Paul Ryan

Residential Energy Productivity: Is 40% improvement possible?

Paul Ryan and Murray Pavia, EnergyConsult Pty Ltd, 655 Jacksons Track, Jindivick, VIC, Australia

Abstract

Energy consumption in the residential sector has been decreasing in Australia since 2009 but the causes of this decline have not been adequately identified. Energy use per household has also been declining at a greater rate, with total energy use per household reducing by 16% over the period 2004 – 2014. A new, comprehensive energy end-use model for Australia and New Zealand has recently be developed and it provided insights into the energy and demand impacts of various appliance programs, and changes to market characteristics, over the last 15 years. It assesses the contribution of solar generation and provides scenario projections of future consumption and demand.

The 2015 Australia Residential Baseline Study (RBS) examines the historical energy end-use trends and makes projections to 2030. Research on the market factors, appliance attributes, building efficiency and use of equipment in the residential sector has provided deep insights into the potential causes of the now declining energy use. The research has utilised up to 20 years of sales matched appliance attribute information (efficiency, size, etc.) of appliances, lighting and building thermal efficiency, to produce a stock and linked energy model of Australia. .

Many of the appliance and equipment used in households have been subject to MEPS and labelling programs, with significant increases in scope and stringency since 2000. These programs are now impacting on the overall energy use in Australia, with dramatic effects that were not considered in earlier forecasts or the planning by energy authorities. We examine the factors contributing to the improvement of energy productivity at the household level, provide projections of the overall energy use per household to 2030, the contribution of solar generation, and potentially what changes might be required to reach a 40% residential productivity goal. BAU projections show an improvement in energy productivity of 20% under BAU (without PV) by 2030 from 2015 base year.

Introduction

Exploring residential energy productivity measures

What is residential energy productivity in the context of the national and business productivity measures? Examples of national and business energy productivity are typically measured in the form of value of output ($) per energy use (GJ) with the national value of output being GDP and the business output being company revenue (A2SE 2015). Although the residential sector does contribute to the use of energy, it is much harder to quantify the value of output, as the residential or household sector is generally a consumer of goods and services, rather than a producer. The national accounts can be used to determine the final consumption expenditure by households and this could be used to provide the value of output numerator in the energy productivity equation. However, this is a perverse measure as it effectively relates increasing consumer expenditure with increasing energy productivity, which does not relate to the productivity of the household sector. The value of output from the household sector could be determined from compensation of employees, but again, many households could be relying on government financial assistance or business profits or investments, which would again not capture the effective contribution of the household sector to the economy.

The most realistic and measurable indicator of residential productivity in relation to the national energy productivity measure is energy use per household. The energy use per household (HH) measure does effectively capture efficiency of energy use, behaviour changes, household energy generation (if appropriate) and is normalised on a per household basis. Another measure could be residential energy use per population. Both these measures can be used to show changes over time and improvements (or reductions in energy/HH) that result from efficiency improvement, renewable energy generation and changes in the usage of energy services in the residential sector. Final energy use (where the energy consumption is related to the actual energy used by the household) is typically used to measure energy use per household. The primary energy use per household would be a more appropriate measure of energy productivity as this would capture the changes in the efficiency of the energy conversion and production processes. However, again it is difficult to attribute the primary energy consumption for electricity used by households (final energy consumption), due to the range of energy generation sources, timing of their output to the grid and demand that is attributed to the residential sector.

Therefore this paper uses final energy consumption per household as the measure of energy productivity in the residential sector, because of the simplicity and data availability, and reliability of the measure over time. It also captures many of the factors that contribute to improvements in national energy productivity, such as efficiency and usage, but does not include the generation of renewable energy by the household. If we subtract PV generation from the final energy consumption, the total energy use per household would be substantially lower, but accounting for the proportion of PV generation used by the household is difficult. The gross PV energy generation is subtracted from the total final household energy use in the following sections to illustrate the impact of distributed generation on energy use per household.

The Federal Government released it Energy White Paper (DoIS 2015) in April 2015 which included a desire to establish a National Energy Productivity Plan. The Energy White Paper states that:

> *"A national improvement target of up to 40 per cent by 2030 is achievable, but will require contributions from a broad range of sectors and actions, both regulated and voluntary"*

The base year for measuring this improvement in energy productivity is critical to the target. The USA is has a target of doubling energy productivity by 2030 from 2010 and the Australian COAG Energy council has supported the recently announced national improvement target of up to 40 per cent between 2015 and 2030 (COAG 2015). To be consistent with the national improvement target, we have chosen 2015 as the base year to measure improvement.

Australian residential energy productivity

The 2015 Australia and New Zealand Residential Baseline Study (RBS) examines the historical energy end use trends up to 2013 and makes projections from 2014 to 2030 (DIS 2015a). This study was funded by the Department of Industry, Innovation and Science on behalf of the Equipment Energy Efficiency Committee (E3). Two similar studies were conducted, in 1999 (AGO 1999) and 2008 (DEWHA 2008). The RBS utilises a 'bottom up' energy end-use model of the residential energy sector, divided into major end-uses (i.e., appliances, hot water, etc.), categories of equipment (i.e., televisions, electric water heaters, etc.) and products (i.e., plasma TV, small water heater, etc.). The recent 2014 update of the RBS expands on earlier studies by including additional products and utilises a slightly different approach to the stock modelling. This 2014 study uses updated information and research derived from several projects undertaken since the 2008 study commenced (the 2008 study used data available up until 2005).

The overall electricity use in the residential sector in Australia (excluding solar electric PV self-consumption) has declined by almost 3% in 2012-13 compared to 2010-11 financial year (BREE 2014). This is the first time in Australia's recent history that electricity use has declined over two subsequent years. There are probably many factors contributing to this decline in overall electricity use, including the improvement in efficiency of appliances, improvements in the thermal efficiency of buildings and fuel switching (including to gas appliances or solar hot water). Decline in usage is also attributed to reductions in the services supplied (such as more efficient shower heads reducing hot water usage and behavioural changes in response to increased electricity prices. When examined on a per household basis, the reduction in electricity use is even more pronounced (see in Figure 5).

In comparison, total gas usage has shown only a small decline in energy consumption over the last five years(DIS 2015a), plus there has not been a substantial upgrade to the standards, labelling or efficiency of gas appliances. Therefore, further analysis of the drives of gas consumption trends will not be undertaken in this paper.

The focus of this paper is on electricity energy use and the drivers of changes in residential consumption of electricity. The paper provides an overview of the methodology, research and data used to develop the RBS and then analyses the BAU trends in consumption for each end use. Several policy scenarios are then explored to investigate the possibility of achieving a 40% reduction in energy use per household.

Methodology and research

Methodology overview

A BAU scenario and increased residential productivity scenarios were explored using the residential energy end-use model developed for the RBS. The underlying methodology 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 individual level and aggregating these consumptions to estimate the total locality or network consumption.

At the heart of this approach is the calculation that for each energy end use:

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

Determining the stock number of energy end-use equipment is undertaken by stock models which are effectively databases that keep a running tally of the number of equipment installed on a year by year basis. The stock in any year will be the sum of all past stock sales, less retirements of equipment.

The next aspect of the energy modelling is determining the value of the Unit Energy Consumption (UEC) for each end-use to be used 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 * Unit Capacity * Unit Efficiency.

The energy use of residential equipment is calculated from these formulae, or from a variation of these formulae for more complex products operating in different modes or different measurement and usage metrics (such as wet appliances where UEC is a function of the usage 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. Although there are several different modes of operation found in appliances these have been condensed to the modes shown in Table 1.

Table 1: Modes of operation used in the RBS

Mode	Description
Operation 1	Main operation mode - heating mode in space conditioning equipment.
Operation 2	Main operation mode - cooling mode in space conditioning equipment
Auxiliary	Auxiliary mode used by some appliances such as energy use by fans in gas heaters
Standby	The modes that are non-operating (standby/off), but consuming power.

Space conditioning energy use requires special attention due to the impact of climate on usage and equipment efficiency, and the interaction of the thermal efficiency of the building shell with the usage of the equipment. There are many methods for estimating space conditioning energy use and demand. Broadly they can be divided into the measurement/metering based approaches (billing, metered data, hours of usage analysis), building thermal modelling, and engineering algorithm approach as identified by Stern (Stern 2013).). In Australia there is insufficient data to use measurement/metering based approaches so a mixed engineering/building thermal modelling, using AccuRate software developed by CSIRO (AccuRate), which has previously been used to predict energy use, is used in this study. The impact of annual variation in climate conditions has not been included in the modelled energy use, as the purpose of the modelling was to examine medium to long term energy use trends rather than to examine annual variations, but climate variation by household location is accounted for in the RBS model as these have an ongoing impact.

A systematic approach to the model development was used to ensure all end-uses were considered and the model was developed by focusing on products in each end use. The end-uses and their categories (where appropriate) are listed as follows:

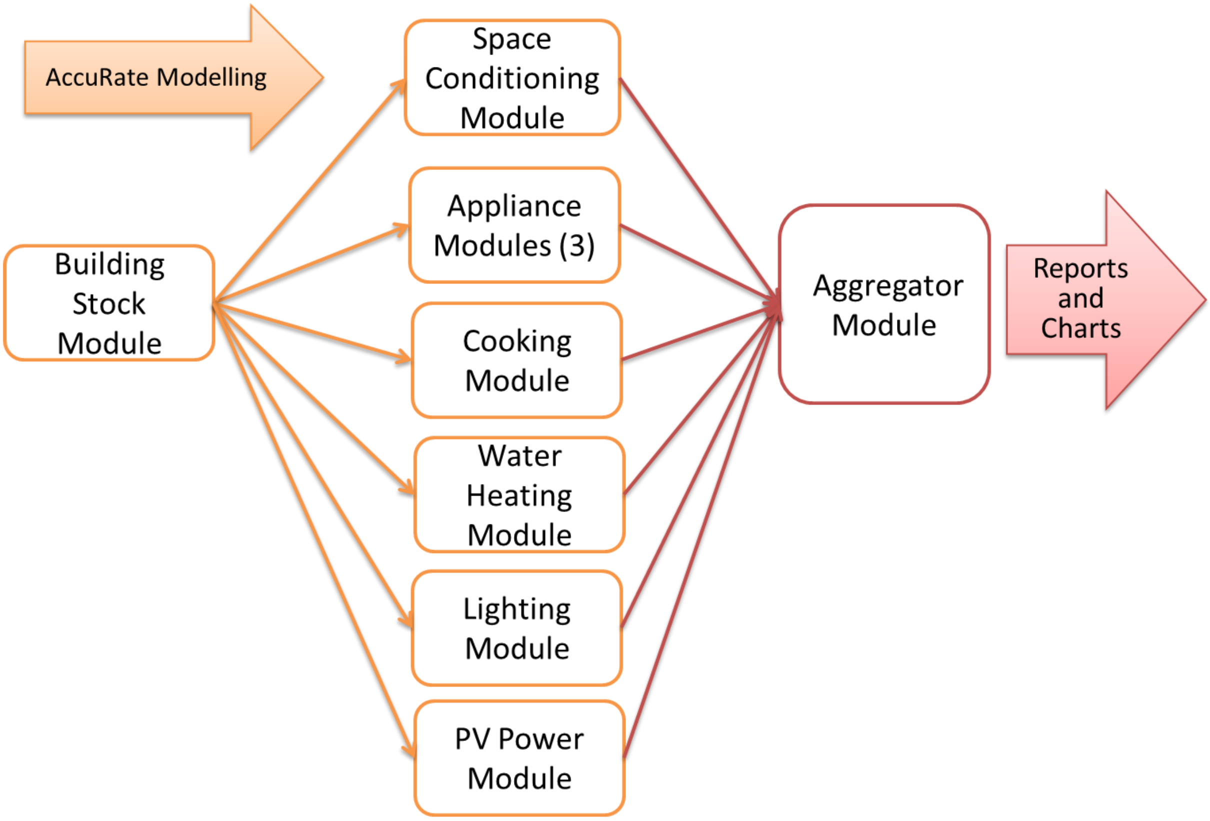
- Water heating
- Space conditioning
- Appliances
    - White Goods
    - IT and Home Entertainment
    - Other Equipment
- Cooking
- Lighting.

Common functions, which will supply data to or accept data in, regarding the products are:

- Building Stock (including thermal demand requirements)
- Energy usage aggregator
- Peak demand calculator (not discussed in this paper)
- User Interfaces for data input/scenario testing.

A schematic of the end-use model is provided in Figure 1.

Figure 1: Schematic of energy end-use model modules and linkages (DIS 2015a)



The end-uses and categories, along with the typical equipment included in the model are shown in Table 2. The model calculates the impact of over 110 separate products.

Table 2: End-uses and categories with examples of typical equipment used in the RBS

End-use & category	Equipment/Products included
Space Conditioning	Air conditioning (heating and cooling), fans, resistive electric heating, gas space heating, wood heaters
Water Heating	Electric and gas storage, gas instantaeous, solar boosted electric and gas, heat pump water heaters
Cooking	Gas and electric cook-tops, oven, microwave oven
Lighting	Incandescent, halogen, LED, CFL
Appliances - White goods	Refrigerators, freezers clothes washers clothes dryers dishwashers
Appliances – IT&HE*	PCs, laptops, network equipment, printers, TVs, game consoles, set top boxes, DVD/BluRay, etc.
Appliances – other equipment	Pool pumps and pool heaters, spas, battery charging systems, other miscellaneous (cleaning appliances, irons, etc.), other misc. standby

BAU scenario and Assumptions for projections

The methodology assumes a BAU scenario based on no additional regulatory or program interventions to improve the efficiency of appliances and equipment will be introduced. The model inputs for the each of the products take into account the current programs that are affecting future energy use (i.e., Minimum Efficiency Performance Standards – MEPS & Energy Rating Labels – ERL) and those that are scheduled to be implemented (where a Decision Regulatory Impact Statement/RIS has been approved by the Government), but assumed no additional new regulation or programs. However, market trends in take up of energy efficiency technologies, such as LED lighting, are considered in the forecasting of product sales and of future changes in product efficiency.

Research and data sources

Usage by households of many products is derived from Australian Bureau of Statistics (ABS) surveys, including a recent survey of 12,000 households in 2012 (ABS 2014). Household projections from the ABS have also been utilised.

The key attributes of the majority of significant equipment installed in households by year, including the average of their size and efficiency, was obtain from analysis of the sales data by model and from MEPS/ERL registration data. Sales of products were estimated from this same data or derived from penetration data, such as that obtained from ABS surveys. Research on the impact of the building thermal performance and the proportion of the building stock with improved thermal performance was also undertaken as part of this study.

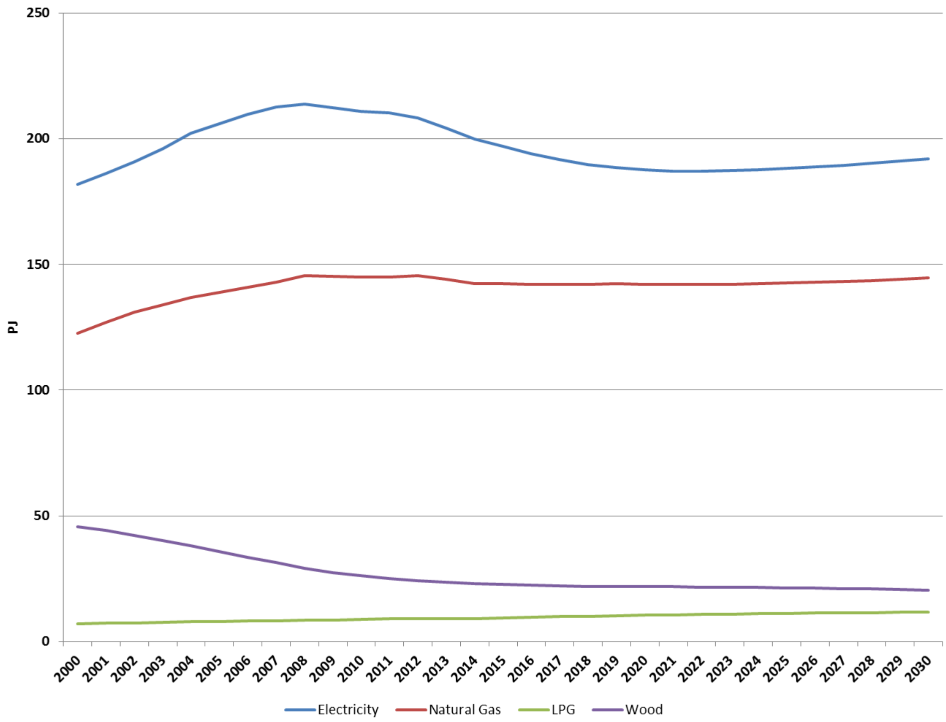
Validation of RBS model

The RBS and ESAA estimates of national residential electricity use were compared for the period 2004-2013, and there was an acceptable difference of less than 5% in the estimates, and for most years a difference of 2% or less was found. For residential gas use over the same period, a maximum difference of 10% was found, which is acceptable considering the RBS model does not account for annual weather variation and the impacts of weather are much greater with natural gas used mostly for heating.

Residential energy use by fuel and end-use 2000 to 2030

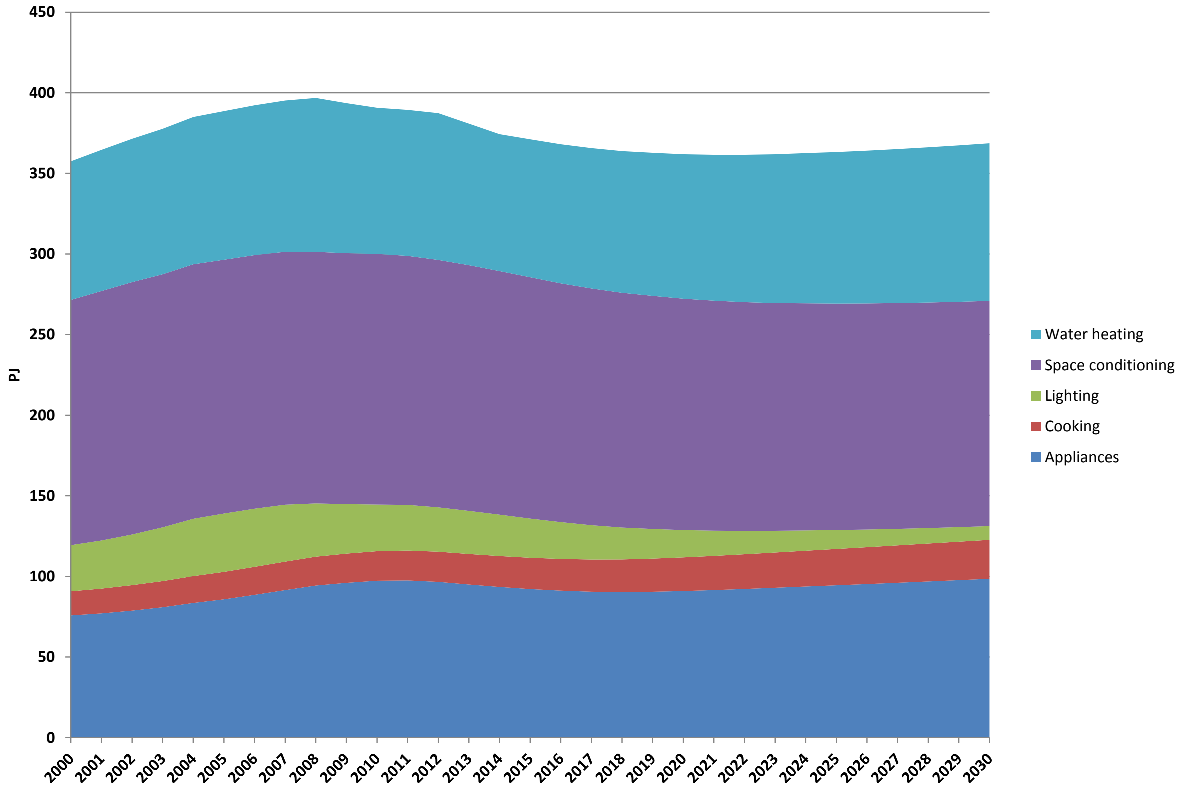
Figure 2 shows the total residential energy consumption by fuel type from 2000 and projected to 2030.

Figure 2: Trend Lines for Residential Consumption by Fuel (DIS 2015a)



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.

Figure 3: Total Residential Consumption by End Use (DIS 2015a)



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%).

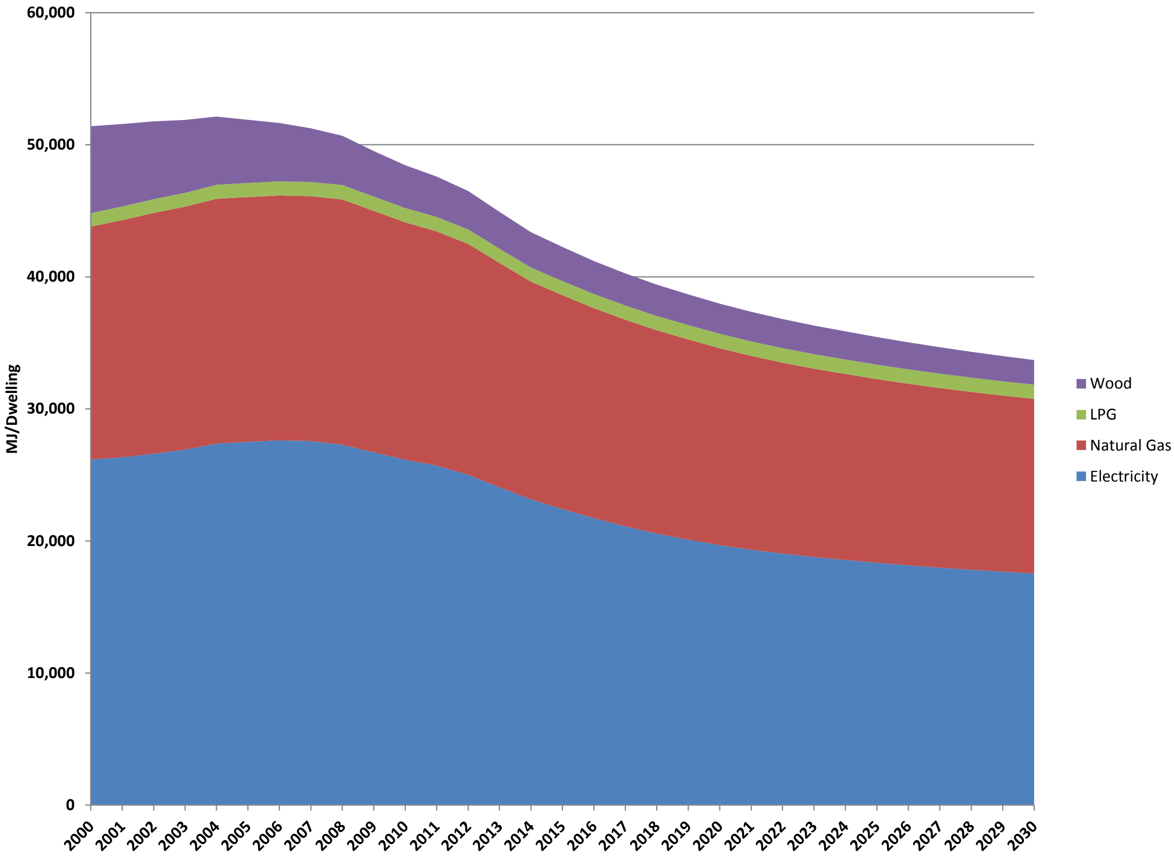
The dominance of space conditioning to energy consumption is again clearly shown in Figure 3, as is the large contributions made by water heating and appliances to total energy use. However, this chart also shows the trend for the energy use of water heating and appliances to make up an increasing proportion 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.

Energy consumption by space conditioning has been in decline since 2004, and is expected to continue to decline throughout the projection period. 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.

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 4 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 4: Total Residential Consumption per Dwelling by Fuel (DIS 2015a)

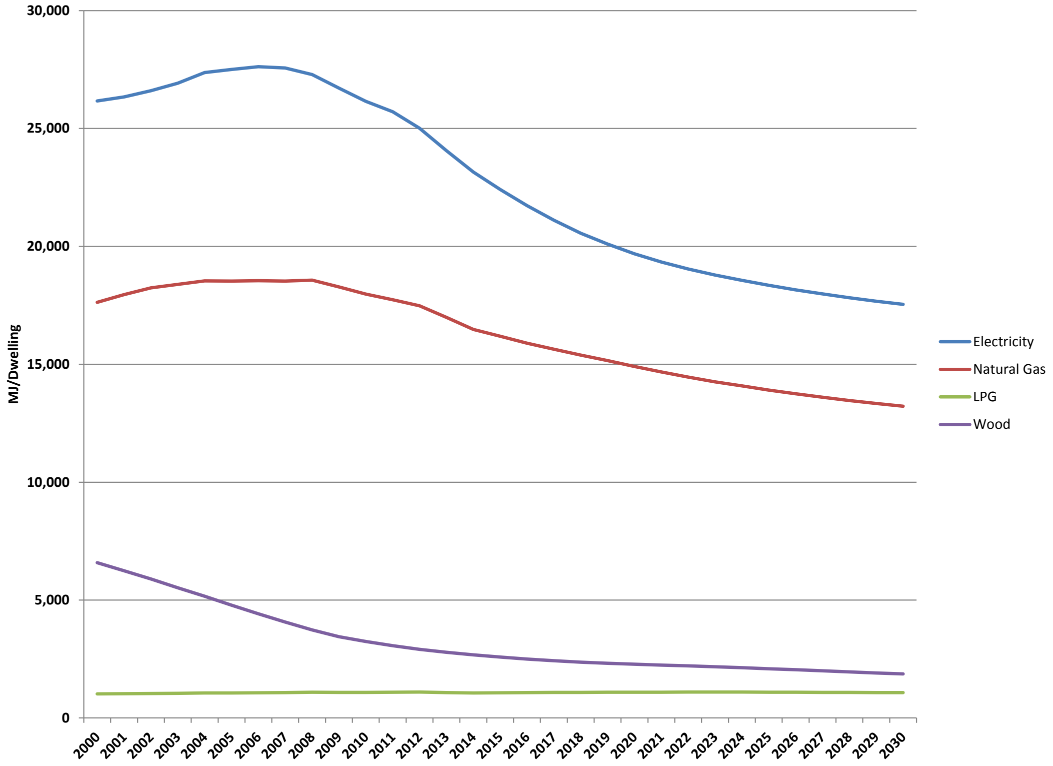


Initially the rate of decline in consumption in the early 2000s was less than the rate that dwelling numbers increased, so total energy consumption increased, but by 2009 the pace of decline in energy consumption per dwelling started to exceed the increase in dwelling numbers, so total consumption began 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.

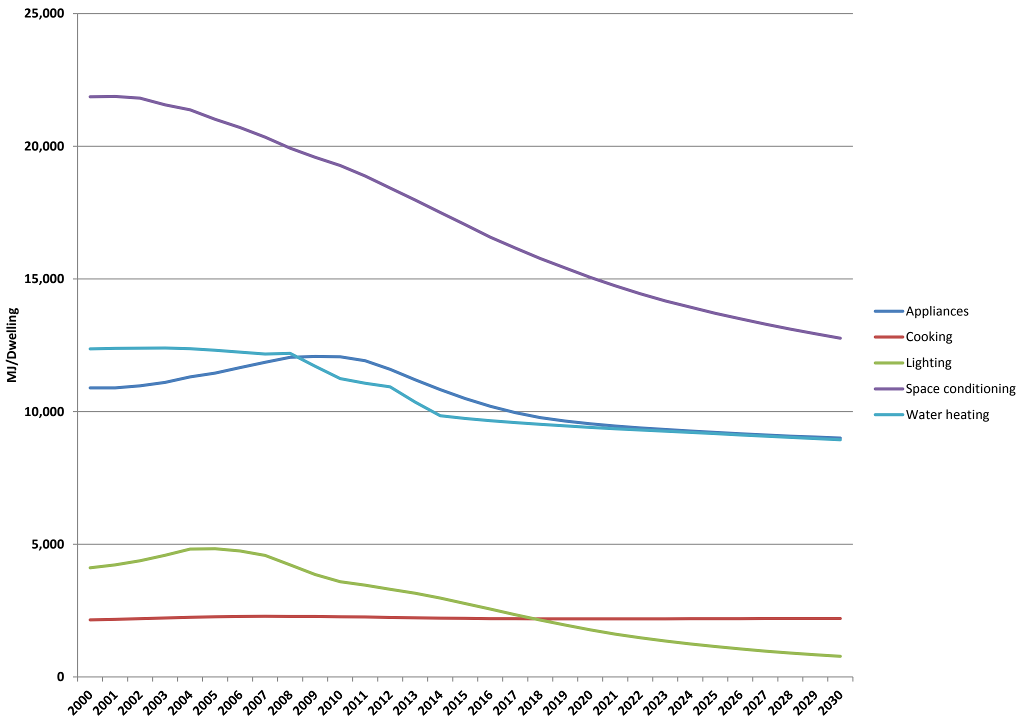
An examination of the trend lines for energy consumption by fuel per dwelling, shown in Figure 5, reveals that the decline in energy use is driven by a decline in the average use of all fuels, except LPG use which remains constant. The decline is most pronounced in electricity, but also strong in natural 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 5: Trend Lines for Total Residential Consumption per Dwelling by Fuel (DIS 2015a)



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 6. 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 paper, but are largely due to appliance efficiency improvements, changes in the technologies being used and fuel switching.

Figure 6: Trend Lines for Total Residential Consumption per Dwelling by End Use (DIS 2015a)



Factors contributing to energy use trends

Space conditioning

Space conditioning electricity use by category displays an overall increase in energy consumption, but is then relatively stable from 2013 to 2030

Space conditioning equipment has shown a rapid increase in energy consumption from 2000 to 2012, which largely reflects the increase in ownership of air conditioners in Australian homes which has increased from 0.52 to 0.94 per household. The main reasons why space conditioning electric energy consumption has not increased further since 2012 are:

- the shift from electric resistive heating to use of reverse cycle air conditioners as heaters,
- an increase in the efficiency of air conditioners, from an average EER of 2.5 to 3.9 by 2013
- the impact of building thermal improvements due to the building code (in 2005 and again in 2010), and the federal governments home insulation program (EES 2011) during 2009-10 that insulated 1.2 million households (15% of total Australian households).

Hot Water

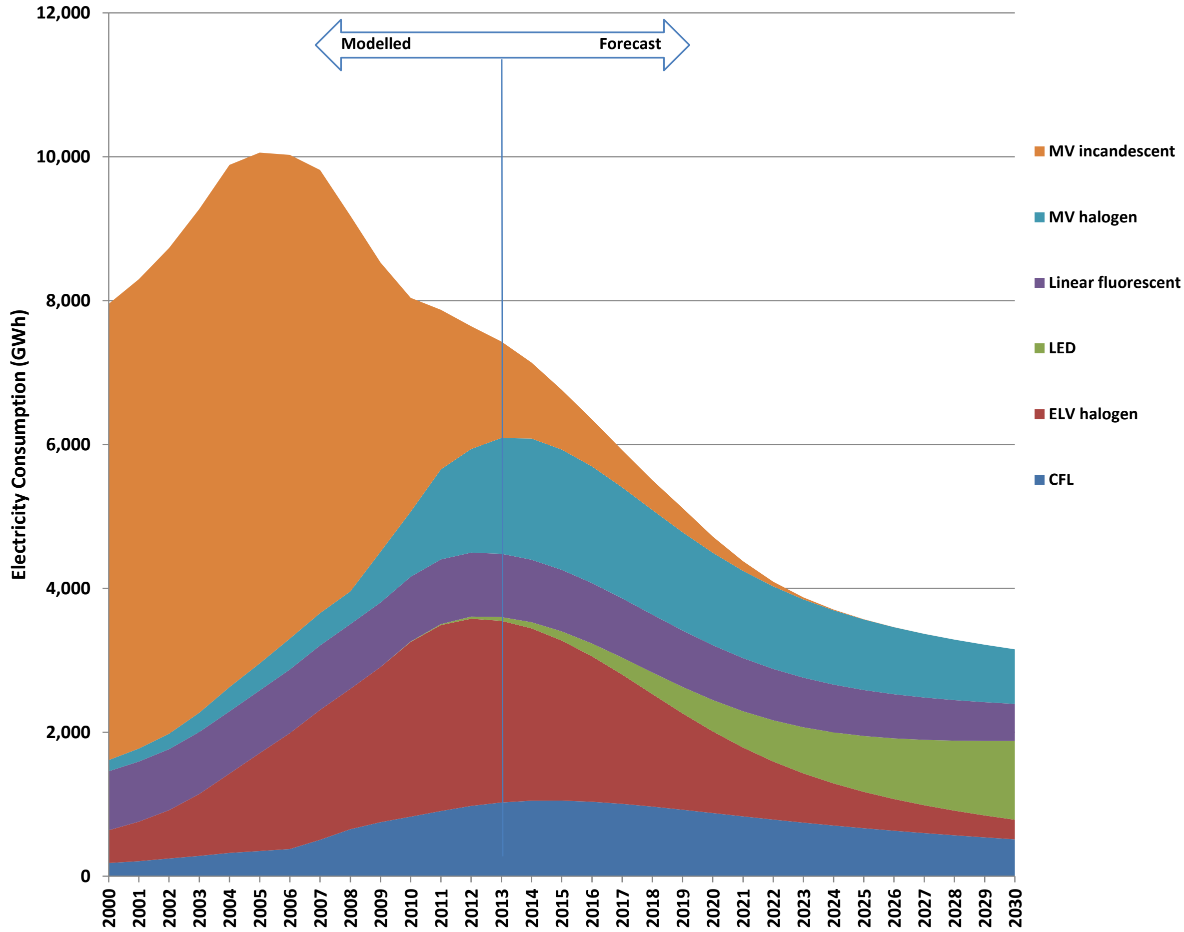
Hot water energy consumption was relatively stable to 2005 and then declined by over 20% to 2013. It is forecast to remain at this level till 2020, and then increase A major factor contributing to the reduction in energy use in hot water, in the second half of the 2000s is the switching by consumers to gas, solar and heat pump water heaters, encouraged by incentives from state and federal governments and regulations that required new homes to install solar and heat pump water heaters. Average ownership of electric water heaters declined from 0.62 in 2000 to 0.46 in 2013. In addition, the introduction of a MEPS that reduced the heat losses from new electric storage water heaters by 30% in 1999, behavioural changes due to an extended drought and rapid take up of water efficient showers have also contributed to significant reductions in energy use per water heater. Research conducted for the RBS, utilising electricity distributor data on off-peak and controlled load water heaters, has found that the a decline in hot water use from water efficiency measures and changes in behaviour has contributed to approx. 10% of the reduction in total hot water electricity consumption in Australia.

The energy use by electric water heaters is forecast to increase slightly, as the fuel switching rate declines and no other MEPS or water efficiency measures are planned to be implemented. The financial incentives for solar and heat pump water heaters have also been significantly reduced resulting in sales reducing to pre-2007 levels. In one Australian state, the requirement to install solar or heat pump water heaters in new dwellings has also been rescinded, and the planned national regulatory measures to phase out electric water heaters have not been implemented.

Lighting

Lighting demonstrates a rapid increase in energy consumption to 2006 and then is forecast to decline by over 60% to 2030, as shown in Figure 7.

Figure 7: Estimated and forecast electricity consumption of lighting end-use in Australia (DIS 2015a)



Lighting energy use increased in the first half of the 2000s due to the increasing number of lights per household, especially of halogen downlights. However the national phase out of incandescent lamps and the state government based white certificate programs caused a market transformation and increased use of more efficient CFLs over the last decade. Now, total energy consumption for lighting is forecast to continue to decline as CFLs and LEDs slowly replace halogen lamps.

Appliances – White goods

White goods electricity use by category shows a slow increase in energy consumption to 2010, then stabilises and is forecast to increase again from 2018 to 2030 Energy use by white goods has been impacted by a number of factors, some causing decreases in energy and others increasing energy use. Refrigerators and freezers have been subject to MEPS (1999 and 2005) and energy labelling (since 1986, with updated scales in 2000 and 2010). The overall energy use of new refrigerators has declined by over 35% from 1996 to 2005, which has had a significant impact on the total refrigerator energy use, although ownership has increased to almost 1.4 refrigerators per household by 2010. The combined impact of these two factors means that energy use by refrigerators has increased by 7% from 2000 to 2010. Further MEPS are planned; however details are not yet published. The other major factor contributing to the increase in energy use by white goods is the shift from top loading to front loading clothes washers, which uses more energy as they generally heat water to a minimum temperature to enhance washing performance while lowering total water use. Clothes washer energy use has increased by a factor of three from 2000 to 2014. Forecast energy use by white goods shows an increase in energy use over the period 2020 to 2030, as current impacts of MEPS diminish and total energy use increases with the projected increase in the number of households.

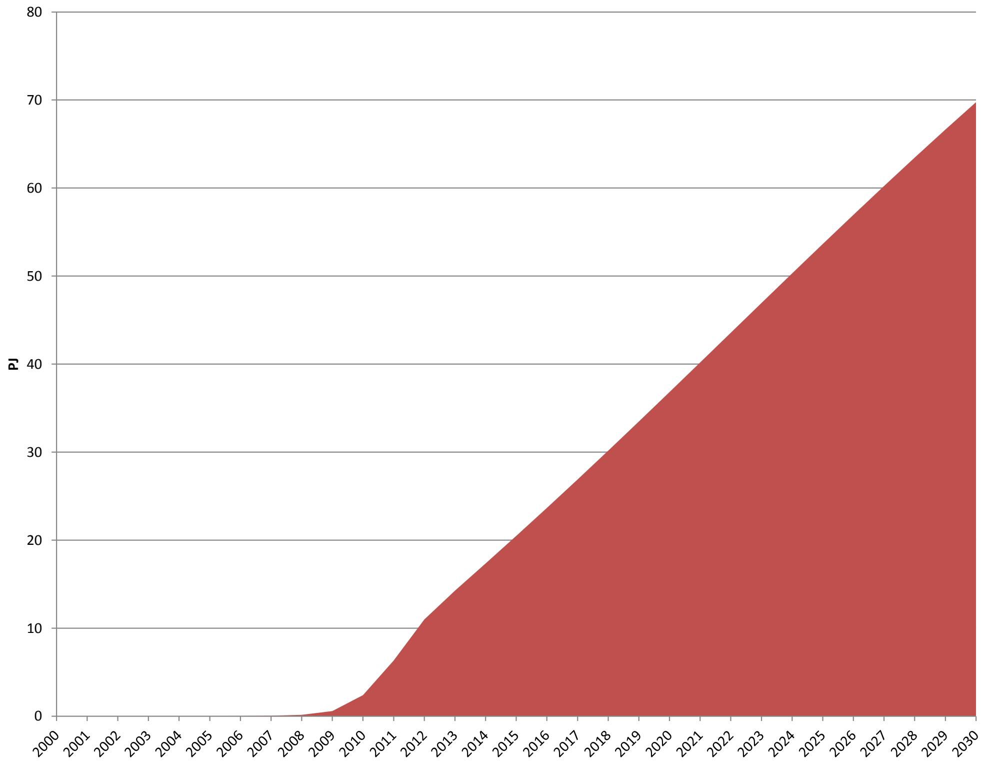
Appliances – IT&HE

The total energy use of Information Technology & Home Entertainment (IT&HE) increased by almost 100% from 2000 to 2010. It is then forecast to decline to 2020 and a slow increase to 2030 The main factor contributing to the rapid increase in IT&HE energy use to 2011 was from the increase in TV ownership (from 1.7 in 200 to 2.2 in 2011) and purchase of larger flat screen TVs. At the same time, energy use of new TVs increased by over 50% from 2000 to 2008. However, due to the technological improvements in the efficiency of new TVs and the introduction of MEPS and labelling in Australia in 2009, the energy use per new TV has now declined to levels below those of the old screen technology used in the last century. Ownership of TVs has also declined to less than 2 per household in 2014 and is forecast to decline further with the change to portable devices for viewing of video by consumers. The forecast increase in energy consumption by TVs from 2020 is due to the increase in average size and number of higher energy consuming TVs, such as ultra-high definition. Another factor reducing energy use is the increased use of laptop/notebook PCs and tablets which has led to the decline in total energy use by all computers in households. Network devices (which are always connected and using power) are forecast to further increase their share of total IT&HE energy consumption as their numbers increase.

Distributed electricity generation in the residential sector

Photovoltaics (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 in the RBS indicate PV generation capacity will grow to over 14,000 MW by 2030. Figure 8 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.

Figure 8: National PV: Gross Annual Energy Output (DIS 2015a)



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. 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.

Scenarios of residential energy use to achieve a 40% increase in energy productivity

If we interpret the national improvement target of a 40% increase in energy productivity as a 40% decrease in energy use per household by 2030, it will be a substantial task. Some of the options available to policy makers that would contribute to achieving this goal are regulatory actions (MEPS and building codes), incentives (such as state based Energy Saving Schemes) and information programs (Energy Rating Labels, Endorsement labels).

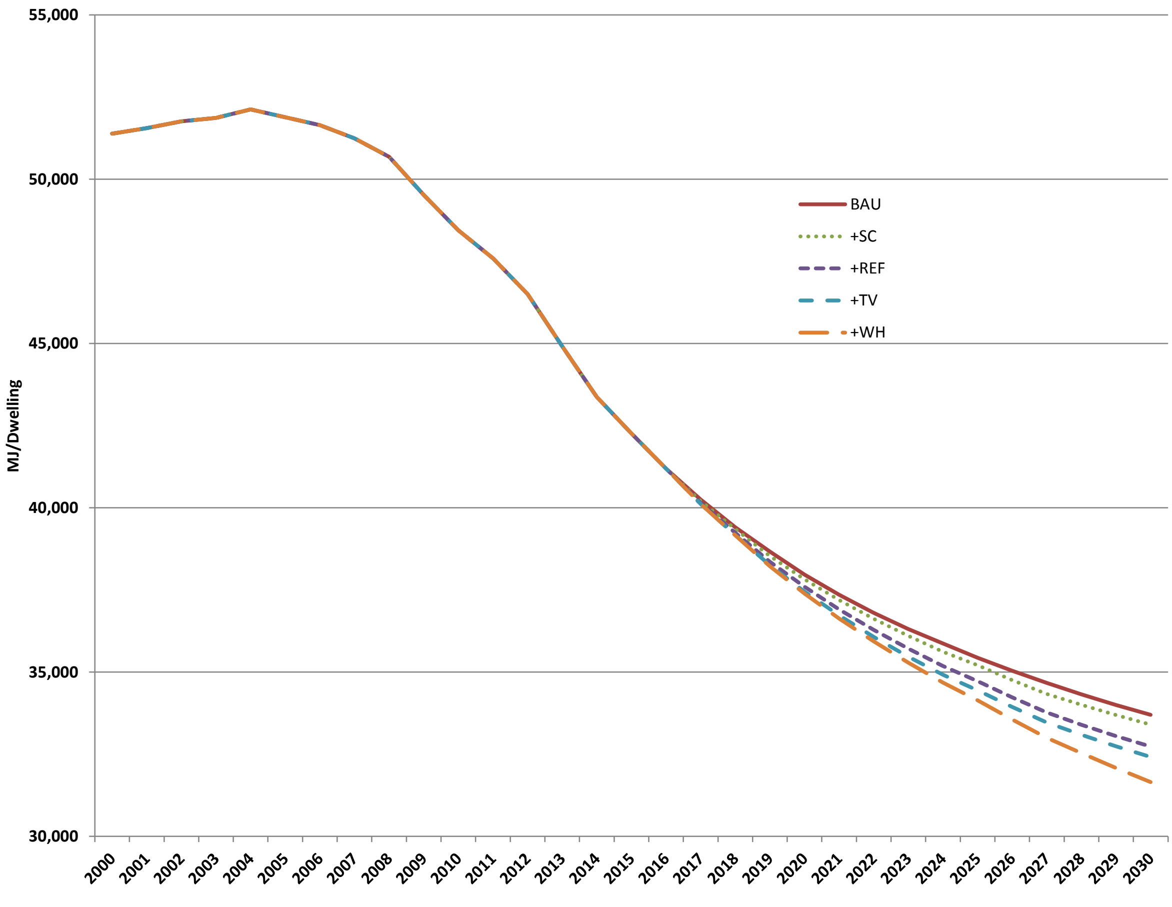
If we consider that under BAU, energy use per household is projected to decrease by 20% by 2030 compared to 2015, another 20% would be required.

To illustrate the potential of regulatory measures (such as MEPS) on top of the BAU improvement of 20%, a number of potential options are explored. These are:

- Space Conditioning – Increase the thermal efficiency of new buildings by increasing the national building code energy performance requirements to 7 stars in 2017 (Shown as +SC in the following figures
- Refrigeration – increase the MEPS for new domestic refrigerators and freezers that is equivalent to a 30% efficiency improvement (similar to the USA standards) in 2017 (+REF)
- TVs – increase the MEPS for new TVs to be equivalent to a 30% efficiency improvement above BAU (similar to the USA Energy Star Specifications) in 2017 (+TV)
- Water heaters – phase out the installation of new medium and large electric storage water heaters in Australian households, beginning in 2017. This would increase sales of solar electric, heat pump, solar gas and gas instantaneous water heaters, while it is assumed that sales of electric storage water heaters would reduce by 80% (+WH)

The impact of these policy options were modelled and compared to the BAU, and are illustrated to cumulatively reduce the energy use per household in Figure 9. The total contribution of these measures is a reduction of 2 GJ per household by 2030 bringing the total reduction in energy use per household from 2015 to 2030 to 25%. The largest contribution is from water heater measures, followed by refrigerators/freezers, TVs and finally space conditioning. The low impact of the increase in building performance to 7 stars is a result of the smaller impact increases in the star rating have on the building stock considering 6 stars is already modelled in the BAU, and the proportion of new housing of the building stock. Also, the model does not account for the impact on renovations and additions to existing houses. Of course measures targeting the existing building stock would have greater impacts in the short term.

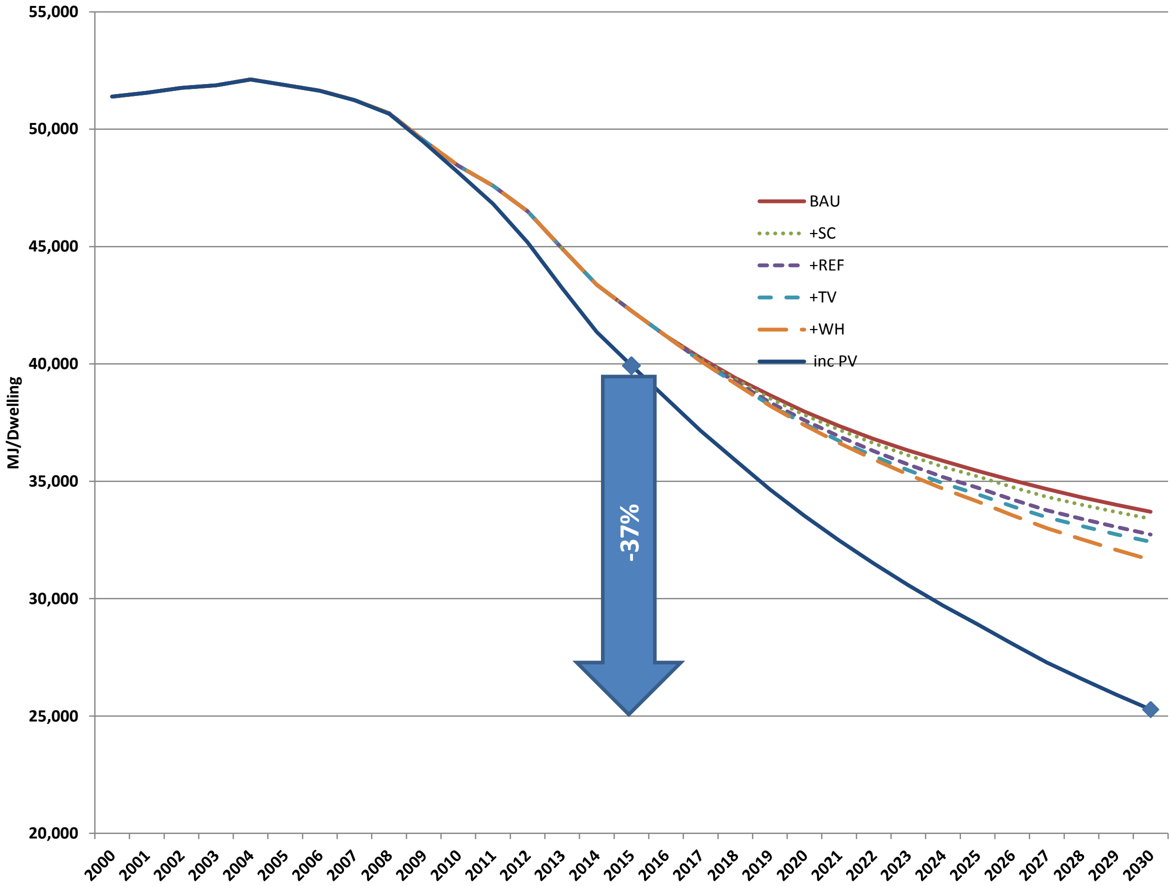
Figure 9: Cumulative impact of various policy measures on energy use per household



Subtracting gross solar (PV) generation from the final energy use by households in both the BAU and the above scenario, the energy use per household would reduce by 37% from 2015 to 2030, as shown in Figure 10. As the PV generation is included in both the BAU and the scenario, the reduction in energy use per household is based on the net average energy use per household of 40 GJ pa in 2015 to 25.3 GJ pa in 2030.

Therefore, with concerted government action, such as increasing the stringency of MEPS programs and building efficiency requirements, the goal of a 40% reduction in household energy use is achievable if measured as final net energy use by Australian households (by including the solar energy generation).

Figure 10: Cumulative impact of various policy measures on energy use per household including gross solar generation



Conclusions

Residential energy use in Australia increased during the 2000s but has declined in recent years since 2008. Average energy use per dwelling has being falling since 2004 and the energy productivity of the average dwelling is expected to continue to improve to 2030, based on projected trends. The modelling reported in this paper explains the major factors contributing to the changes in energy use in the residential sector and explores the impacts of these trends on forecast energy use. There have been dramatic declines in the last five years in the energy consumption in some end-uses, such as hot water, IT&HE and lighting, but these have been masked by the increase in energy use of space conditioning and white goods. With continued changes in types of equipment installed in households, and the improvements in efficiency being realised in the stock of equipment, total energy use is now declining and forecast to continue to decline till 2020. With increasing population and hence households, total energy consumption is then forecast to increase from 2020.

The efficiency measures introduced by governments during the period 1999 to 2012 have contributed significantly to the decline in total residential energy use seen in the last few years. The largest regulatory impacts have been from MEPS for heat losses of electric storage hot water heaters, MEPS for lighting, and

MEPS and Labelling for TVs, refrigerators/freezer and air conditioners. Significant impacts have also occurred due to state and federal government programs that encouraged the installation of efficient showers, solar/heat pump water heaters and efficient lighting.

Energy productivity in the residential sector is defined in this paper as energy use per household. The total contribution of the measures modelled for this paper is a reduction of 2 GJ per household by 2030 bringing the total reduction in energy use per household from 2015 to 2030 to 25%. If solar energy generation is included in the total net final energy consumption by households, a 37% reduction is found. This would come close to the national productivity improvement of 40%.

However, the energy use forecast also shows that without further regulated improvements in the efficiency of electric water heaters, refrigeration and TVs in Australia, there is likely to be increasing energy use over the period 2020 to 2030. The continual refreshment of MEPS and energy labelling programs will be essential to the achievement of the national energy productivity goal in the residential sector. Also, contributions by state based energy saving schemes and other market incentives will be required to ensure that the residential sector effectively contributes to national energy productivity.

References

A2SE 2015, *Unlocking Australia's energy productivity potential*, Australian Alliance to Save Energy, 2015

ABS 2014, *Household Energy Consumption Survey (HECS)*, Australian Bureau of Statistics, published as 4670.0 Household Energy Consumption Survey, 2013, Australia. Available from www.abs.gov.au

AccuRate software available from Hearne Software, www.hearne.software/Software/AccuRate-Sustainability/Editions

AGO 1999, *Australian Residential Building Sector Greenhouse Gas Emissions 1990–2010*, Australian Greenhouse Office, Canberra, Australia, 1999, Prepared by Energy Efficient Strategies Available from www.energyrating.gov.au

BREE 2014, *Australian Energy Statistics*, Bureau of Resources and Energy Economics, Canberra, Australia, 2014, Available from www.industry.gov.au

COAG 2015, *COAG Energy Council Statement Perth – 23 July 2015*, COAG Energy Council Secretariat Canberra, Australia, July 2015

DEWHA 2008, *Energy Use in the Australian Residential Sector 1986–2020*, Canberra, Australia 2008, Department of the Environment, Water, Heritage and the Arts Prepared by Energy Efficient Strategies Available from www.energyrating.gov.au

DIS 2015a, *Residential Energy Baseline Study: Australia*, Department of the Industry and Science, Canberra, Australia, August 2015, Prepared by EnergyConsult Available from www.energyrating.gov.au

DIS 2015b, *2015 Energy White Paper*, Department of Industry and Science, Commonwealth of Australia, April 2015

EES 2011, *The Value of Ceiling Insulation - Impacts Of Retrofitting Ceiling Insulation To Residential Dwellings In Australia*, Energy Efficient Strategies for the Insulation Council of Australian and New Zealand, 2011. Available from www.icanz.org.au

Stern 2013, *Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocols*, The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, US National Renewable Energy Laboratory, Frank Stern, Navigant Consulting, Subcontract Report NREL/SR-7A30-53827, April 2013.

Yuning Ou 2012, *Proposing a Bottom-up End-use Energy Model for Chinese Residential Sector at City-Level*, November 2012. Presented at PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture Lima, Perú 7-9 November 2012