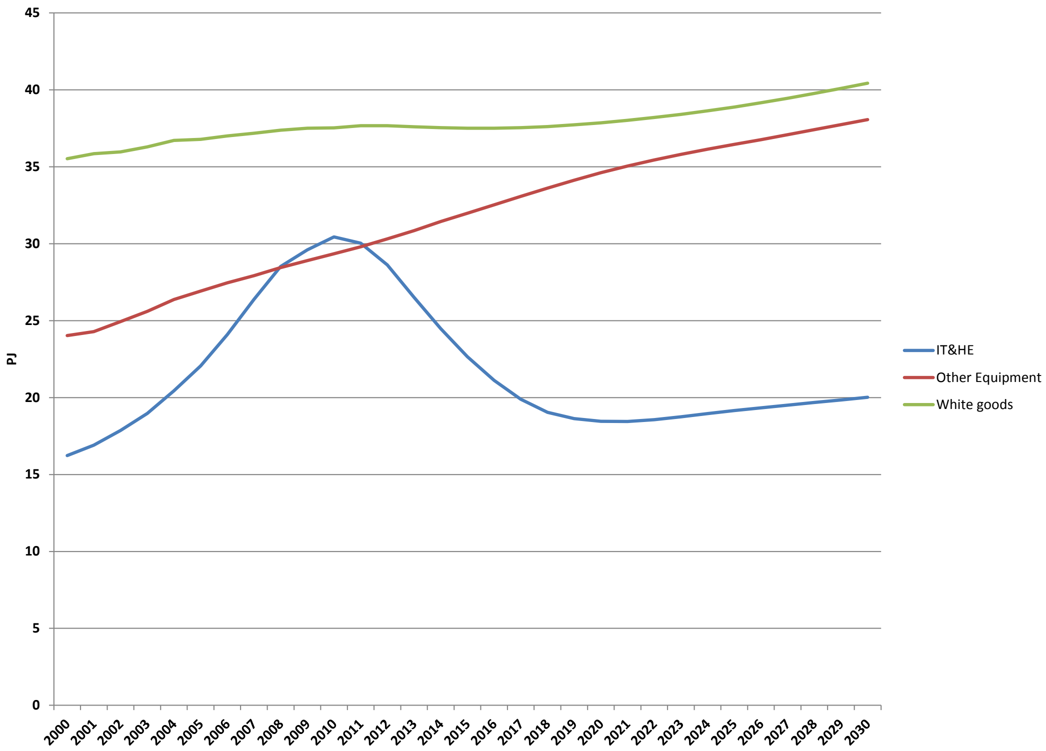


Figure 34: Trend Lines for National Appliance Energy Use per Product Group

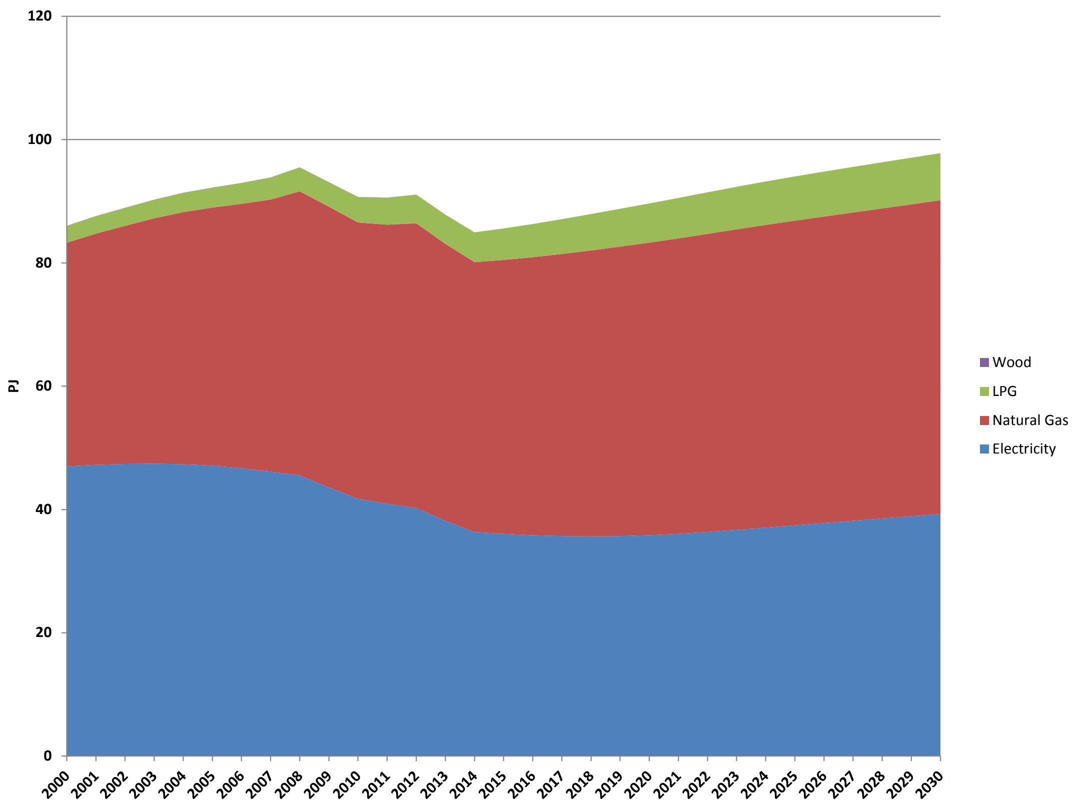


The driver of this increase then decease in appliance energy use is the energy use of the IT&HE product group, as shown by trend line in Figure 34 above. This shows that though Other Equipment and White Goods energy use has continued to grow over the study period, IT&HE energy use grew rapidly in the 2000s, then declined rapidly, before being projected to grow slowly again in the 2020s. The main reason for this trend in the IT&HE energy use was product numbers peaked around 2010 and then started to decline, plus more energy efficient products, especially televisions, were introduced around 2010.

Water Heating

Water heating also contributes around a quarter (24%) of the overall residential energy consumption of all the end uses. Water heating's energy use was 85 PJ in 2014, having declined from a peak consumption in 2008 of 95 PJ, as shown in Figure 35. However, total water heating energy use is expected to start to increase and grow until it reaches around 98 PJ in 2030, assuming there are no changes in water heater regulations or incentive programs.

Figure 35: National Water Heating Energy Use by Fuel



Note that wood water heaters (wetbacks) only consume a very small amount of energy that cannot be seen on the chart.

This chart also illustrates the relative mix of fuels used in water heating. Electricity previously dominated the water heating market but since the early 2000s the total use of electricity for water heating has declined and is not expected to start to increase until the 2020's. Electricity's contribution to the total water heating energy use is now less than that of natural gas. By comparison, the use of natural gas increased from 2000 to 2008, where it reached a temporary peak, then declined slightly to 2014 but now projections indicate it will increase again through to 2030. LPG's use has steadily increased since 2000 and is expected to continue to do so, though it remains a minor contributor to the total water heating energy use.

Figure 36: National Water Heating Energy Use by Product Group

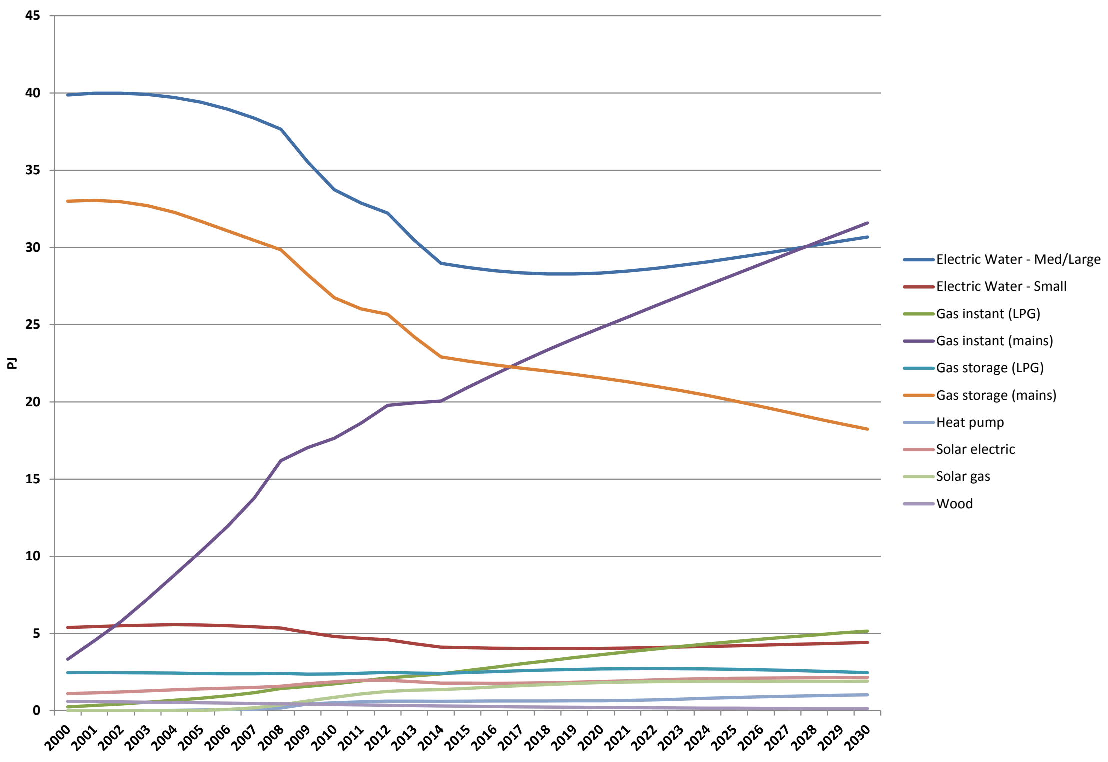


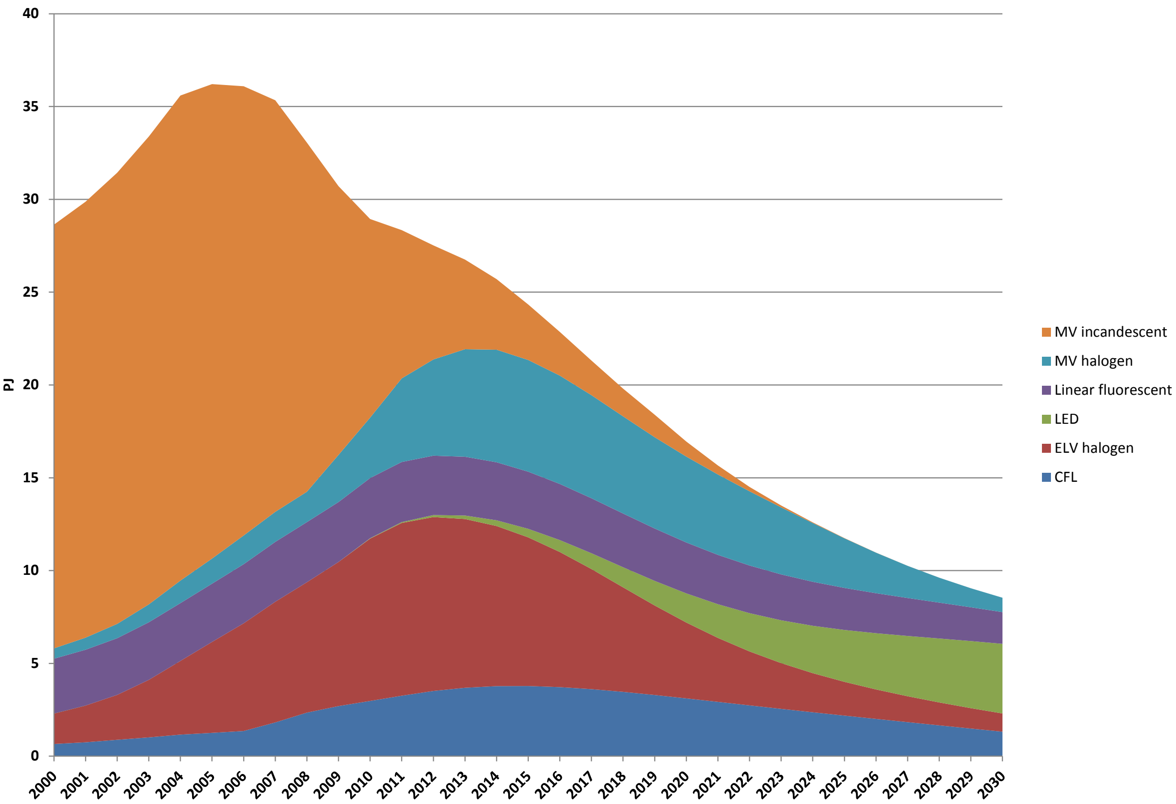
Figure 36 above provides further insight into the drivers of the changes in energy and fuel use by water heaters, such as:

- The energy use of all electrical water heaters has declined for fifteen years but now projections indicate it will stabilise and then increase slightly in the 2020s, which is reflected in the falling, then stabilising, use of electricity for water heaters
- The energy use of natural gas storage water heaters declined throughout the study period but the energy use of gas instantaneous water heaters is increasing rapidly, which is driving the increase in natural gas usage
- LPG storage water heater energy use remains stable throughout the study period, but is growing for instantaneous LPG water heaters
- Solar gas, solar electric and heat pump water heaters use grew since the mid-2000s, together with their energy use, but it is expected to remain relatively stable now for the next fifteen years unless new incentives are introduced to encourage the take up of these high efficiency water heaters.

Lighting

The energy use of lighting is shown in Figure 37 below. This chart shows a clear peak in energy consumption in 2005, at 36 PJ, and then projections indicate a steady decline in energy use will continue through to 2030. Energy use is 26 PJ in 2014.

Figure 37: National Lighting Energy Use by Product Group



The key drivers of these changes in lighting energy use over the three decades are the change in the lighting technology mix, and the associated change in the average efficiency of the lighting stock. The lighting stock can be seen as going through three technology phases over the thirty years, as follows:

- Incandescent lamps: During the 2000s incandescent lamps dominated lighting stock numbers and energy use. As these lamps produce energy intensive lighting, the energy use of lighting was at its highest during this decade
- Halogens and Compact Fluorescent Lamps (CFLs): Use of halogen and CFL lamps grew during the 2000s and started to displace incandescent lamps, a trend accelerated by the introduction of regulations effectively banning general purpose incandescent lamps in 2009. This resulted in energy use by halogen and CFL lamps dominating lighting energy use in the 2010s. However, because halogens, and

especially CFL lamps, are more efficient than the incandescent lamps they had displaced, the total energy use by lighting declined.

- Light Emitting Diodes (LEDs): The use of LED lamps has grown over the last five years and these lamps are predicted to gradually displace halogen and CFL lamps over the next fifteen years. If this occurs, then LED energy use will eventually dominate lighting stock numbers and energy use in the 2020s. Again, as LED lamps are more efficient than any of the earlier lighting technologies, the total energy use by lighting projections show energy use declining as these lamps become more widespread.

In addition to the lighting technologies mentioned above, linear fluorescent lamps are commonly used in the residential sector but they have only contributed a relatively small proportion of the total lighting energy use. This reflects both their relatively high energy efficiency but also because their total numbers remain relatively small, as usually there are only a few linear fluorescent lamps per dwelling. Their energy use has remained stable over the last fifteen years but is expected to slowly decline as linear LEDs are gradually used to replace them.

Cooking

Figure 38 below shows that cooking energy is supplied by three fuels: electricity, natural gas and LPG. The total energy use in 2014 was 19.7 PJ, of which over half was supplied by electricity, and around a third by natural gas. Energy used by cooking has grown steadily since 2000 and is expected to continue to grow, but almost all this growth is from growth in electric cooking. The use of LPG and natural gas has been stable since the mid-2000s and projections indicate it will not increase until the late 2020s.

There may also be a small amount of cooking undertaken on wood-fuelled stoves, but no information was available on the number of stoves and their energy use was considered likely to be immaterial and not modelled.

Figure 38: National Cooking Energy Use by Fuel

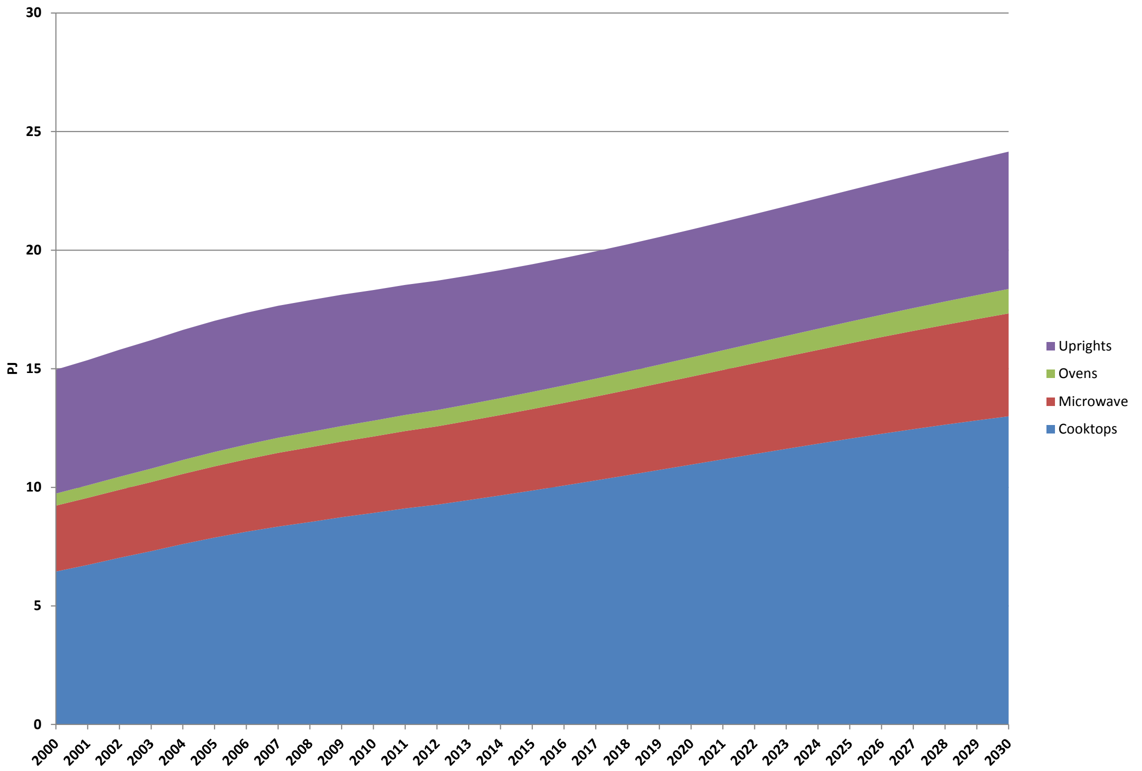


Figure 39: National Cooking Energy Use by Product

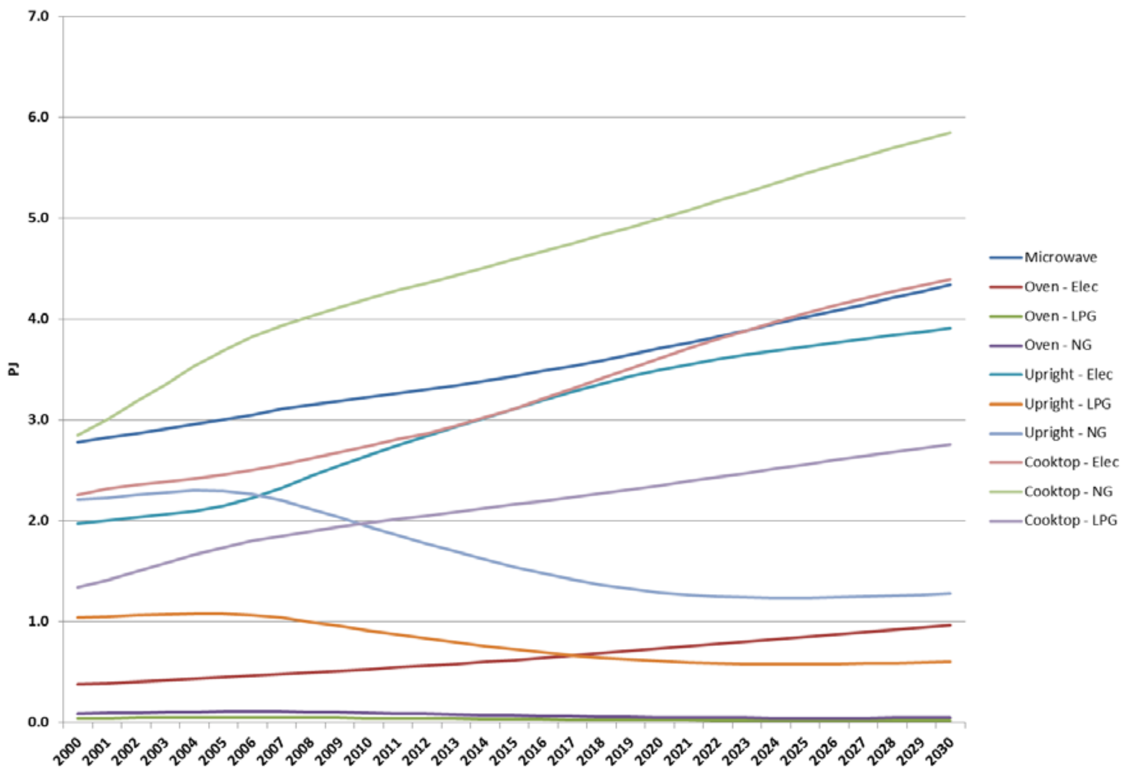


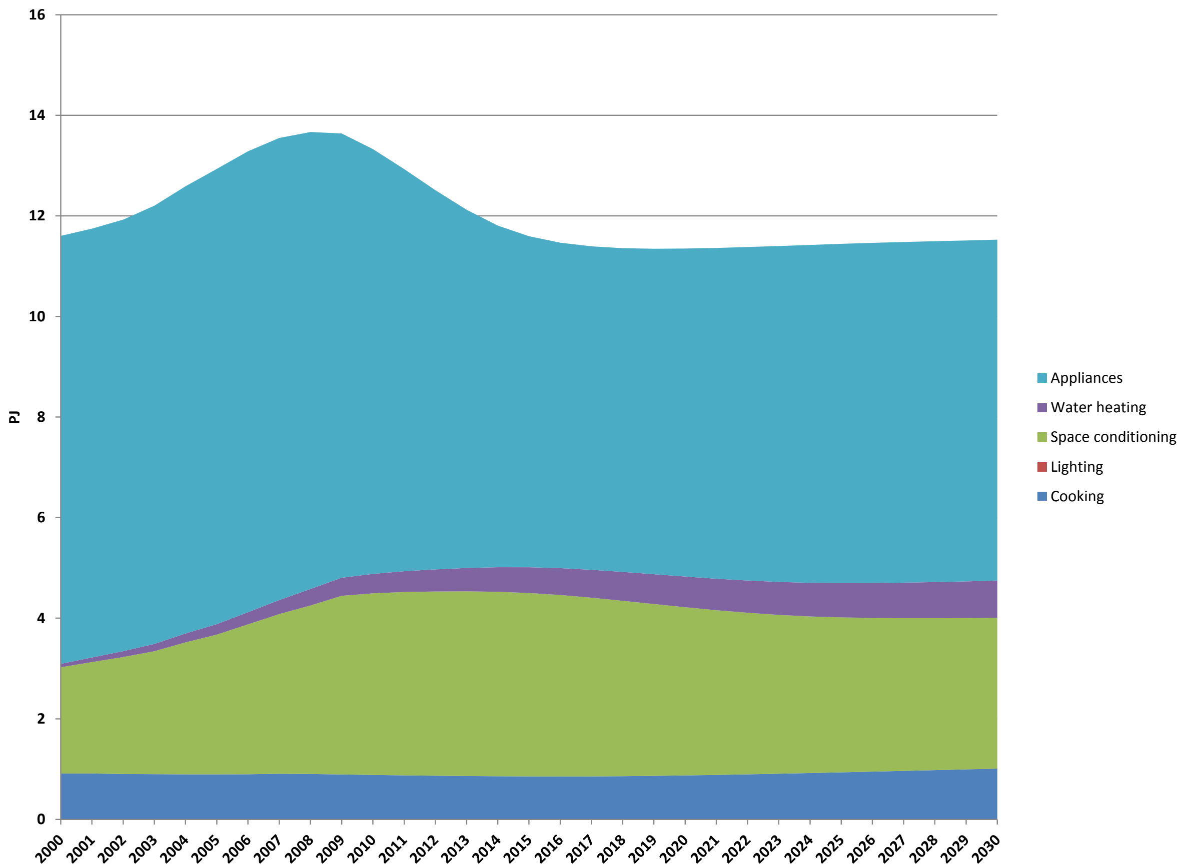
Figure 39 shows the energy contribution of different types of cooking products to the total energy use of cooking. Currently the largest single user of energy is natural gas cooktops, which is followed by three products having similar energy usage, these being microwave ovens, electric cooktops and electric upright cookers.

The energy use of all the cooking products are increasing, with two main exceptions, natural gas and LPG upright cookers whose energy use have been declining since around 2005. This reflects declining numbers of these products, not increased product efficiency. The growth in all electric cooking products, and the decline in gas upright's energy use, help explain why electric products are driving the increase in total cooking energy use.

Standby Power

Standby power is not an energy end-use as such but, as it is known to add significantly to the electricity in the average home, it is separately reported here. Figure 40 shows total standby power use slowly growing from around 12 PJ in 2000, rising during the mid-2000s but then decreasing again and remaining around 12 PJ from 2015 until 2030.

Figure 40: National Standby Energy Use by End Use



The main contributor to standby power is the appliance products, followed by space conditioning. The contribution from appliances to standby power use peaked in 2007 and has been in decline since, but is expected to grow from around 2020. The contribution from space conditioning and water heating has been growing since 2000 and is expected to continue to do so. The contribution from water heating will have started with the introduction of electric ignitions to instantaneous gas water heaters, and electronic controls and pumps for solar gas water heaters.

On a per household basis, standby power is estimated to use 1.34 GJ p.a., which is 3% of the total energy use of the average dwelling in 2014, and 6% of its average electricity use. This percentage of standby is lower than the previous survey estimate of 10% (E3 2010) of electrical consumption. However, the difference between the two estimates is understandable given there was some reduction in standby energy use in the last few years, plus some appliances surveyed as contributing to standby power, e.g. battery chargers and network devices, in the RBS are separately classified and not included in the measure of standby power. When these products are included in the RBS standby power, the total standby power use per dwelling was 8% in 2014.

PV Generation

PV generation is also not an energy end-use, but is presented here as it will increasingly impact on the net energy consumption of Australian homes. The chart below shows generation was immaterial before 2009, after which it has rapidly grown to around 3,600 megawatts (MW) in 2014. Projections indicate PV generation capacity will grow to over 14,000 MW by 2030, as shown in Figure 41.

Figure 41: National PV: Gross Generation (MW)

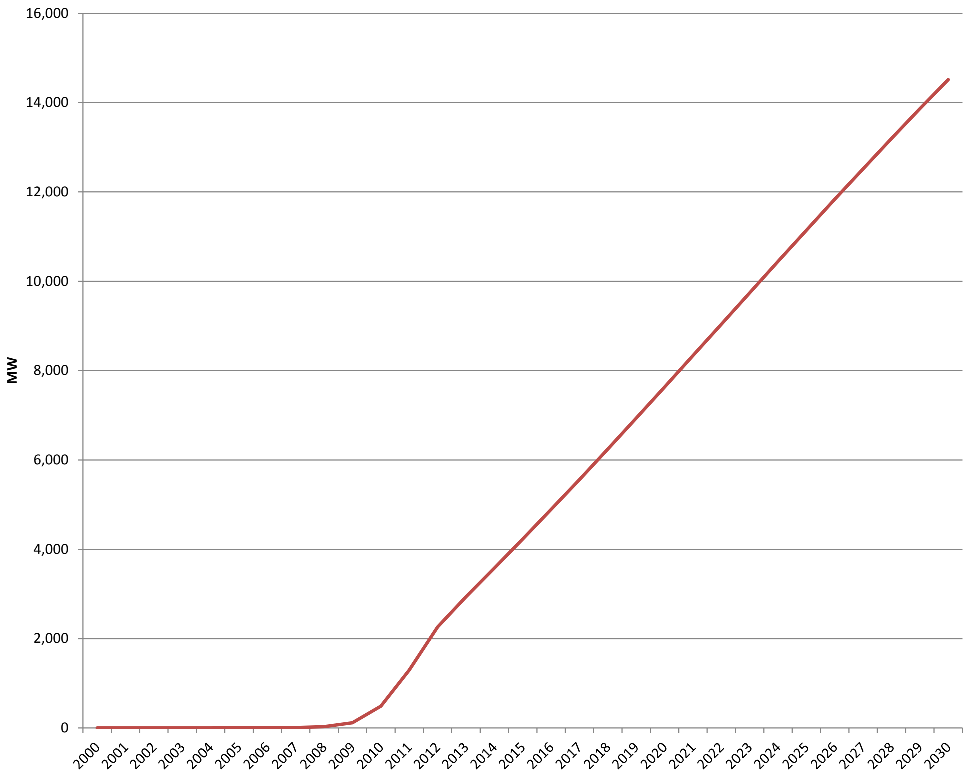


Figure 42: National PV: Gross Annual Energy Output

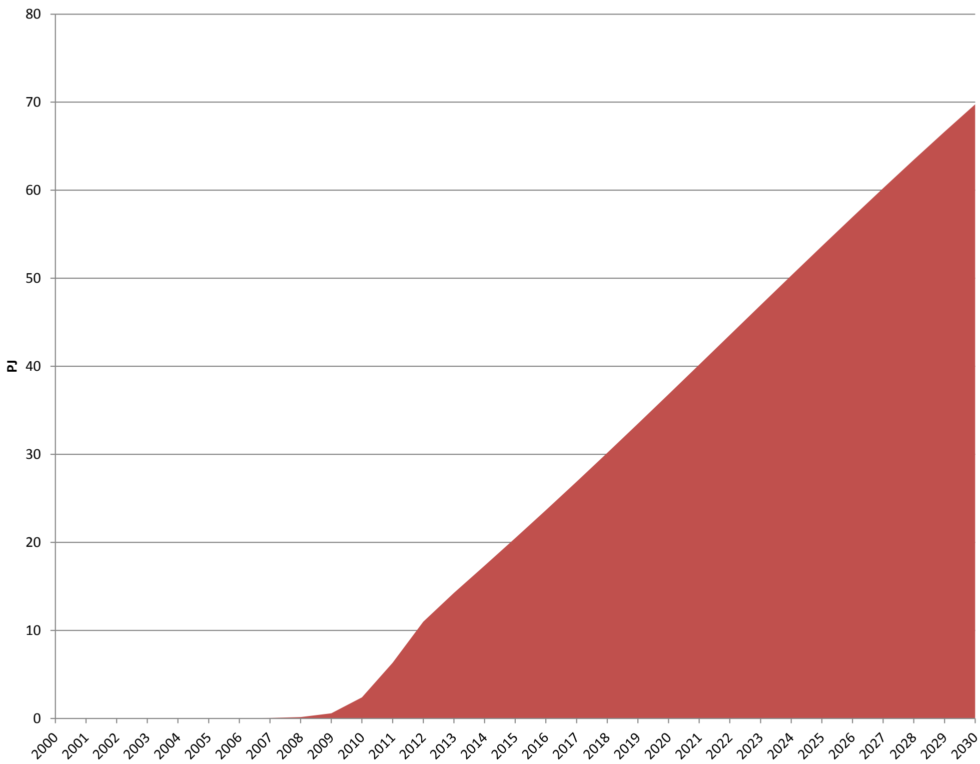
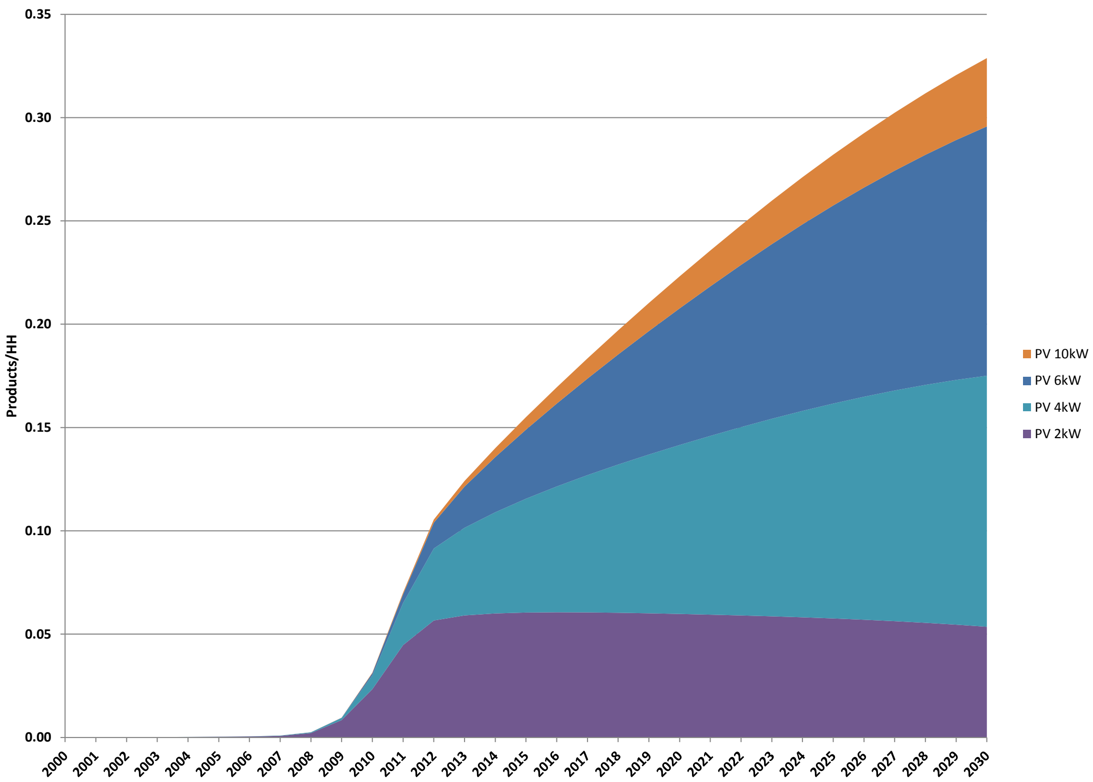


Figure 42 above shows that annual gross PV energy generation output has grown and by 2014 was 17.3 PJ (4,800 gigawatt hours (GWh) p.a. and is expected to increase to over 69 PJ (19,000 GWh) p.a. by 2030.

The projected growth in generation capacity and energy output is based on the growth in sales and stock of PV systems. Using these stock projections, ownership rates were estimated. The estimated ownership of PV systems is presented in Figure 43 and shows 14% of households own PV systems in 2014 and that ownership is expected to increase to 33% by 2030. Generation output is expected to grow faster than ownership as households are expected to install PV systems which are larger on average in the future.

Figure 43: National PV Stock Estimates by System Size



Note: System size in is shown as up to the specified legend value in kW

Growth rates for these projections are based on the sales and growth over the last two years where government incentives for installing PV systems have been reduced or withdrawn. However, the installation of PV generation will be an aspect of residential energy behaviour which will remain strongly influenced by government incentives, regulations and feed-in tariffs, so future generation amounts could significantly vary from those presented here.

5. Validity of RBS Results: Top-Down Comparison

In order to check the accuracy of the RBS model results, it was necessary to compare them to alternative estimates of historic residential energy use. Such estimates are invariably measures of the aggregate energy use of the residential sector nationally and in different States, usually by fuel type. Key sources of such data are:

- Office of the Chief Economist (OCE) within the Department of Industry and Science
- Energy Supply Association of Australia (ESAA)
- Various electricity and gas distributors.

Ideally the reported measurements of historic residential energy use would be consistent, allowing the RBS results to be compared to the historic findings in a simple manner. However, this has not proven to be the case, as the different sources of energy use data use different measurement methodologies that produce different results. When such variation exists, the data most relying on relevant direct measurements has been chosen for the RBS results comparison.

It is worth noting that the RBS model cannot be expected to produce 100% accurate estimates of energy use in a given year, as energy use will vary annually for many reasons, such as economic conditions, energy price variations and especially weather variations. Weather variations alone potentially could produce variations in energy use approaching 4%[20] and, as the RBS estimates do not include any allowance for weather impacts, this means up to a 4% variation between the RBS results and measured energy use p.a. is to be expected. Also the top-down energy use estimates are usually prepared on a financial year basis, and they are reported in this chapter as the end of the FY (i.e., FY 2012-13 is shown as being 2013), and then compared to the RBS calendar year results, which could introduce additional variation between the sets of results.

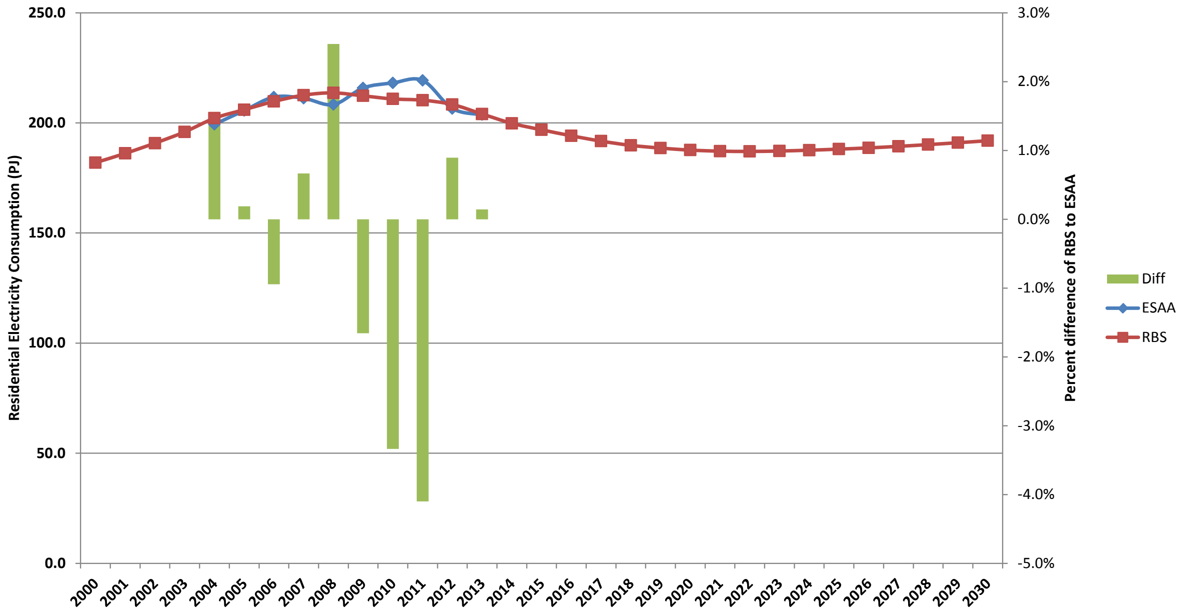
Electricity Use Comparisons

The two national sources of information on residential electricity use, the OCE and ESAA, have produced different estimates of the total residential electricity use. The OCE estimates of residential electrical use were based on aggregated data from market operators for Australia's electricity networks, who provide estimates and forecasts of residential consumption. In comparison, the ESAA residential energy measurements were closely aligned with distributor data, which is based on actual metered consumption data. This meant the ESSA measurements were more appropriate for assessing how the RBS estimates compared to actual residential consumption, and the figure below shows the comparison for national electricity consumption.

[20] As space conditioning is 40% of total residential energy use and assuming a conservative +/-10% variation in degree days p.a., this could potentially result in a 4% variation in energy use from variations in space conditioning alone.

The RBS and ESAA estimates of national residential electricity use were compared for the period 2004-2013, in Figure 44. For all the years compared there was an acceptable difference of less than 5% in the estimates, and for most years a difference of 2% or less was found. In addition, the ESAA figures for recent years support the RBS's identification of a downward trend in energy consumption.

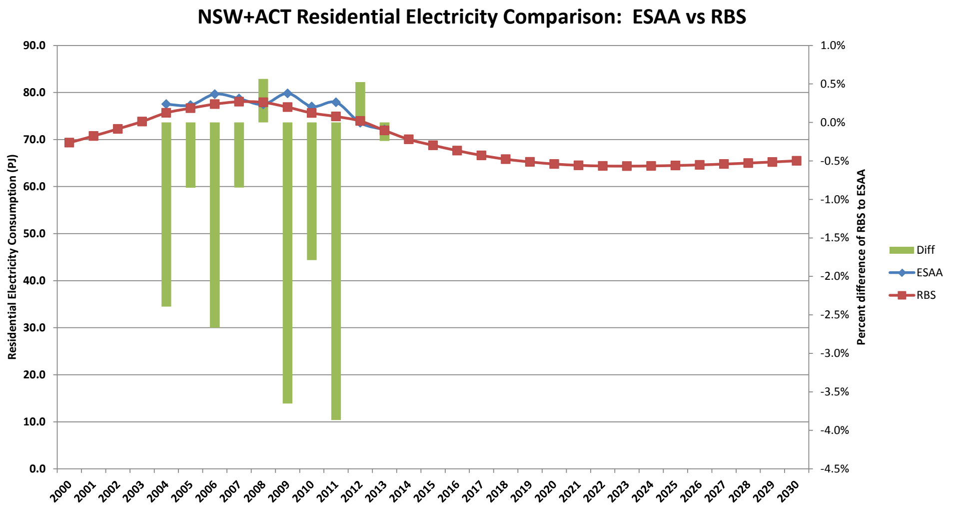
Figure 44: Comparison of RBS and ESAA Estimates of Australian Residential Electricity Consumption

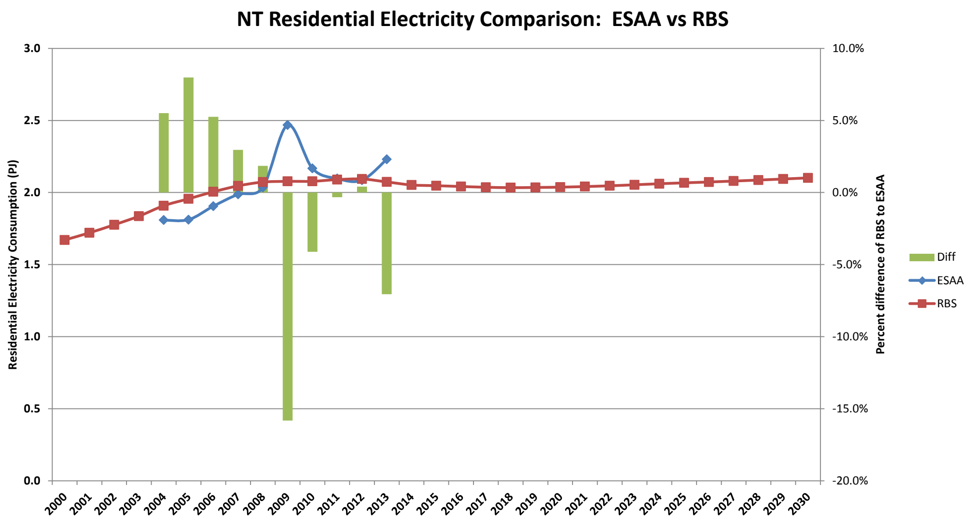


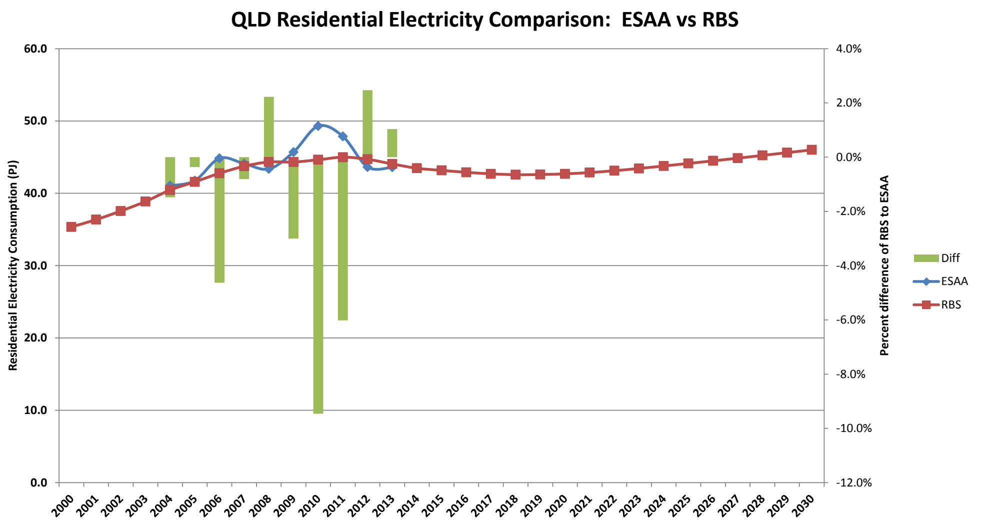
This finding clearly indicates that the RBS is providing valid estimates of national residential electricity consumption. The differences between the RBS and ESAA estimates are within the boundaries of the variation in energy use that would be expected due to weather variations and other factors.

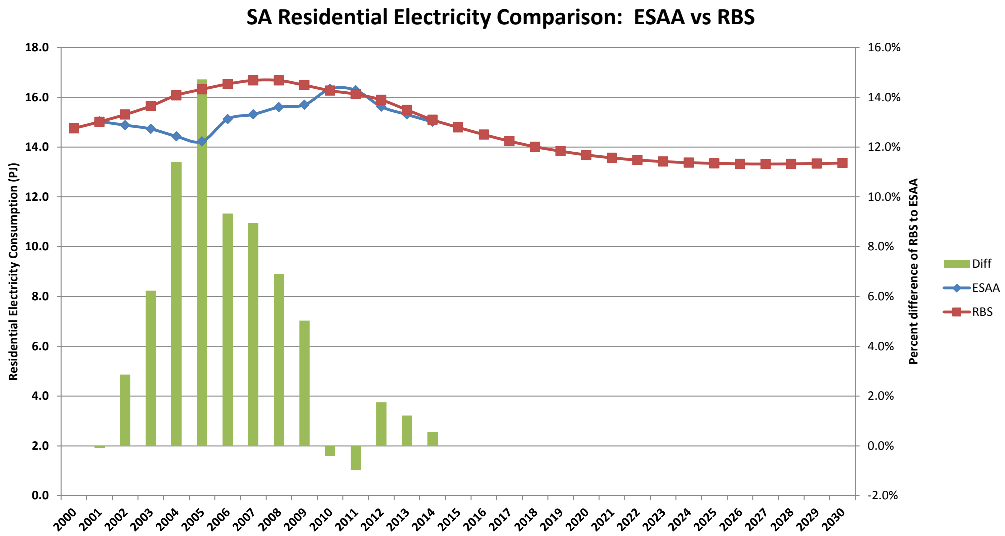
The ESAA findings and RBS results were then compared for all States and the results are shown in Figure 45 below.

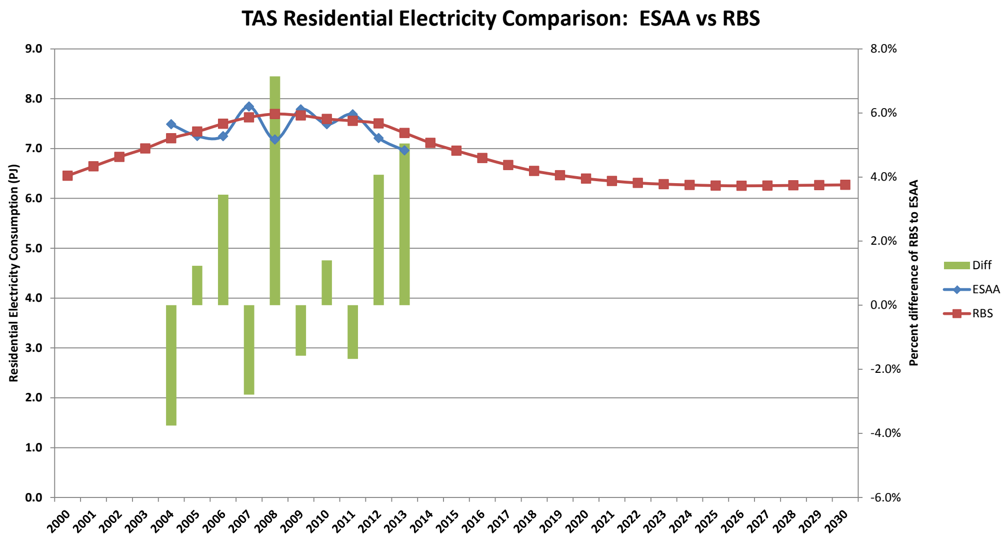
Figure 45: Comparison of RBS and ESAA Estimates of Residential Electricity Consumption by State

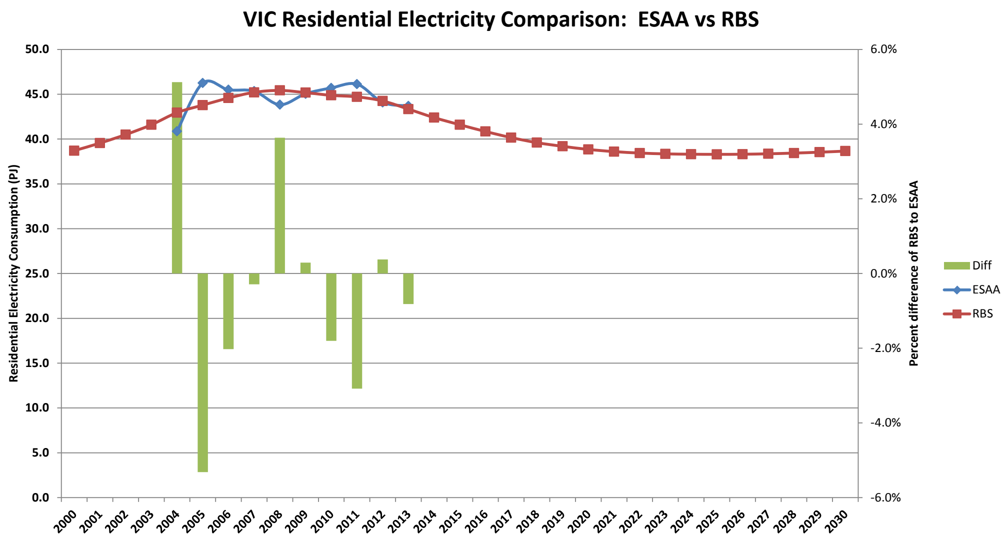


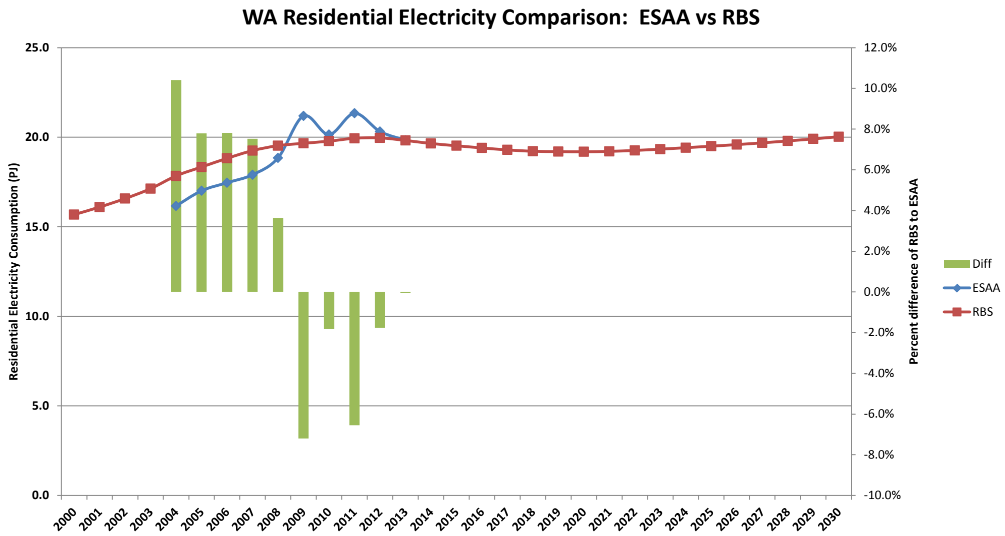





SA Residential Electricity Comparison: ESAA vs RBS
Residential Electricity Consumption (PJ)
Percent difference of RBS to ESAA
Diff
ESAA
RBS


TAS Residential Electricity Comparison: ESAA vs RBS
Residential Electricity Consumption (PJ)
Percent difference of RBS to ESAA
Diff
ESAA
RBS


VIC Residential Electricity Comparison: ESAA vs RBS
Residential Electricity Consumption (PJ)
Percent difference of RBS to ESAA
Diff
ESAA
RBS



Not surprisingly the State results shown above do not display the same level of consistency between the RBS results and the ESAA estimates as was found at the national level. The maximum variation was still under 10% except for South Australia and Northern Territory, and for most years and States the variation was under 5%. Given the poorer data available on appliance numbers and use at the State versus the national level, a larger variation in the RBS results at the State level is probably to be expected and a maximum of a 10% variation from the ESAA measurements appears satisfactory.

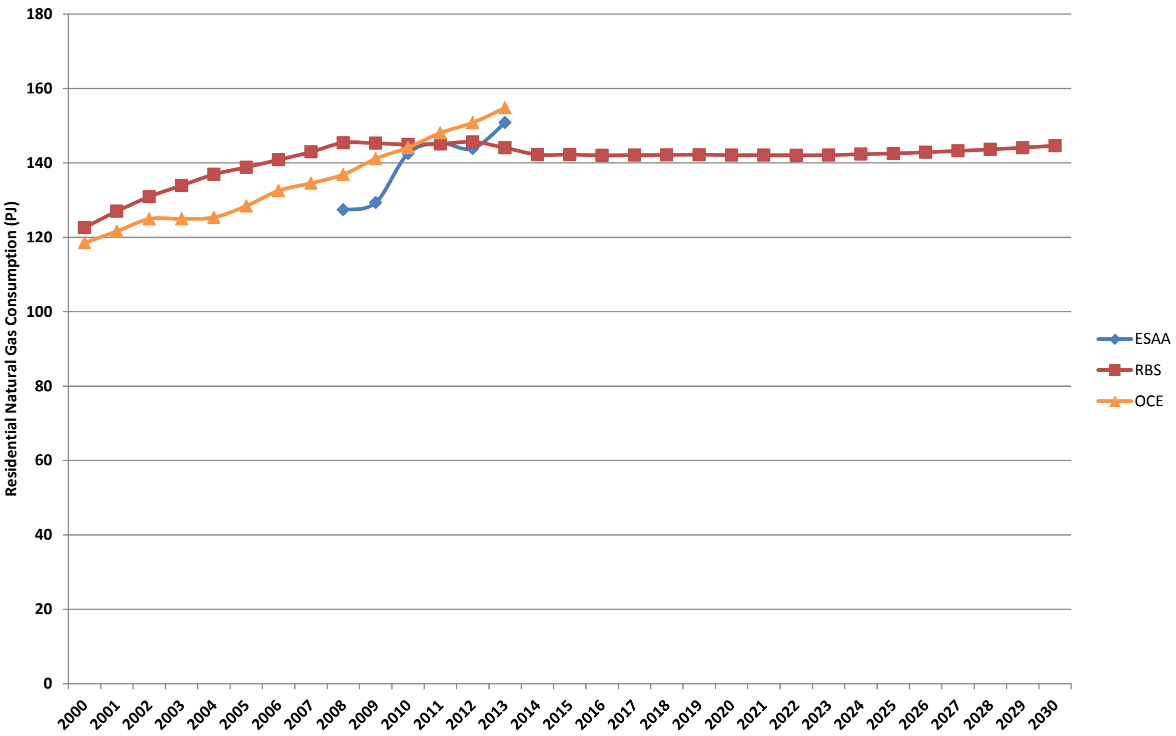
The larger variations for South Australia and Northern Territory, of up to 15%, are harder to understand. However, the RBS results for the Northern Territory were within 7% of the ESAA electricity use estimates, except 2009 where consumption jumped significantly for a single year, but 2009 may be an outlier result due to the very hot summer experienced that year.

The South Australian situation is more complex as its electricity consumption trend deviates from the national electricity consumption trend, for about nine years between 2001 and 2010. Consumption in South Australia declined from 2000 to 2005, while it grew rapidly in this period in all other States. South Australia consumption increased for five years while elsewhere it was flat or declining. There is no apparent reason for this unusual trend, but it is not surprising the RBS modelling was less accurate for South Australia given the energy use behaviour was so unusual over this period. Interestingly, the RBS versus ESAA figures differ by less than 2% for the recent five year period of 2010 to 2014 in South Australia.

Natural Gas Use Comparisons

Obtaining appropriate natural gas consumption figures for comparisons at the national level proved to be difficult. The OCE and the ESAA gas use figures are estimates only, and are not directly based on measurements of residential energy use, so they have limited value for assessing the RBS results. However, a comparison between the OCE, ESAA and the RBS results was undertaken and is shown in Figure 46. This chart shows the RBS results were found to be within a satisfactory 10% of all the OCE estimates, and with 15% of the ESAA estimates. However, the chart also shows neither the ESAA nor OCE estimates recognise the decline in gas consumption that has occurred in the last few years, despite State distributor data clearly showing this trend.

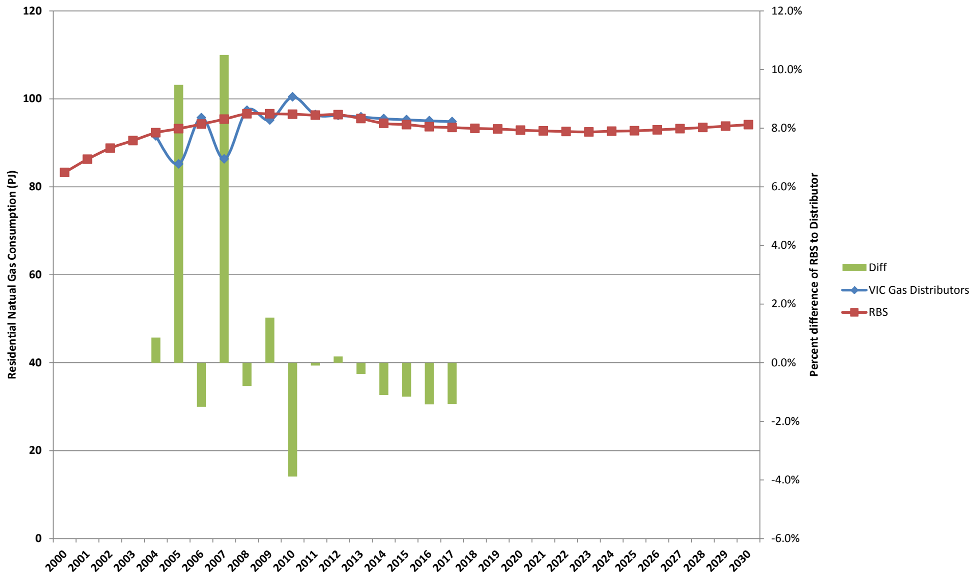
Figure 46: ESAA, OCE and RBS Estimates of Australian Residential Natural Gas Consumption



Given the limitations of the comparisons of the RBS results and estimates of national natural gas usage, comparisons of the RBS results and those of State distributor's figures for residential gas use were undertaken. These should provide a better measure of the accuracy of the RBS as distributor data is based on actual metered consumption data.

A comparison was done for Victoria and showed RBS results being within 10% of the distributors' data. This is a satisfactory result given gas consumption is so strongly influenced by annual weather variations and annual heating degree days, a measure of heating demand, vary by over 10% in Victoria.

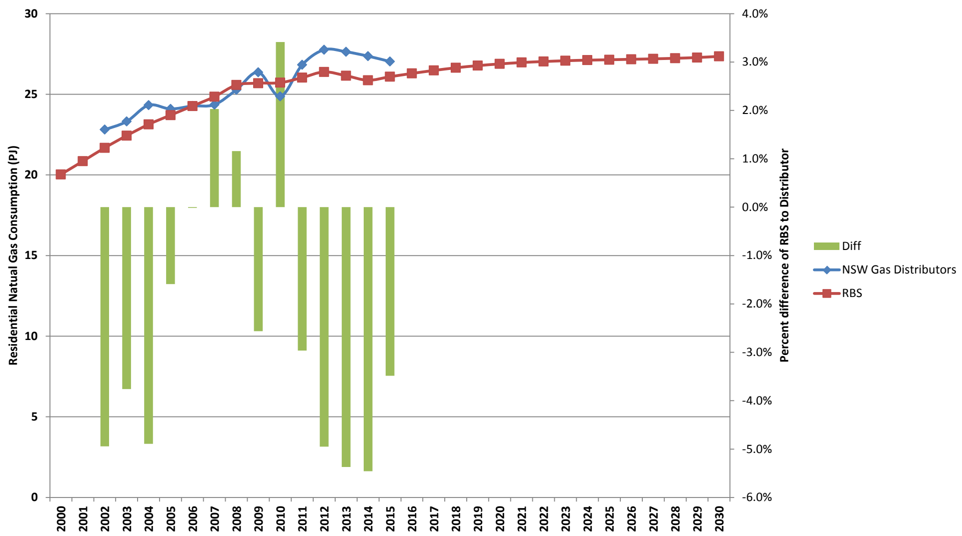
Figure 47: Victorian Distributor and RBS Estimates of Residential Natural Gas Consumption



Note: Using distributors' forecast data from 2011-2017

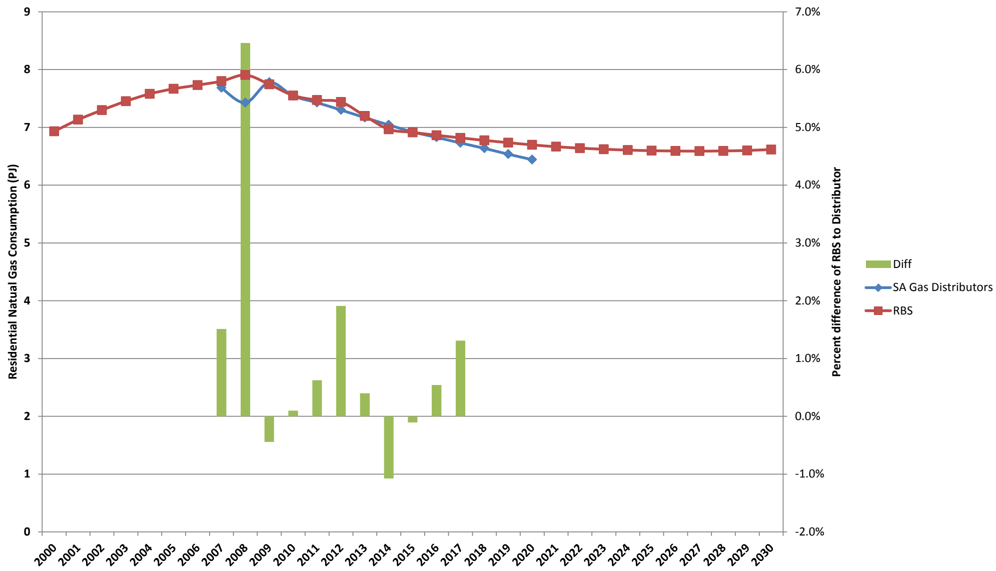
A similar comparison was undertaken for NSW/ACT and SA, and the results below show the maximum difference in the RBS and distributor results of 7% in any given year. Again these are satisfactory results given the impact of annual weather variations on gas consumption.

Figure 48: NSW/ACT Distributor and RBS Estimates of Residential Natural Gas Consumption



Note: Using distributors' forecast data from 2014 to 2015

Figure 49: SA Distributor and RBS Estimates of Residential Natural Gas Consumption



Note: Using distributors' forecast data from 2011 to 2020

6. Data Sources, Input Processing and References

Introduction

Data used as input for the model came from a variety of sources and, though there are some common sources used for most products, such as ABS surveys and industry sales data, there is considerable variation in data sources for many products. Whatever the data source, it is rare that data obtained can be directly used as an input to the model and usually it must be processed in some way so as to become applicable and in the right format to be used.

The nature of this input processing varies with the product and data sources concerned, and with the type of data input required by the model. For example, sales data on non-ducted air conditioners may need to be aggregated across equipment sizes, household numbers may need to be estimated for the years between censuses, or average television size may need to be estimated from data on model registrations in a given year.

This following section provides an overview of the type of processes used for preparing data so it may be entered into the RBS model. Typical data sources and input processing for the following critical inputs to the model are described:

- Sales
- Usage
- Efficiency
- Life
- Standby when relevant.

The data sources for the Building Stock module are also described. This section is then followed by a list of data sources and references used in preparing the RBS. Further details of data sources and input processing are provided in the Technical Appendix.

Data Sources and Input Processing

Sales

Sales data is a key driver of the RBS model as it is used to determine the stock level for each product modelled. The two keys sources of sales data are:

- Market and industry research on sales figures
- Surveys of product penetration/ownership in the general population

Sales were derived principally from a few key suppliers of market research data, including GfK and BIS Shrapnel[21]. Such sales data was then supplemented by sales estimates

[21] These are market research firms that track sales of a wide range of residential products.

reported in a variety of reference sources, including the department's Regulatory Impact Statements (RIS) and Product Profile documents, and also occasionally by interviewing appliance suppliers.

Surveys of product penetration in the general population are an alternative source of data, and generally this penetration information comes from ABS census data and also from a series of ABS energy and environment surveys, including the ABS 4602 Surveys (1999, 2002, 2005, 2008, 2011, 2014). The penetration data is converted to an estimate of the total stock of the relevant product in a series of years by multiplying the penetration of the product by the number of dwellings and products per dwelling in Australia or the State in the relevant years. The sales numbers are then 'backcast' by a program that calculates what sales would be required to produce those stock numbers, allowing for the typical operating life of the product concerned.

Penetration data is also used to develop estimates of stock and ownership levels which are compared to the output of the RBS modelling, when based on sales data, to double check the sales data and model outputs.

Usage

Data on appliance use comes from a variety of sources. Survey data such as the ABS 4602 Surveys (1999-2014) previously mentioned and the ABS Household Energy Consumption survey (HECS, 2013) are a prime source of such data, especially for space conditioning appliances. Data from such sources often provided different usage rates for different States.

Other sources include water usage surveys, for appliances also using water, overseas research, such as a USA DOE study (DOE 2005) on microwaves and the extensive New Zealand study by BRANZ on home energy use (BRANZ, 2006). A range of Department sources were also used, such as RIS and Product Profiles conducted on residential appliances, when these sources contained information on usage.

The usage data collected would usually be presented as daily hours of use, hours used per week or number of loads done per week. In most cases this data would be converted to annual hours of use or number of cycles conducted annually (e.g. for dishwashers).

Usage rates sometimes vary with locality and such variations were included and input into the RBS model where relevant.

Efficiency

The highest quality efficiency data was obtained when sales data for individual product models was available, such as that supplied by GfK, and could be matched with each model's data in the Energy Rating registration database, to produce sales data matched with efficiency data. When this occurred, the resulting matched data was used to determine sales weighted energy consumption averages across each of the relevant products. Such data was generally available when the product was subject to Minimum Energy Performance Standards (MEPS) requirements or mandatory energy labelling requirements. In addition, installation (sales) data from the Clean Energy Regulator on solar water heaters and PV was matched with efficiency data. So this high quality efficiency data was available for air conditioning equipment, most water heaters, white goods, some information and home entertainment products and PV systems.

The main source of efficiency data when sales weighted efficiency was not available was research reports. These included Department sources, such as RIS and Product Profiles conducted on residential appliances. Overseas research was then used for products where Australian data was not available, which was mainly for miscellaneous appliances. In addition, for some products such as resistive electric heaters, data was not required as it is known that these are 100% efficient.

Once efficiency data was obtained on a product it was converted into the appropriate metric to be used in the RBS model and input.

Life

The operating life of products was obtained from a wide variety of sources. Department sources, such as RIS and Product Profiles conducted on residential appliances, were the first source sought and provided information for the majority of appliances. Research papers prepared overseas, such as by the USA Department of Energy, were also used.

Occasionally market research data, concerning purchase intentions or age of products discarded, was found which could be used to determine operating life. Information was obtained for some products from the previous RBS (EES 2008). Occasionally also when no data was available, then estimates of operating life were made based on the life of comparable products and the known stock and estimated sales of products.

Standby

For products subject to MEPS requirements or mandatory energy labelling requirements, standby power data has been collected and is provided in the Energy Rating registration database, if relevant to the product. Such data was available for air conditioning equipment, most water heaters, white goods, some information and home entertainment products and external power supplies.

Another prime source of standby data was the series of residential standby energy surveys conducted by the Department both in stores (E3 2011) and in houses (e.g. EES 2011) and the Standby Power Consultation RIS (EC 2013). Occasionally, when no data was available, estimates of standby power consumption were made based on that of comparable products.

Building Stock Model

The building stock model required different data inputs and calculations. The building stock model was developed in several stages, with the focus of the modelling in each stage being as follows:

- Dwelling stock numbers by state, by dwelling type and by occupancy
- Dwelling construction, as it related to thermal efficiency
- Calculation of average relative thermal efficiency

Dwelling stock numbers, by housing type, were available from the ABS census data, (ABS 1986, 1991, 1996, 2001, 2006 and 2011). The ABS also provide both household projections and population projections for the project projection period 2012 (post the 2011 census) to 2030. Household projections were used for estimating dwelling numbers, allowing for the ratio of households to dwellings.

The key data required on dwelling construction were the penetration of insulation in housing, obtained from the ABS 4206 Environmental Issues surveys, and the annual number of new dwellings by building type per State, which was derived from the dwelling stock numbers.

The relative thermal efficiency of uninsulated and insulated Class 1 dwellings was obtained from EES (2011B), "The Value of Ceiling Insulation: The impact of retrofitting ceiling insulation to Australian homes". For Class 2 dwelling, results from the Burghardt (2008) modelling study were used. For newer, post 2004 dwellings, State regulatory requirements were used to estimate building 'star' ratings, hence their thermal efficiency.

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