The effect of building age on yearly energy consumption

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1 Introduction

In this brief report, we examine in further detail the building age effect identified in the report by Goldsworthy et al. (2017). The report noted that for the analysis of three years (2010–2012) of annual household residential electrical energy consumption across Australia (except for the Northern Territory), the variables listed in Table 1 significantly explained some of the variation in average household yearly energy consumption for SA2 regions. Further information about these variables and the linear mixed-effects analysis undertaken can be found in Goldsworthy et al. (2017).

Table 1 Variables that significantly explain variation in annual average household energy consumption

Variable	Description or comment
Building age	Represents proportion of buildings built at different times
Wall type	Represents different materials used for residential buildings
Roof type	Represents different materials used for residential buildings
Building type floor area	Represents floor area of different building types
Equivalised income	An income variable defined by the Australia Bureau of Statistics
Tenure type	Represents the proportion of different tenure types for residential properties
Cooling degree days	Cooling days are calculated from meteorological readings from local weather stations
Climate zone	The seven climate zones are: • high humid summer, warm winter • warm humid summer, mild winter • hot dry summer, warm winter • hot dry summer, cool winter • warm temperate • mild temperate • cool temperate
Interaction between cooling degree days and climate zone	Cooling degree days × Climate zone

In this report, we examine the effect of three building age categories (built before 1982, built from 1982 to 1996, and built after 1996) while accounting for all the other variables in Table 1. In the next section, we present the results of the analysis. The report concludes with a brief discussion.

2 Results

We conducted a preliminary analysis of a linear mixed-effects model using two age categories of *built before 1992*, and *built from 1992*. The analysis revealed that building age effect did not significantly explain the variation in the household average yearly electrical energy consumption for the SA2 regions. However, using the three building age categories of *built before 1982*, *from 1982 to 1996*, and *after 1996* – and combining this with the other variables listed in Table 1 – revealed a significant building age effect for explaining household average yearly energy consumption for the SA2 regions[1]. Hence, we used these three building age categories in further analysis.

Figure 1 and Figure 2 illustrate ternary diagrams showing the effect of the building age composition variables with the three building age categories. The plot in Figure 2 is the same as in Figure 1, but is scaled so that the 95% confidence region for the building age effect parameters is more easily seen. In these figures, the intersection of the two green dashed lines represents the neutral point where building age had no significant effect on average yearly household energy consumption. If the red 95% confidence region for the building age effect parameters does not include this intersection point (as is the case here), then it suggests that building age significantly explains some of the variation in the yearly household energy consumption data. The red 95% confidence region does not cross either the green vertical or horizontal lines, and is closest to the *1982 to 1996* building age category. This implies that, everything else being equal, buildings built in that category have, on average, significantly higher household average annual energy consumption than the buildings built during the other two categories. The difference between the other two categories was only marginally statistically significant, with residential buildings *built before 1982* having lower average yearly household energy consumption.

[1] It is unclear exactly why this is the case, but one possibility is that the residences built before 1992 are highly heterogeneous, which masked any building age effects. Some of these heterogeneous effects would have been accounted for in the modelling by including the variables listed in Table 1, but others are likely not captured by these variables, or otherwise not measured. For example, no variables capturing behaviour are included. Also, it is difficult to capture the effect smaller, older residences have on restricting the purchase and or use of high-energy-consuming devices, such as large-screen televisions.

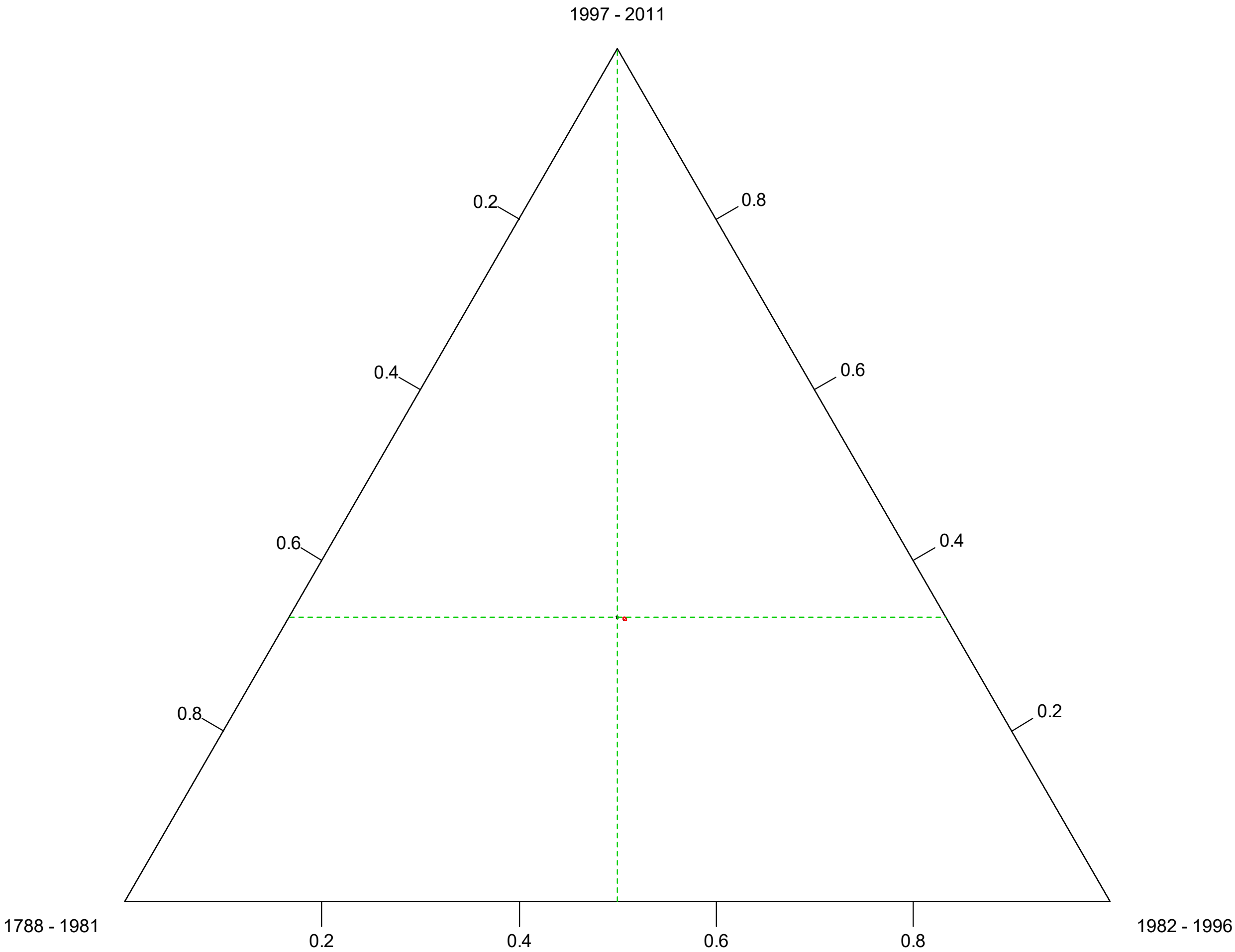

Figure 1 Ternary diagram for the three building age linear regression coefficients and their 95% confidence region (in red)

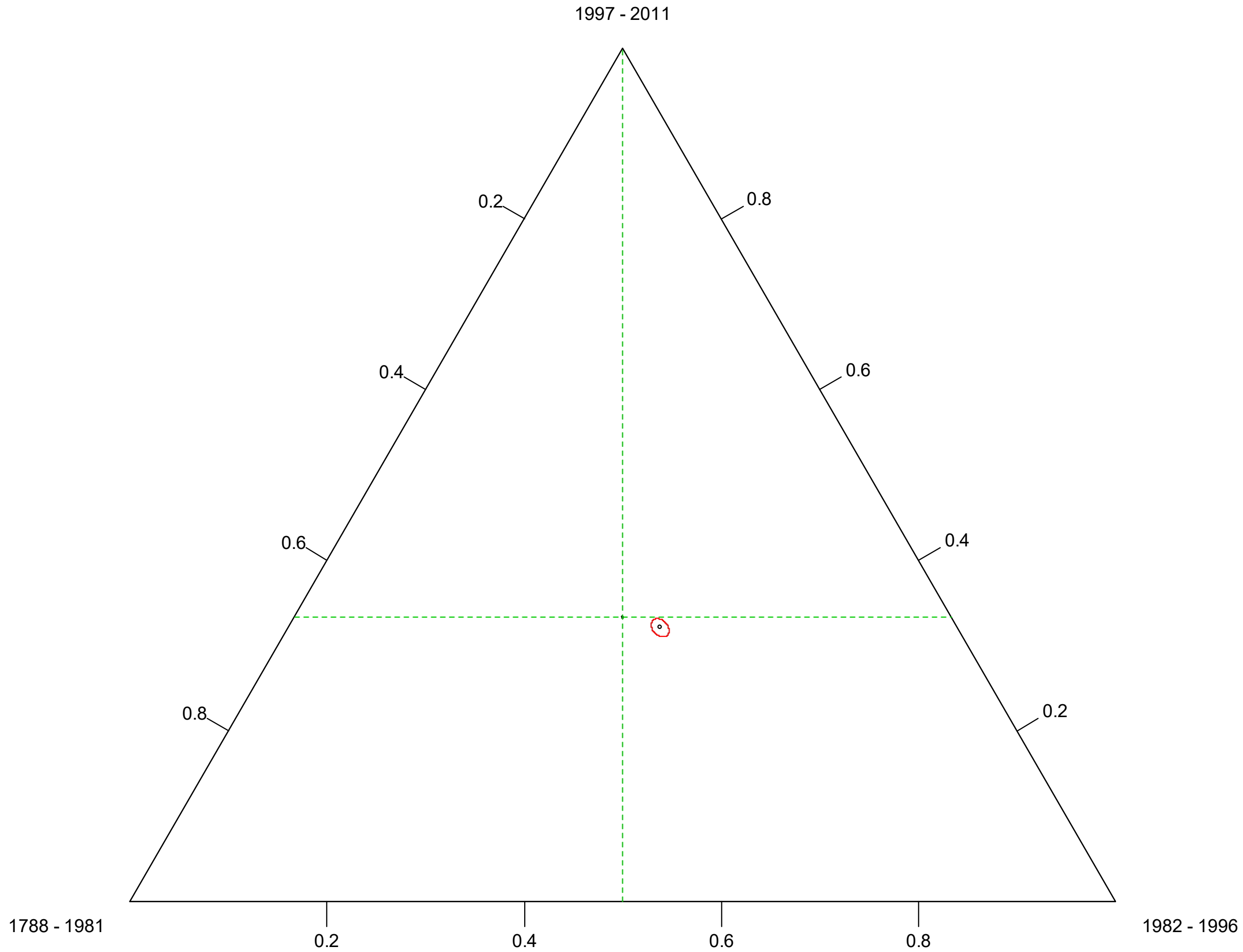

Figure 2 Ternary diagram for the three building age linear regression coefficients, scaled to make the 95% confidence region for the parameters (in red) more prominent

To better see how building age can affect energy consumption, we examined the average yearly household energy consumption for zone substations under two models:

- a *fitted* model, which *includes* the effect of building age
- a *neutral* model, in which there is *no* effect of building age.

Figure 3 shows the ratio of residential energy consumption estimated by the fitted model versus the neutral model for SA2 regions with different building age characteristics. This figure reveals that as the proportion of residences built *before 1981* increased within an SA2 region, the ratio of the fitted and neutral average yearly household energy consumption reduced from approximately 1.04 to 0.95. This suggests that as proportionately more residences in an SA2 region were built in this period, the *lower* the average household energy consumption level became (relative to the case where no age effect is considered).

The opposite is the case for the category of *1982 to 1996*. For this period, the ratio values suggest that as proportionately more residences in an SA2 region were built, the fitted model (with significant building age effect) estimated increasingly *higher* yearly residential energy consumption than the neutral case, in which there was no building age effect.

For the period *1997 to 2011*, there was no marked change, irrespective of the proportion of these buildings seen in the SA2 area: all values were close to 1.

The actual differences between the estimated average yearly household energy consumption values of the fitted and neutral models could be as great as 380 kWh for the SA2 regions in which the proportion of residential buildings built between *1982 to 1996* was at least 80%.

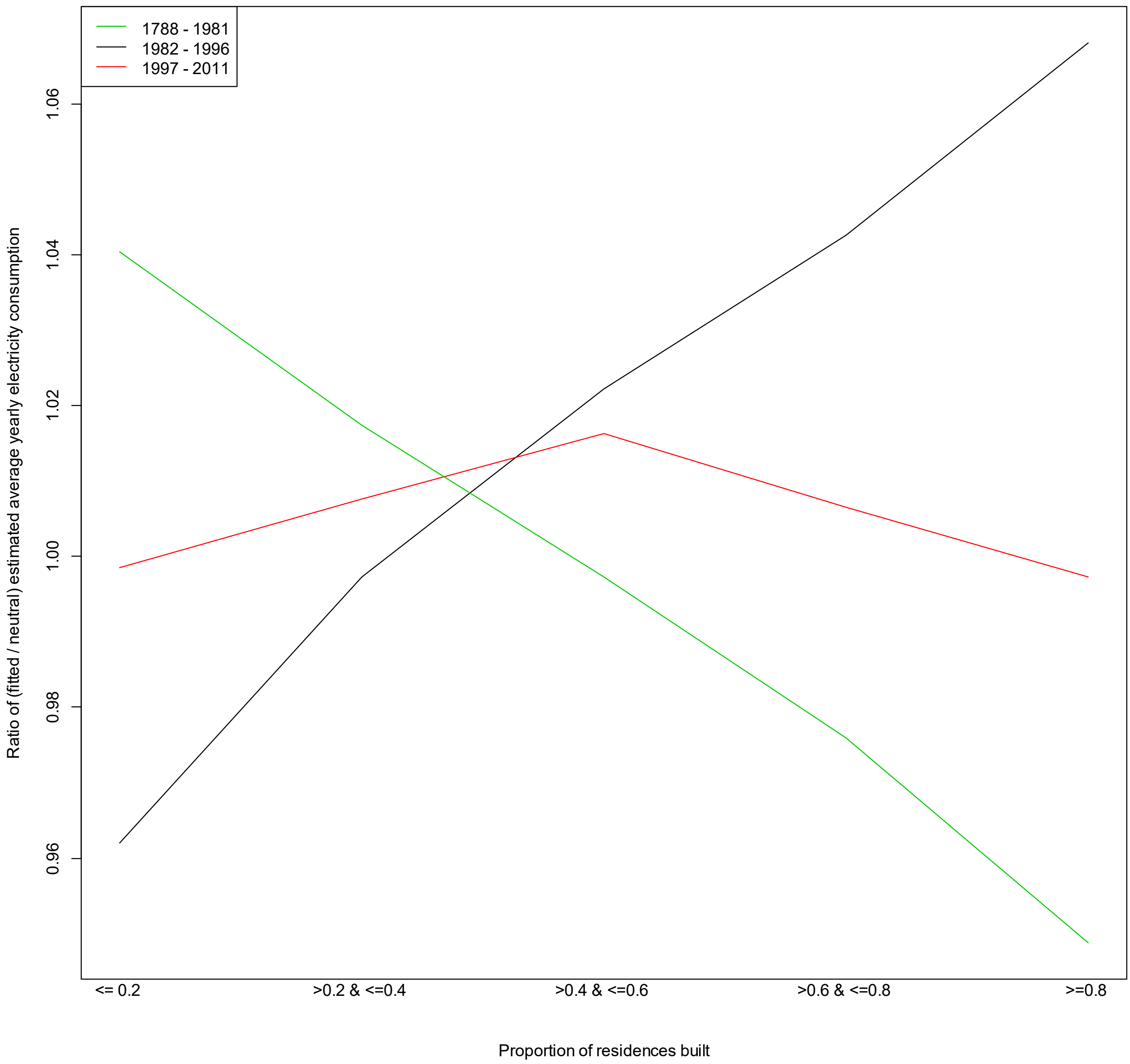

Figure 3 Ratio of the fitted and neutral model estimated average yearly household energy consumption for three building age categories

Figure 4, Figure 5 and Figure **6** show the ratio of the estimated fitted and neutral household consumption values broken down by state for the periods of *before 1981*, *1982 to 1996* and *1997 to 2001*, respectively.

From Figure 4, it is clear that the general trend is similar across the six states: the higher the proportion of buildings built *before 1981*, the *lower* the energy consumption (relative to the neutral case).

In Figure 5, another general trend across states emerges: the higher the proportion of buildings built between *1982 and 1996*, the *higher* the energy consumption (relative to the neutral case). Note that the values that appear to be outliers in the trend are based on fewer than 25 SA2 regions.

As can be seen from Figure **6**, the major differences between the states were for residential buildings built from *1997 to 2011*. Focusing on the lower penetration levels (where 40% or less of the residential buildings were built between 1997 and 2011), there is a sharp difference between New South Wales (NSW) and Victoria, in particular, with NSW having higher energy consumption than the neutral case and Victoria having lower energy consumption.

To obtain a better understanding of what is contributing to the state-level differences identified in Figure **6**, Figure 7 shows the average proportion of residential buildings built in each state from *before 1981* and from *1982 to 1996* for different penetration levels of buildings built from *1997 to 2011*. From this figure it is evident that NSW has a different building makeup from the other states, particularly for those SA2 regions in which the proportion of residential buildings built from *1997 to 2011* is 40% or lower. For example, in these SA2 regions, the proportion of residential buildings built from *before 1981* was markedly *lower* than for the corresponding SA2 regions in the other states, while the proportion of residential buildings built from *1982 to 1996* was *higher*. Unlike other states, NSW's SA2 regions that have a relatively *small* proportion of buildings built from *1997 to 2001* have a *high* proportion of buildings built from *1982 to 1996*. In this report, buildings from the latter category have been shown to consume *more* energy than the younger buildings.

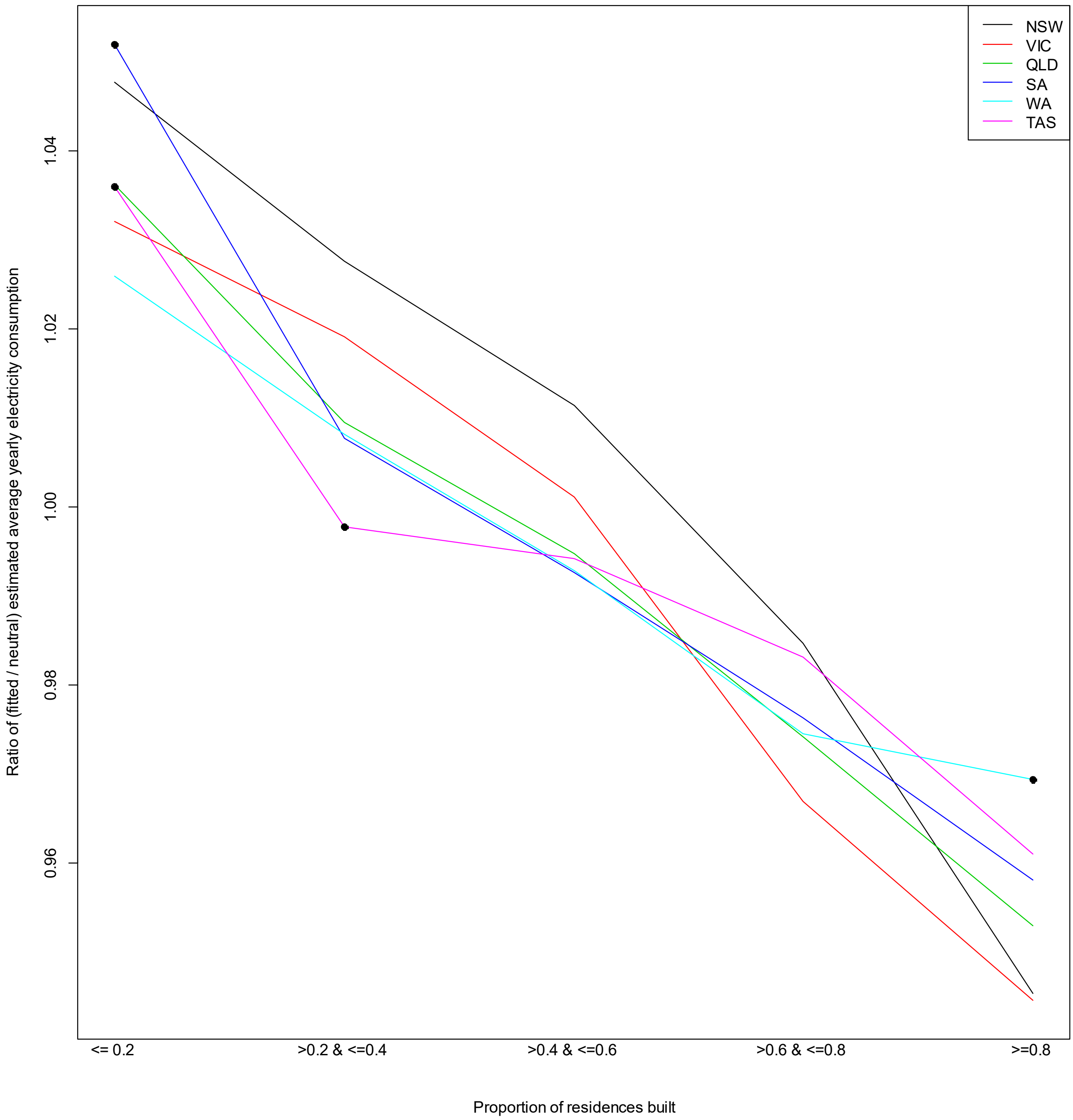

Figure 4 Ratio of the fitted and neutral model estimated household average yearly energy consumption for six states for residential buildings built from 1788 to 1981. Black dots represent values based on observations from fewer than 25 SA2 regions

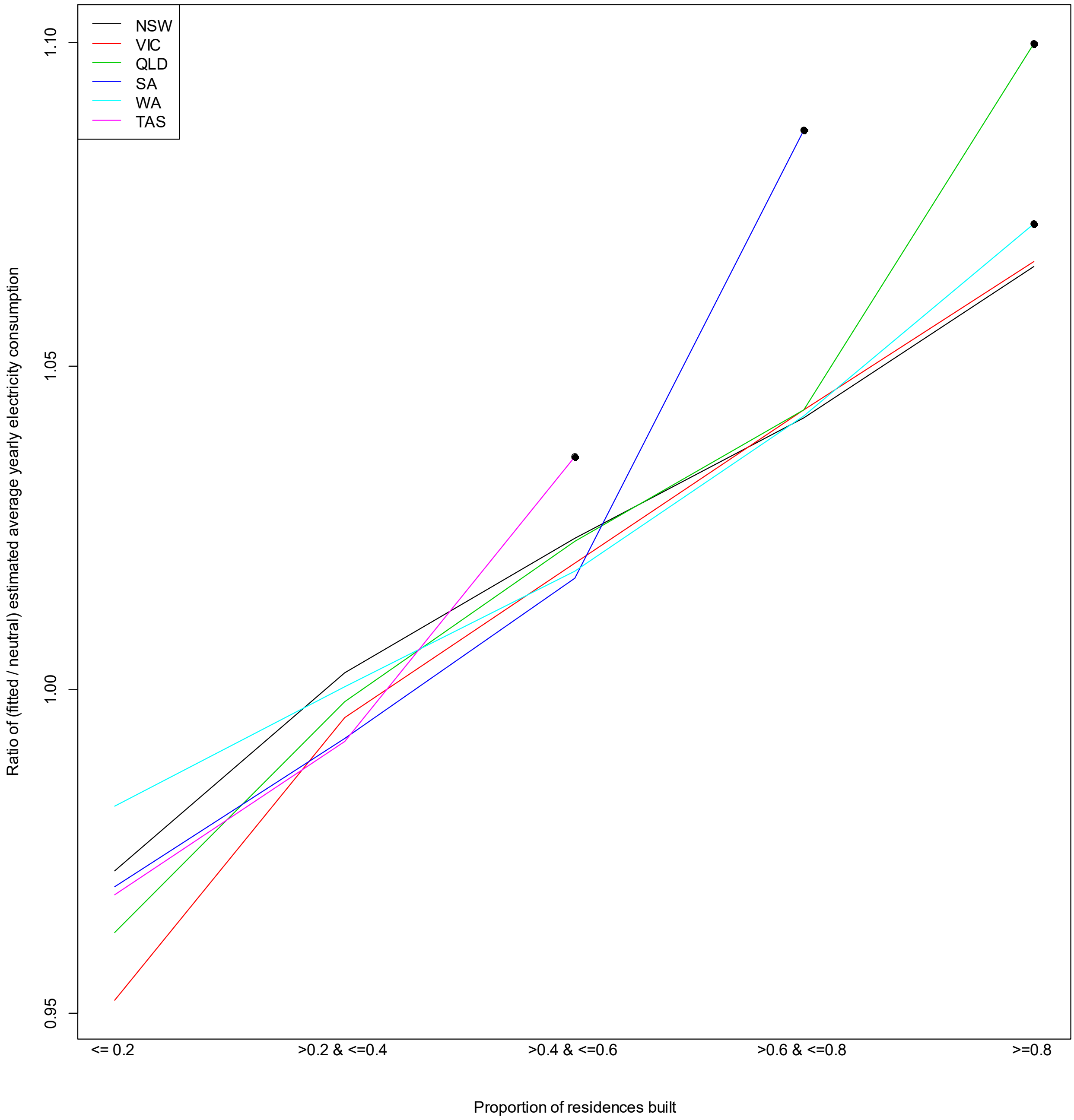

Figure 5 Ratio of the fitted and neutral model estimated household average yearly energy consumption for six states for residential buildings built from 1982 to 1996. Black dots represent values based on observations from fewer than 25 SA2 regions

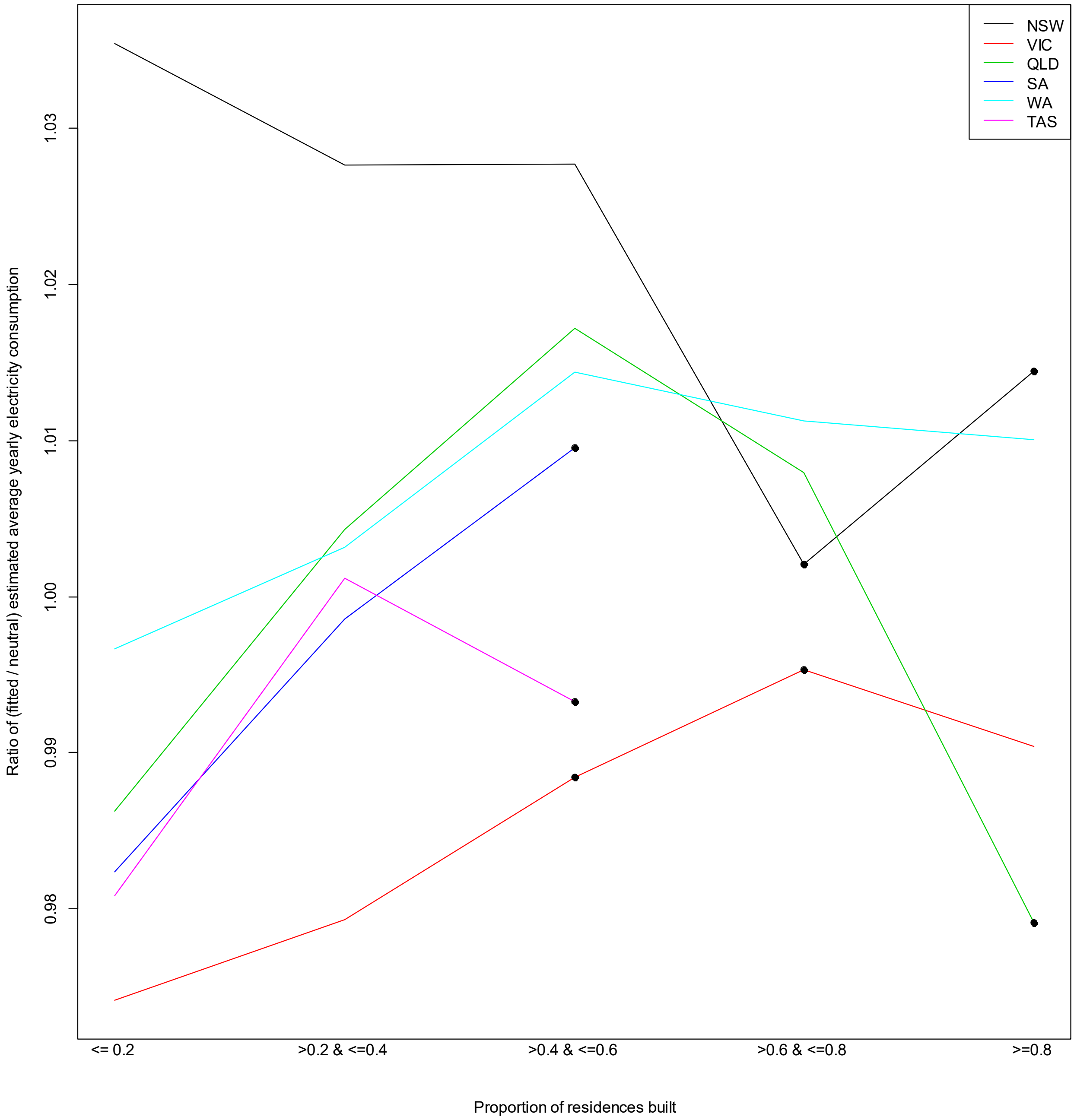

Figure 6 Ratio of the fitted and neutral model estimated household average yearly energy consumption for six states for residential buildings built from 1997 to 2011. Black dots represent values based on observations from fewer than 25 SA2 regions

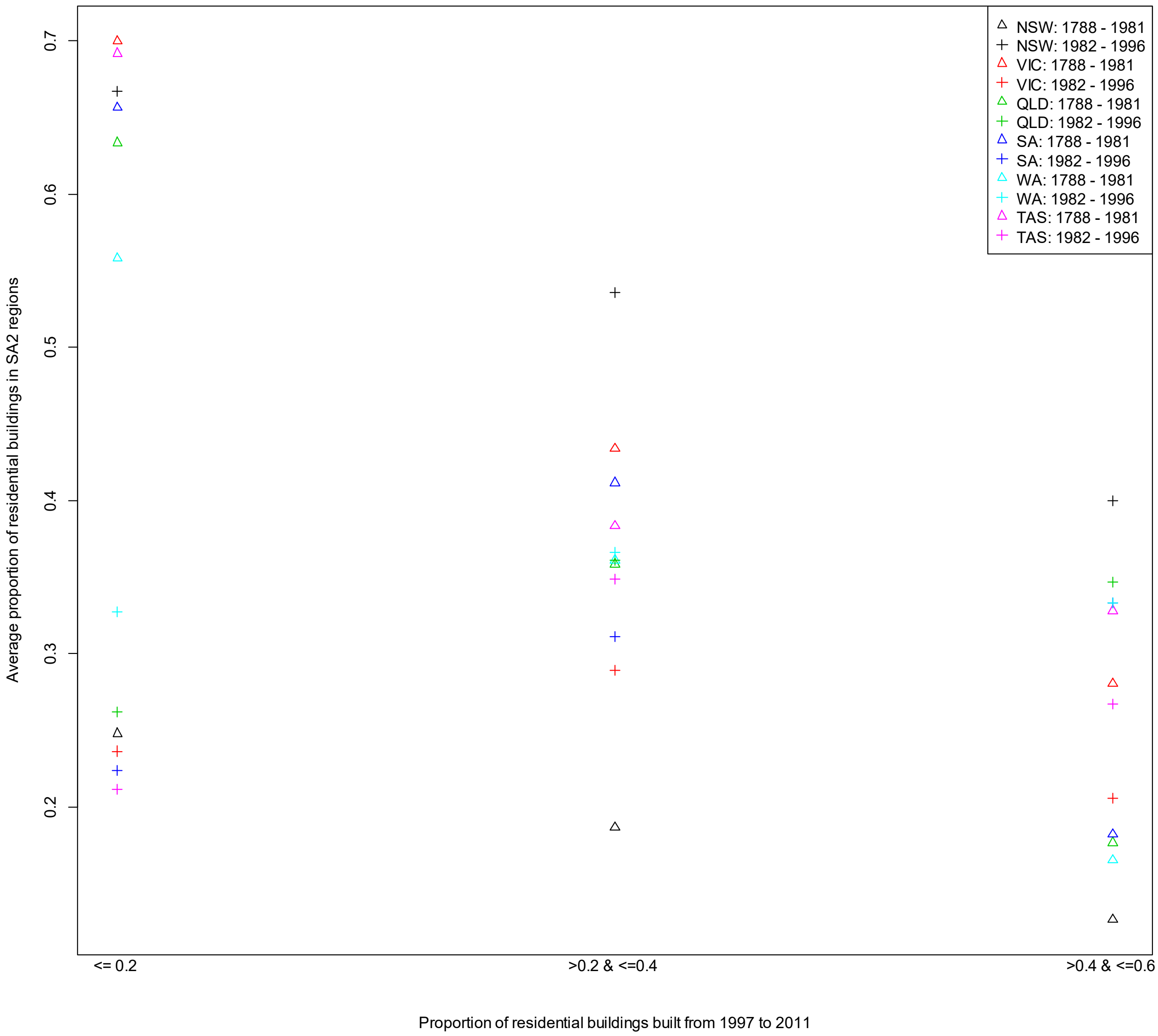

Figure 7 Average proportion of residential buildings built from 1788 to 1981 and 1982 to 1996 in the SA2 regions of six states for which the proportion of residential buildings built from 1997 to 2011 is ≤0.2, >0.2 and ≤ 0.4, or >0.4 and ≤0.6

3 Discussion and conclusion

Our results suggest that as the proportion of residences built from *1982 to 1996 increases* in an SA2 region, the estimated yearly household electricity consumption also *increases* (relative to the result that would have been expected if there was no building age effect). This trend holds across states. For SA2 regions in which the proportion of residential buildings built from *1982 to 1996* is at least 80%, the estimated annual *increase* in household consumption (compared with the neutral case) is 380 kWh. Based on a conservative retail charge of 25c/kWh, this increase amounts to an average annual electricity bill that is approximately $95 more expensive than the neutral case. A direct comparison between SA2s with >80% of residences built from *1982 to 1996* with SA2s with >80% of residences built from *1997 to 2011* suggests that residences from *1982 to 1996* use (on average) 271 kWh more electricity than those built between 1997 and 2011 (noting that this comparison factors-in building construction, climate zone and income variables).

Interestingly, areas with a high proportion of older buildings (built *before 1982*) have relatively lower electricity consumption than the neutral case, and this general trend holds across states. Looking at areas where at least 80% of the residential building stock is composed of properties built *before 1982*, the average yearly electricity consumption for each residence is approximately 5% *lower* than the neutral case.

Finally, the proportion of buildings constructed from *1997 to 2011* appears to have minimal effect on the observed average residential electricity consumption. The two older building age categories appear to have the strongest connection to average yearly electricity consumption levels across Australia.

Reference

Goldsworthy, M, Toscas, P, Guo, Y and Motlagh, O (2017). Residential air-conditioner use behaviour and building performance analysis. CSIRO Energy, Australia.

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