Do near zero energy homes stay near zero energy?

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Abstract

Net zero and near zero energy buildings are firmly on the agenda as a key policy action to reduce anthropogenic greenhouse gas emissions. But what is the reality of energy use in so called zero energy homes? Does the combination of energy efficient appliances, thermally efficient building shells and renewable energy technologies result in significantly lower energy use? Using empirical evidence from the extensive monitoring of an estate of (nearly) zero energy homes, this paper examines the longitudinal energy use from a sample of buildings to explore whether homes maintain their intended performance level over time. Disaggregated to major energy end-uses (heating and cooling, lighting, refrigeration) and solar electricity generation, this paper examines the continuous operation of near zero energy homes over a period of four years to identify any evidence of energy use rebound, asking the research question – do near zero energy homes maintain their performance over time. The results show that with the exception of lighting energy end-use, there is no visible change in performance or pattern of change across the four years of monitoring. Fixed indoor lighting energy use shows a relatively small but consistent annual increase for each of the monitored years.

Introduction

In the context of the need to mitigate anthropogenic climate change, building energy efficiency remains a key policy option (Intergovernmental Panel on Climate Change 2014). Very low and zero energy homes are a hot topic of discussion in research and policy circles as a mitigation strategy. Zero energy building case studies are found in many countries, with the International Energy Agency's "Towards Net Zero Energy Solar Buildings" project mapping almost 300 net zero energy and energy-plus buildings worldwide (Research for Energy Optimized Building 2013). Many governments are steadily moving building energy regulatory levels towards zero energy or zero carbon (Lovell 2009; Kapsalaki and Leal 2011; European Commission 2010; Department of Communities and Local Government 2006).

While much of the zero energy home literature has focussed on design strategies and technology application, little evidence has been presented demonstrating the performance sustainability of a zero energy standard. This paper utilises the monitored results from a relatively large estate of near zero energy homes to address the research question: do nearly zero energy homes maintain their intended performance level over time?

Literature review

Numerous studies attest to the reduction of operational energy use through the application of passive solar design, appliance efficiency and renewable technologies (Gill et al. 2011; Hodge and Haltrecht 2009; Heinze and Voss 2009; Parker 2009; Kapsalaki and Leal 2011; Musall et al. 2010; Thomas and Duffy 2013; Berry et al. 2014a; Berry et al. 2014c; Miller and Buys 2012). Similarly, other studies (Chance 2009; Sartori and Hestnes 2007) have documented the reduction of embodied energy impacts due to specific design strategies.

Kapsalaki and Leal (2011) examined zero energy homes in USA, Canada, Germany, Austria and the UK to document the design strategies that significant reduce the energy impact of residential buildings. Not only did many of the buildings reach their intended net zero energy performance target, but the study concluded that reaching an annual net zero energy balance was not technically difficult and could be reached by combining reasonable building design practices with the integration of on-site renewables.

Parker (2009) documented the energy performance of low energy and net zero energy homes in the United States, finding considerable energy savings, in many cases savings of 60–75 %. From a combination of passive solar design strategies, the use of energy efficient appliances and equipment, and high levels of insulation. With the application of solar energy for water heating and electricity generation, many homes reached the target net zero energy balance.

Gill et al. (2011) monitored the performance of low-energy dwellings within East Anglia in the UK, achieving reductions in operational energy performance of 56 % compared to the national average. The strategies employed included a biomass fuelled district heating to provide renewable heat energy, passive solar design, increased levels of insulation, whole house mechanical ventilation with heat recovery, and low energy lighting.

Heinze and Voss (2009) document the performance of the Solarsiedlung Freiburg am Schlierberg solar estate in Germany. Energy reduction strategies included high insulation levels, an airtight building fabric, together with efficient ventilation heat recovery, electricity-saving appliances and water-saving tap fittings with primary energy savings against the 2008 building code of approximately 57 %. The buildings included photovoltaic arrays and were connected to a combined heat and power plant operating with woodchips and natural gas. The study found this estate achieved a net energy surplus from a primary energy perspective.

BedZED, in the UK, was the first large-scale residential project to combine passive solar design, energy efficient appliances and systems, and renewable technologies to appreciably reduce energy use (electricity by 45 %, gas by 81 %), and a strategy to reduce the embodied energy impact of construction (Hodge and Haltrecht 2009; Chance 2009; Twinn 2003). The design incorporated high levels of thermal mass and insulation with passive solar design to reduce demand for heating and cooling, and then employed a combined heat and power (CHP) system utilising local tree waste, supplemented by photovoltaic panels to supply both electricity and heat.

Musall et al. (2010) identified over 280 mostly residential net zero energy buildings across USA, Canada, Europe and the UK, determining the strategies for energy use reduction as passive solar architecture, high levels of insulation, power saving appliances, combined with solar thermal systems, heat pumps and photovoltaics. Musall et al. point to energy demand savings of around 60% in comparison to standard buildings.

Miller and Buys (2012) provide details of a highly energy efficient single dwelling in South East Queensland which is a net contributor to the national electricity grid, but for such a small sample it is difficult to determine what contribution to energy savings is made by the building design and fit-out, and what contribution is made by the specific lifestyle of the occupants. The energy saving strategies include passive solar design with high levels of shading, high levels of floor, wall and roof insulation, LED and CFL lighting, and energy efficient appliances. Water is heated by a flat plate solar collector, and electricity is generated by the 1.7 kW_p photovoltaic system. The same authors (Miller et al. 2012) also evaluate eight low-energy homes in South East Queensland but examine thermal comfort rather than detailed energy end-use performance.

Thomas and Duffy (2013) monitored the performance of net zero energy and near net zero energy homes in New England, USA, finding 6 of the 10 net zero energy homes performance at the targeted net energy balance, and all homes saving no less than 50 % net annual energy use compared to the control house.

The literature provides little evidence that the target low energy or zero energy performance level is maintained beyond the initial monitoring period. Several studies (Summerfield et al. 2010; Hodge and Haltrecht 2009) have examined the performance of low energy homes many years after completion to assess ongoing performance, but provide little detail of the year by year variation per major energy end-use. Summerfield et al. (2009) examined the performance of 36 low-energy homes in Milton Keynes, UK, some 15 to 17 years after a similar study of the same dwellings, finding that energy savings strategies were enduring in the medium term for low and medium energy users, but not for higher energy use households. For BedZED, after 7 years of operation the development was successful at reducing heat energy and electricity impacts by 81 % and 45 % respectively when compared to the local community (Hodge and Haltrecht 2009), this is in spite of some systems significantly underperforming compared to design expectations. A comparison of monitored results in 2003 and 2007 showed that the electricity, hot water and heating energy use was reasonably consistent, although inconsistencies in data collection and analysis methodologies prevented a more definitive result.

There is a substantial body of empirical evidence demonstrating that technical improvements in building energy performance do not always deliver expected energy savings according to engineering calculations, but often deliver smaller than expected savings (Greening et al. 2000; Hens et al. 2010; Sorrell et al. 2009; Milne and Boardman 2000; Tsao et al. 2010; Vale and Vale 2010; Bladh and Krantz 2008). The evidence in the literature strongly supports the position that elasticity of demand (rebound effect) is more typically between 10 % and 30 % for domestic energy services; although when demand is close to saturation, elasticity tends to zero.

Given the policy thrust towards net zero energy homes, further evidence of sustained ongoing performance at the target level would provide policy makers with more certainty that a near zero energy home standard would deliver the expected ongoing energy and greenhouse gas emission savings.

Case study

The Lochiel Park Green Village in South Australia has been chosen as the most appropriate case study due to: (a) the relatively large size of the sample set; (b) the quality and detail of energy end-use data available; (c) the closeness of average building energy performance to a net zero energy target; and (d) the representativeness of the householder characteristics, being similar in a range of demographics to the regional population.

Lochiel Park is a suburban estate of just over 100 nearly net zero energy homes (Berry et al. 2013). The energy used and generated within each house is being monitored and analysed to help develop our understanding of the energy habits of typical households in zero energy homes. Appliance and equipment audits, and user interviews have also been conducted to extend our knowledge of the energy service expectations of contemporary digital-age lifestyles. All homes at Lochiel Park are built to the same high environmental standard, published in the Urban Design Guidelines (Land Management Corporation 2009). The minimum requirements include:

- 7.5 NatHERS Stars thermal comfort (i.e. <58 MJ/m² per annum to maintain thermal comfort).
- Solar water heating, gas boosted.
- 1.0 kW_p photovoltaic system for each 100 m² of habitable floor area.
- High energy star rated (energy efficient) appliances.
- Energy efficient lighting (i.e. compact fluorescent lights CFLs or light emitting diodes LEDs).
- Ceiling fans in all bedrooms and living spaces.
- An in-home energy feedback display.

The Urban Design Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon within the local building industry at the time (Berry et al. 2013). The average floor area at Lochiel Park is 203.3 m², similar to the 2008/9 regional average for new homes (Australian Bureau of Statistics 2010). The local climate is temperate with mild winters and relatively hot summers reaching peaks over 35 °C. Analysis of the response of the Lochiel Park households to nearly net zero energy housing has been published by the authors (Berry et al. 2014b).

Results and discussion

The disaggregated household energy data is drawn from a sample of 9 homes fitted with 1 minute interval monitoring systems. Details of the monitoring methodology and equipment have been published by the authors (Whaley et al. 2010). Individual households are randomly coded (e.g. Household AA) to maintain privacy.

LOCAL CLIMATE

Monthly temperature data for the region collected by the Bureau of Meteorology is shown in Figure 1a to highlight the consistent nature of seasonal weather patterns and the annual differences. These annual differences are reflected to a degree in energy use impacts for those systems (i.e. space conditioning) where climate is likely to influence household behaviour. Of significance is the warm late summer of 2012/13 and the colder than usual winter of 2014. Figure 1b shows the monthly global solar radiation collected by the Bureau of Meteorology.

TOTAL DELIVERED ENERGY USE

The total delivered energy (total energy use less onsite electricity generation) in Figure 2a (n=9) highlights the significance of the combination of higher energy use and lower solar generation during the winter months. In the summer period, the higher energy use, mainly due to air-conditioning, is offset by the increased solar generation, achieving a near net zero energy balance. The annual mean across the four years is 16,560 MJ, with a standard deviation (EXCEL STDEV.S) of 768 MJ, and a coefficient of variance of 0.046. Of note in the estate monthly average graph is the surprising dip for 2012 winter energy use, for which further investigation identified as a period whereby several high energy use households were absent from the estate at the same time. This pattern can also be seen in the space conditioning and lighting energy use graphs. Figure 2b illustrates that for Household W the solar electricity generation for around half the year is greater than the monthly energy use for all household services, although during the winter months demand easily outstrips generation.

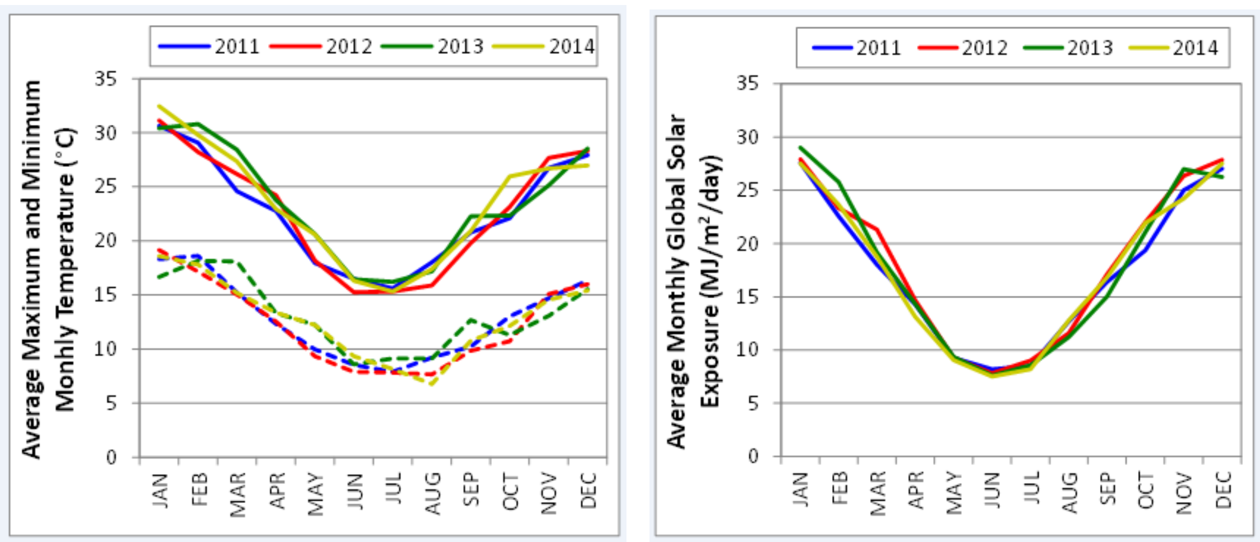

Figure 1. a) Maximum and minimum temperatures 2011–2014; b) Global solar radiation 2011–2014.

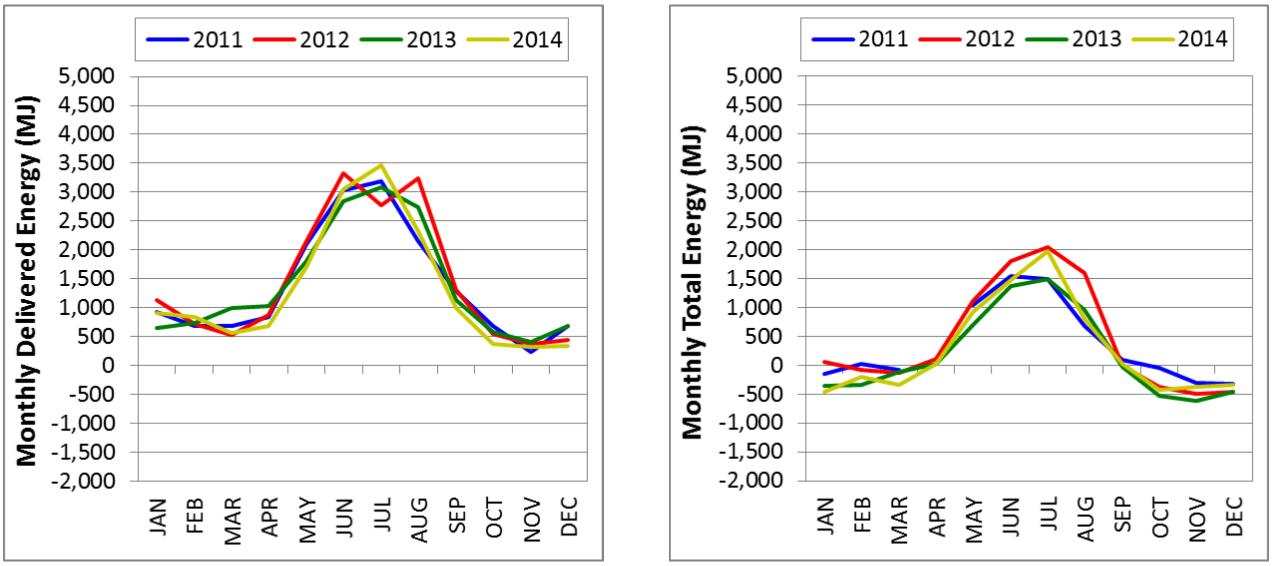

Figure 2. a) Average monthly delivered energy 2011–2014; b) Monthly delivered energy Household W.

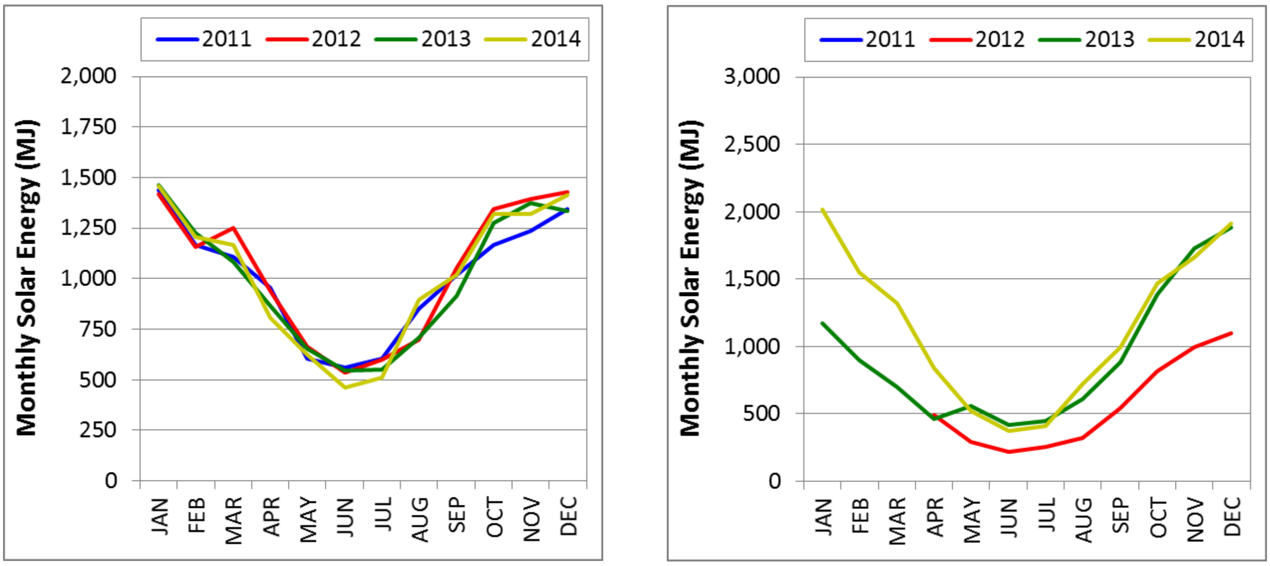

Figure 3. a) Average monthly solar generation 2011–2014; b) Monthly solar generation Household K.

ELECTRICITY GENERATION

The electricity generated from the photovoltaics shown in Figure 3a (n=24) indicates a reasonably consistent seasonal pattern with maximum generation during the summer months. The annual mean across the four years is 12,178 MJ, with a standard deviation of 217 MJ, and a coefficient of variation of 0.018. The March 2012 generation result is unusually high, a feature that is noticeable across the results from almost all households. Any degradation of the photovoltaic systems performance over this timeframe is likely to be small and is probably masked by natural annual solar radiation variations. Figure 3b, which shows the electricity generation from Household K, highlights an approximate increase in gross energy generation of 71.8 % during April 2013 due to the identification and rectification of a system fault (Whaley et al. 2014).

HEATING AND COOLING ENERGY USE

The energy used for reverse-cycle based space conditioning shown in Figure 4a (n=7) follows a simple pattern of seasonal energy demand for both summer and winter, and very little energy (i.e. mainly standby power) is used during the spring and autumn months. The annual mean across the four years is 3,907 MJ, with a standard deviation of 230 MJ, and a coefficient of variation of 0.059. There is no distinguishable pattern of energy use increase over time where households take higher levels of thermal comfort which might be expected through micro rebound effects. The energy impact of a warmer 2013 late summer and the colder 2014 winter is highlighted in the graph for Household AA (Figure 4b).

LIGHTING ENERGY USE

Lighting energy use, which also includes the energy used by exhaust fans and bathroom heat lamps, shown in Figure 5 (n=9) is relatively consistent throughout the year, with slight seasonal low during October and November. The annual mean across the four years is 1,292 MJ, with a standard deviation of 65 MJ, and a coefficient of variation of 0.050. Lighting energy use increases on average 3.8 % annually, with a clear pattern of small annual increases across the four year period. The 2012 July figure, which is unusually low, is influenced by the absence of several households from the estate for lengthy periods (e.g. interstate or overseas holidays).

REFRIGERATION ENERGY USE

The refrigeration energy use pattern for Household Q shown in Figure 6 highlights the influence of seasonal temperature impacts and household demand for food refrigeration, with higher energy use in warmer seasons. The refrigeration analysis is limited due to the availability of detailed monitoring data from a sample of only two homes, although the pattern of energy use is consistent for both households.

COMPARISON WITH EXPECTED PERFORMANCE

The policy target for the Lochiel Park estate was a reduction in energy use of 66 % against average household energy use in South Australia. Estate-wide figures for the periods 2011/12 and 2012/13 (n=44) show a consistent reduction of over 70 % for delivered energy use, exceeding the policy goal (Berry et al. 2014a).

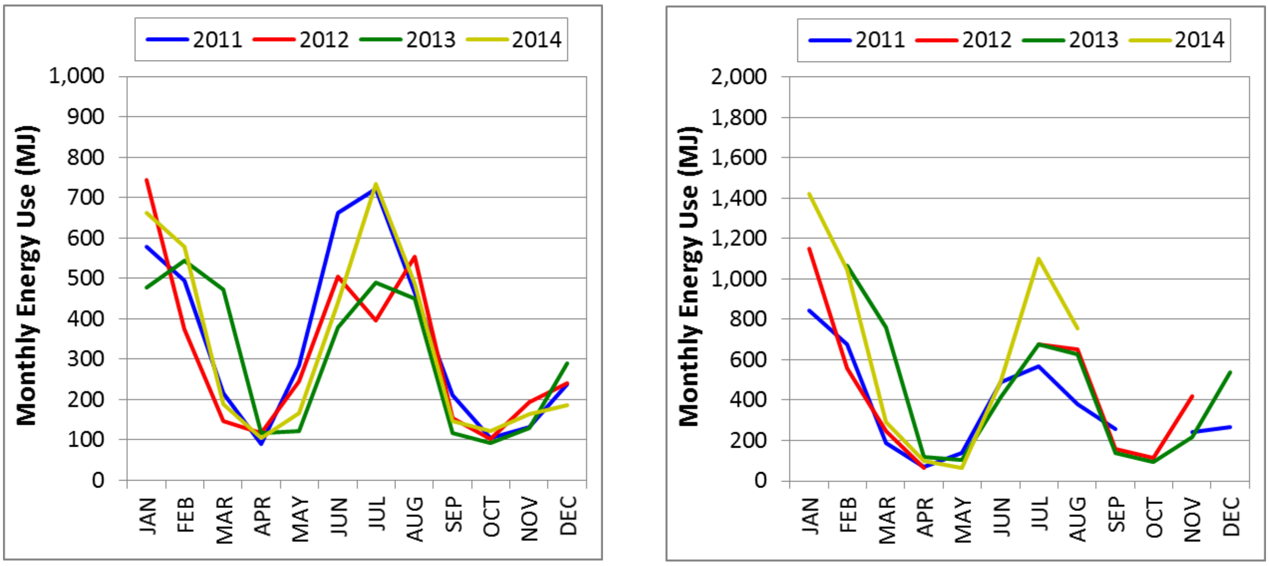

Figure 4. a) Average space conditioning energy use 2011–2014; b) Monthly space conditioning energy use Household AA.

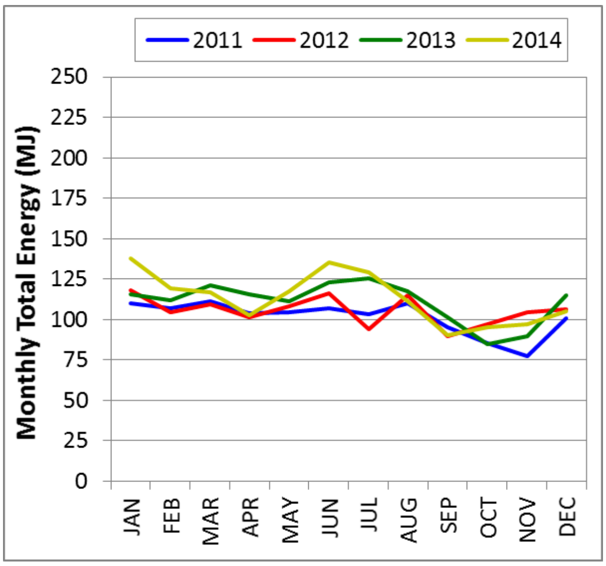

Figure 5. Average monthly lighting energy use 2011–2014.

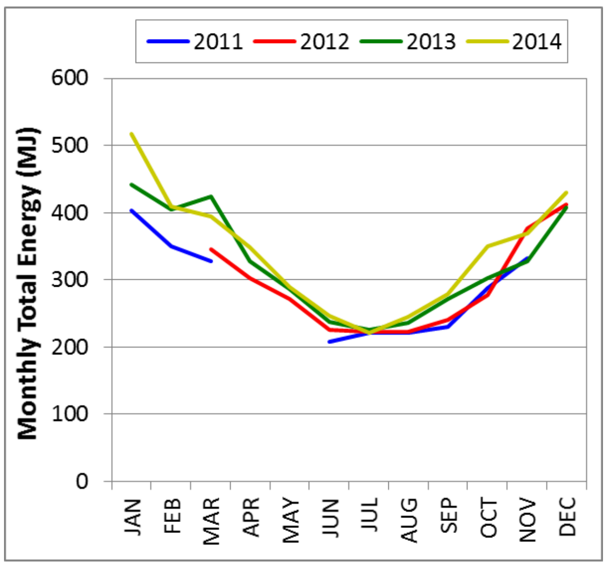

Figure 6. Monthly refrigeration energy use Household Q 2011–2014.

Conclusion

The monitored data from the sample of households at Lochiel Park shows no pattern of change in energy performance over the four year period analysed except for a relatively small lighting energy use increase. A further year of data (2010) is available for six of these homes and no visible change in total annual delivered energy use can be identified.

Although the whole 'near zero energy' housing estate when completed in 2015 will contain just over 100 individually monitored homes, the 9 selected for this study represent a continuously occupied subset. Future studies will allow the analysis of a larger sample size.

Seasonal and annual differences in energy end use and electricity generation due to climatic variation can be clearly identified graphically, which in the context of climate change, points to likely changes in overall energy performance over time as summer periods become warmer and winters milder.

The analysis has included total delivered energy use, electricity generation and individual end-use for reverse-cycle space conditioning, lighting and refrigeration, with reasonably consistent results across the four year monitored period. Only fixed lighting shows a visible pattern of energy use change, albeit a small change.

Further analysis using statistical and engineering methods would provide a clearer picture from the available 4 year data set. Ongoing research using larger household samples and longer time periods will improve confidence in the results, but from the preliminary analysis of the data, homes constructed to a near zero energy standard in temperate climates appear to maintain energy performance levels over the short and medium term.

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