Climate Change Impacts on Housing Energy Consumption and its Adaptation Pathways

Zhengen Ren, Xiaoming Wang and Dong Chen

Abstract Australian household energy consumption contributes about 13 % to the total national greenhouse gas (GHG) emissions, and thus, to climate change. At the same time, climate change will in turn impact the total energy consumption and GHG emissions from the residential sector. This study investigated the potential impact of climate change on the total energy consumption and related GHG emissions of housing in Brisbane, Australia (a heating and cooling balanced climate region) and identified potential pathways for existing and new residential buildings to adapt to climate change by simulations in terms of the resilience to maintain the level same as or less than the current level of total energy consumption and GHG emissions.

Keywords Household energy consumption · Climate change · Adaptation pathways

1 Introduction

It is now widely acknowledged that global warming is very likely the result of increasing greenhouse gas concentration due to human activities such as the use of fossil fuel and deforestation. Climate change mitigation and adaptation are two general approaches in response to global warming. Climate mitigation is designed to reduce GHG emissions and in return to reduce the global warming impact. Climate adaptation is designed to adjust actions in the society to cope with climate changes that are already happening or are the likely consequences of current GHG emissions (The Royal Institute of British Architects 2011).

40 % of the world's energy is consumed by the building sector which resulted in one-third of the global greenhouse gas emissions (Nethad 2009). The Inter-

Z. Ren · X. Wang (✉) · D. Chen
Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia
e-mail: Xiaoming.Wang@csiro.au

A. Khare and T. Beckman (eds.), *Mitigating Climate Change*,
Springer Environmental Science and Engineering, DOI: 10.1007/978-3-642-37030-4_11,
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governmental Panel on Climate Change (IPCC) identified that reducing energy consumption of the building sector and its associated greenhouse gas (GHG) emissions has one of the highest benefit-cost ratios among many possible mitigation measures across different sectors (Levine et al. 2007).

Australian household energy consumption contributes about 13 % to the total national greenhouse gas (GHG) emissions, which is not the largest contributor to GHG emissions in Australia, but it is one of the fastest growing sources (Australian Bureau of Agricultural and Resources Economics and Sciences 2011). The total heating and cooling energy consumption in cold regions may benefit from global warming, meanwhile it will increase in cooling dominated or space heating and cooling balanced regions (such as Brisbane and Sydney in Australia) due to significant increase in cooling energy consumption. Therefore, in these regions climate adaptation measures should be properly considered in both building design and operation stages to reduce energy consumption and carbon emission.

This study presents the likely extent of total household energy consumption and GHG emissions under climate change in Brisbane using the recent developed method by the authors (Ren et al. 2011a). The impact of global warming on total energy consumption and GHG emissions was discussed for both representative existing and new housing. It was demonstrated that in Brisbane the potential contemporary mitigation strategies for residential buildings (such as improving energy performance of a building envelop, using higher energy efficient equipment and appliances), if implemented immediately, become adaptation strategies as global warming reaches 4 °C for existing housing and 2 °C for new housing. Further adaptation strategies (such as the applications of renewable energy for hot water and daily electricity usage) are required as global warming becomes higher.

2 Impact of Climate Change on the Total Energy Consumption and Carbon Emissions

To analyse climate change impact on energy consumption and carbon emissions, the methodologies of predicting future weather and the total household energy consumption and associated carbon emissions were developed (Ren et al. 2011a). The future weather data were constructed using the ‘morphing’ methodology developed by Belcher et al. (2005), in which hourly weather data for the current climate is adjusted with the projected monthly mean changes from atmosphere–ocean general circulation models (AOGCM). The total energy consumption and associated carbon emissions were estimated by the AusZEH design tool (Ren et al. 2011b, 2012), which included energy use calculation modules for space heating and cooling, hot water, lighting and other appliances.

The majority (80 %) of Brisbane dwellings are separate houses (DEWHA-Department of the Environment, Water, Heritage and the Arts 2008). Figures 1 and 2 illustrate two detached single-storey houses of different sizes and

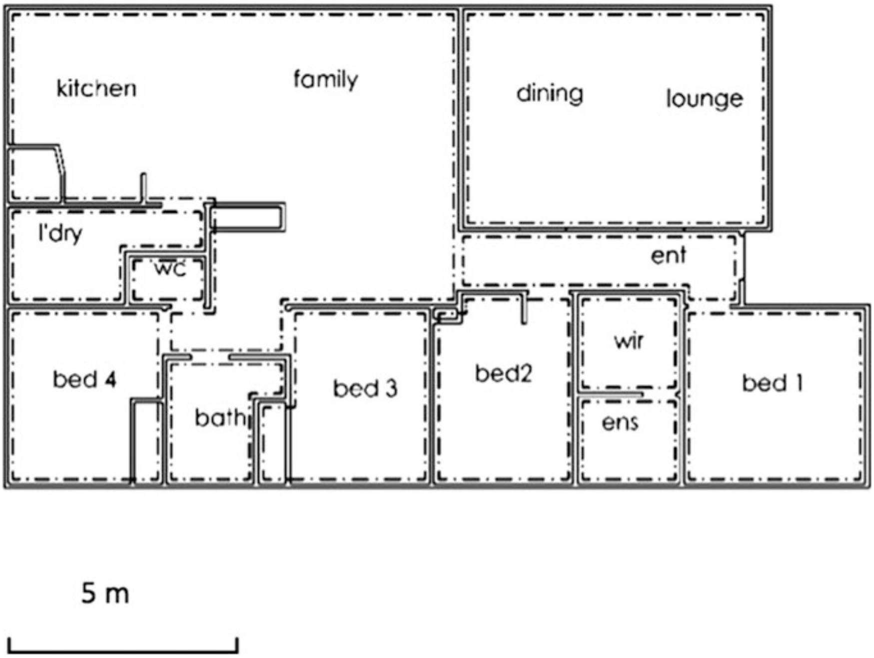


Fig. 1 The floor plan of House 1

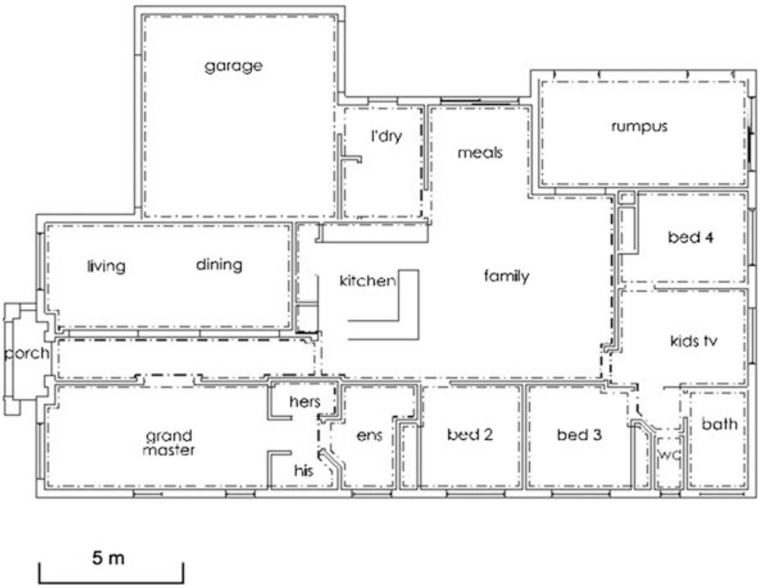


Fig. 2 The floor plan of House 2

constructions. The houses were selected from two of the eight sample houses previously used for energy rating software accreditation by Nationwide House Energy Rating Scheme (NatHERS 2012). ‘House 1’ has a gross floor area of 160 m^2 (conditioned floor area of 140.75 m^2) that is equivalent to the average floor area of the national detached houses built before 1990 (DEWHA 2008). ‘House 2’ has a gross floor area of 263.4 m^2 (conditioned floor area of 207.4) that is equivalent to the average floor area of the national detached houses built after 2004 (DEWHA 2008).

In this study, the floor plans for both houses were maintained whilst various changes of wall insulation, ceiling insulation, window types, infiltration controls etc. were used to achieve energy ratings of 2, 5 and 7 star house energy efficiency in Brisbane.

Among the houses, ‘House 1’ with 2 stars was selected to represent existing housing stocks built before 1990, and ‘House 2’ with 5 and 7 stars represent new housing stocks that satisfy current energy standard and likely future energy performance requirements respectively (Horne et al. 2005). Reverse cycle electric heat pumps with ducted central systems are assumed to be used for space heating and cooling. The energy coefficients of performance (COPs) of these systems were assumed to be 2.5, which complies with the Minimum Energy Performance Standards (MEPS) of 2006–2007 (DCCEE—Department of Climate Change and Energy Efficiency 2012). Energy efficient compact fluorescent lamps are used for lighting.

A 2010 survey found around 32 % of Brisbane homes used natural or LPG/ bottled gas (Milles 2010). In this study, two fuel resources are considered:

- Electricity intensive: electricity was used for all the equipment, systems and appliances.
- Gas intensive: natural gas was used for water heating and cooking, and electricity was used for other equipment and appliances.

Considering that lighting, water heating and other household appliances are insensitive to global warming, climate change impact on residential building energy consumption and carbon emission is dominated by its impact on space heating and cooling (H/C) energy use (Ren et al. 2011a). Consequently, understanding the climate change impact on space heating and cooling energy use and carbon emission is important for the development of proper adaptation pathways for residential houses.

Figure 3 shows the projected heating and cooling energy consumption for 2 star ‘House 1’ and 5 star ‘House 2’ in relation to the global temperature increase on the basis of three AOGCMs (see Table 1) in Brisbane. The average values from the three AOGCMs were shown in red lines. The results revealed that the increase in the total H/C energy consumption prevails in the heating and cooling balanced regions (such as Brisbane) due to significant increase in cooling energy consumption. The total H/C energy consumption of 2 star ‘House 1’ was projected to remain almost unchanged until the global warming reaches 1 °C, meanwhile, for 5

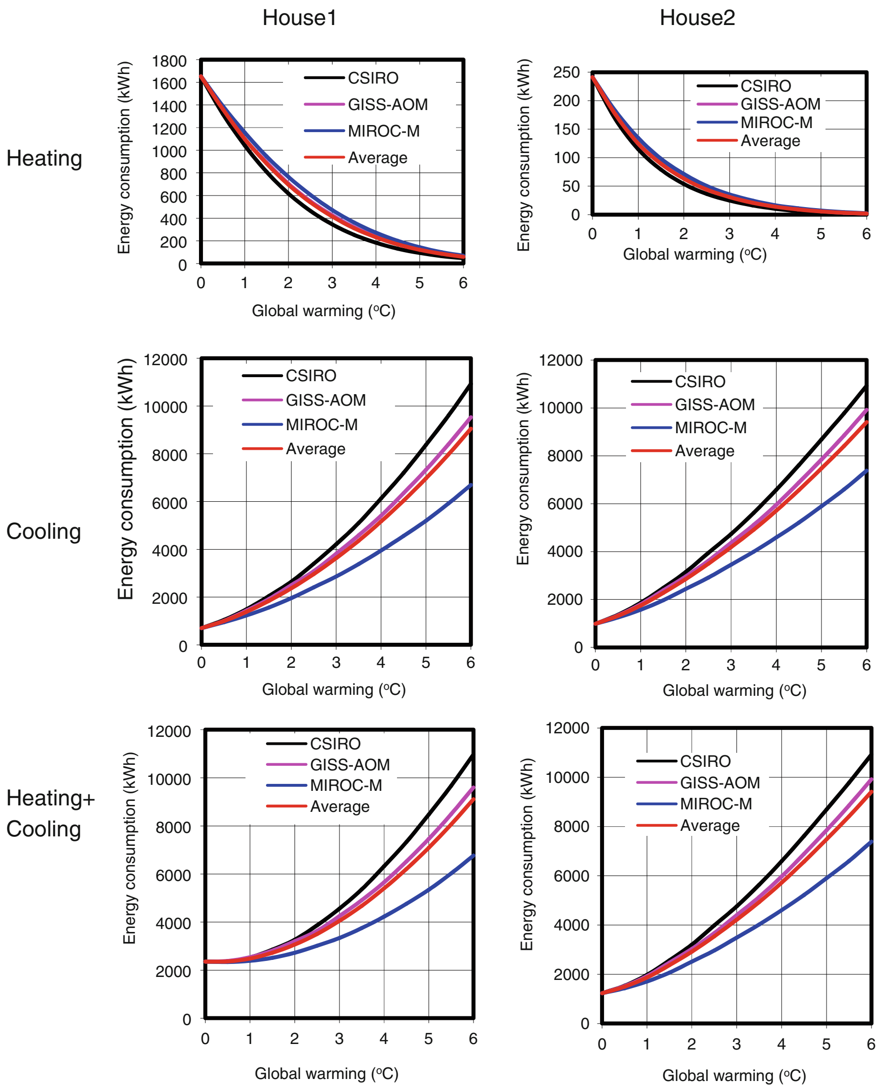


Fig. 3 Sensitivity of changes in space heating and cooling energy consumption (kWh/year) to the global warming for 2 star House 1 and 5 star House 2 in Brisbane (electricity intensity)

star 'House 2' it was projected to increase immediately with globe warming. This shows high energy efficient buildings are more sensitive to global warming.

In Brisbane, as shown in Fig. 4, the future total energy consumption of retro-fitted 5 star 'House 1' in response to 3 °C global warming is projected to be higher than the 2 star "House 1" under the current climate. With only a 1.5 °C global mean temperature increase, the future total energy consumption of an upgraded 7 star 'House 2' will surpass that of a 5 star "House 2" under the current climate.

Table 1 Models used for predictions of future local climate change

Model	Developer
CSIRO-MK3.5	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
GISS-AOM	National Aeronautics and Space Administration, Goddard Institute for Space Studies, USA
MIROC-M	Centre for Climate System Research, National Institute for Environmental Studies, and Frontier Research Centre for Global Change, Japan

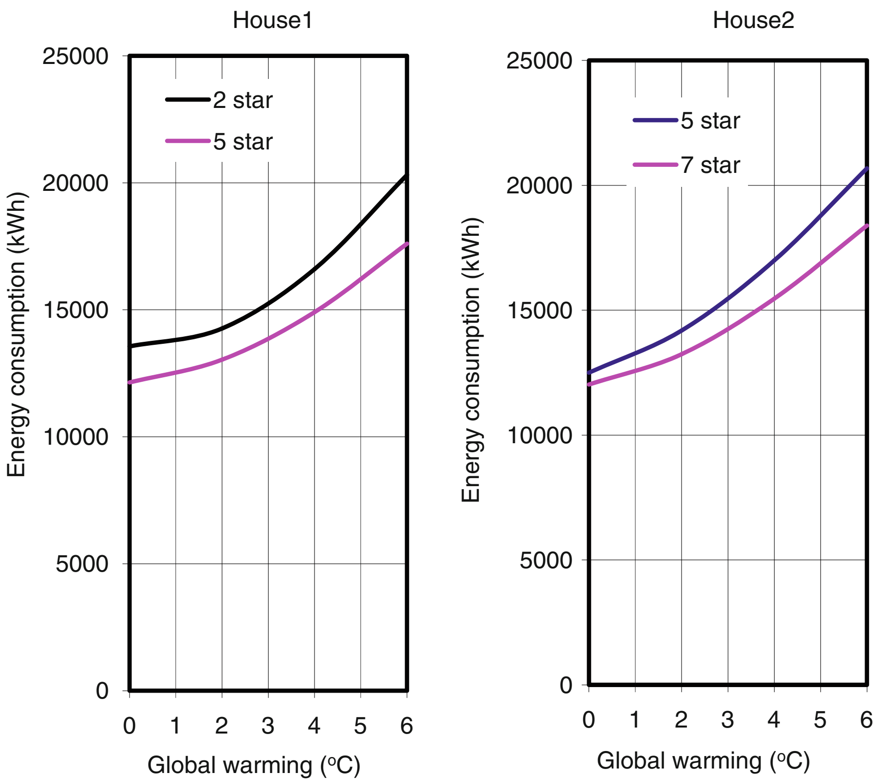


Fig. 4 Sensitivity of the total energy consumption to global warming for House 1 with 2 and 5 stars and House 2 with 5 and 7 stars in Brisbane (gas intensive)

Meanwhile, Table 2 revealed that in Brisbane, considering 6 °C global warming, the total carbon emissions of 5 star 'House 2' are projected to be around twice as much as those under the present climates. The total carbon emission of retrofitted 5 star 'House 1' at 6 °C global warming is even higher than the 2 star house under the current climates.

Table 2 The reduction of total carbon emissions for Houses 1 and 2 by increasing envelop energy efficiency

Energy use type	House 1			
	Present-day climate		Global warming increases by 6 °C	
	Total GHG emissions of 2 star	Reduction in GHG emissions 2 → 5 star	Total GHG emissions of 2 star	Reduction in GHG emissions 2 → 5 star
Electricity intensive (Tonne/year)	11.01	1.42	17.77	2.65
Gas intensive (Tonne/year)	8.46	1.42	15.22	2.65
Energy use type	House 2			
	Present-day climate		Global warming increases by 6 °C	
	Total GHG emissions of 5 star	Reduction in GHG emissions 5 → 7 star	Total GHG emissions of 5 star	Reduction in GHG emissions 5 → 7 star
Electricity intensive (Tonne/year)	9.95	0.46	18.13	2.22
Gas intensive (Tonne/year)	7.40	0.46	15.58	2.22

Considering the uncertainties in future global warming due to variable potential global carbon emissions in the future (a set of 40 emission scenarios defined in IPCC's Special Report on Emission Scenarios (SRES) (IPCC 2000), three carbon emission scenarios were selected in this study, i.e. A1B, A1FI and 550 ppm stabilisation scenarios, representing medium emissions, high emissions and the emissions under policy influences (IPCC 2000). With A1B, A1FI and 550 ppm stabilisation emission scenarios, the corresponding global CO_2 concentration and global warming projections can be obtained by the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC), developed by Wigley's Group in USA (Wigley et al. 1996). From the global CO_2 concentration and global warming projections obtained by MAGICC for a given emission scenario, climate changes in Australia with different Atmosphere–Ocean General Circulation Models (AOGCMs) can be simulated using OZClim (Wang et al. 2011), which is a climate change projection software developed by CSIRO. Then climate change impact on total energy consumption and GHG emissions can be predicted. Figure 5 shows the average total energy consumption from the three AOGCMs model varies with the global warming at the given emission scenarios of AIFI, A1B and 550 ppm respectively in Brisbane.

It can be seen that the total energy consumption for the existing 2 star 'House 1' and new 5 star 'House 2' in Brisbane will increase apparently starting from 2030

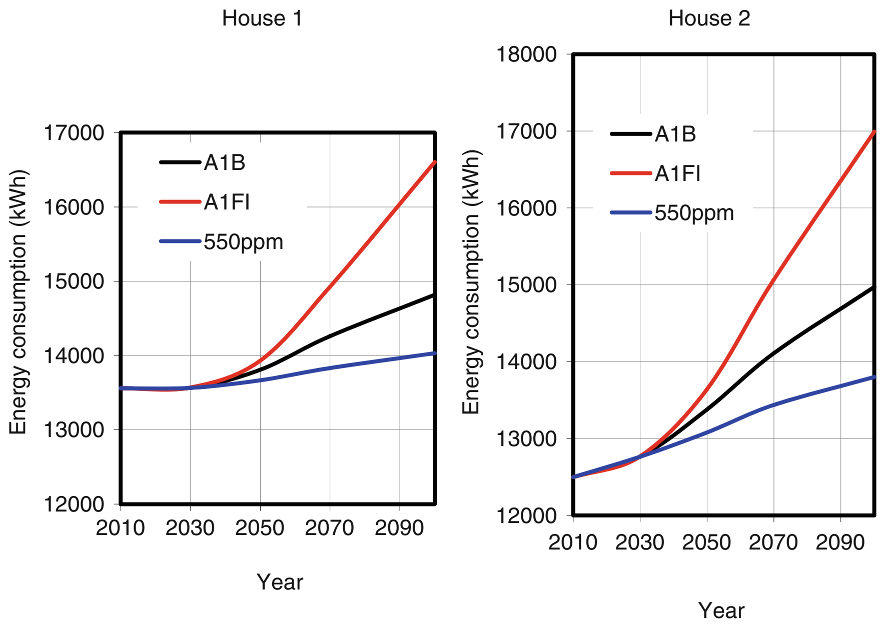


Fig. 5 Prediction of total energy consumption in Brisbane to 2100 (gas intensive)

given the high carbon emission scenario A1FI and medium emission scenario A1B. Particularly after 2050, they will increase linearly. From present to 2100, the total energy consumption will increase around 23 and 9 % for 'House 1' given emission scenarios of A1FI and A1B, respectively, and 36 and 20 % for 'House 2' for the high and medium emission scenarios. From present to 2100 given medium emission scenario A1B, energy consumption for space heating and cooling of 'House 1'(in kWh/m^2 of conditioned floor area per annum) will increase from 17 to 29 kWh/m^2 (e.g., increase by 71 %), and from 6 to 20 kWh/m^2 (e.g., increase by 233 %) for 'House 2'. They will increase by 142 % for 'House 1' and 394 % for 'House 2' from present to 2100 given high emission scenario A1FI. Considering their conditioned floor areas, the increase in the total annual heating and cooling energy consumption of 5 star 'House 2' is projected to be 4,915 and 3,406 kWh for 2 star 'House 1' from present to 2100 given high emission scenarios A1FI. It is clear that attentions should not only be given to low level energy star rating existing housing, but also to large 5 star new houses for adaptation strategy.

3 Climate Adaption Pathways

In general, there are three main practical approaches to reduce the energy consumption of residential houses in Australia if occupant behavioural changes are not included (Ren et al. 2011):

1. Demand reduction by improving energy performance of building envelops;
2. Applications of energy efficient appliances; and
3. Installation of renewable energy, such as solar PVs, wind turbines, solar hot water, etc.

There is an additional approach to reduce carbon emissions of houses, that is:

4. Fuel switching: switching to appliances that use alternative low greenhouse gas emission energy sources.

As shown in Table 2, in Brisbane, it can reduce 2.55 tons of GHG emissions yearly for ‘House 1’ and ‘House 2’ switching fuel from electricity to natural gas for water heating and cooking. Energy efficient compact fluorescent lamps have already been used for lighting (see previous section). In addition to these two options, the other measures will also be considered in this study to enhance adaptive capacity in response to global warming as following:

- The existing houses are retrofitted from 2 to 5 stars, and new houses constructed to satisfy 7 star requirement instead of the current standard of 5 stars. Modifications implemented for the houses to achieve above energy star rating are listed in Table 3;
- MEPS of the ducted air-conditioning systems are upgraded from 2.5 (MEPS 2006–2007) to 2.75 (MEPS 2010–2011);
- The ‘average’ energy performance household appliances based on the DEWHA report (DEWHA 2008) are replaced with the best energy performance appliances available on market. The change reduces about 25 % energy consumption of average household appliances (Newton and Selwyn 2010);
- Solar PVs are installed as an on-site renewable energy supply in connection with a grid electricity network.

Table 3 Modifications of House 1 from 2 stars a to 5 stars and House 2 from 5 to 7 stars

House 1 (2 to 5 stars)	House 2 (5 to 7 stars)
Ceiling 55 % R1.0 insulation upgraded to 100 % R2.0 insulation	*Ceiling* R4.0 insulation changed into R3.5
External Wall Brick veneer upgraded to brick veneer with R1.0 insulation	*External wall* brick veneer with R2.0; insulation upgraded to brick veneer with R3.0 insulation
	Windows timber frames with single glazing changed into aluminium

Adaptation pathways for existing houses are discussed assuming three levels of global warming, i.e., 2, 4 and 6 °C. As shown in Fig. 6, in order to maintain the future energy consumption of an existing house in its service life (i.e. 'House 1' in 2 stars) no more than the current levels, the house in Brisbane is only required to be retrofitted to 5 stars if global warming reaches up to 2 °C. However, as the global warming increases to 4 °C, it requires the houses be retrofitted to 5 stars together with high EE air-conditioning and high EE household appliances to fully counteract the effect of 4 °C global warming. As the global warming increases to 6 °C, all four procedures for 'House 1', i.e., retrofitting to 5 stars, use of high EE appliances and air-conditioning and the adoption of on-site solar PVs, are required for houses in Brisbane to maintain the future electricity consumption no more than the current level. The size of solar PVs is determined by the local average daily electricity production, which is 4.2 kWh/day for 1 kW PV in Brisbane (Clean Energy Council 2011).

It is understood that earlier adoption of those adaptation measures will reduce the house energy consumption to less than the current level and thus contribute to climate change mitigation. In fact, considering average house service life of over 50 years, the current results further support that house energy rating standard today should be carefully designed for future global warming as pointed out by the authors (Wang et al. 2011).

As shown in Fig. 6 and Table 2, to maintain the future energy consumption of new houses no more than current levels as global temperature increases to 2 °C, the houses are required to satisfy the energy performance requirement of 7 stars, along with the use of high EE air-conditioning and appliances in Brisbane.

As the global temperature increases to 4 °C or more, all the four options described previously has to be implemented to keep energy consumption of a new house no more than the current level. In comparison, these implementations are only required for existing houses when global temperature increases up to 6 °C as discussed above. This again indicates that new high energy efficient housing is more sensitive to climate change.

The adaptation pathways analysed here is carried out for different global warming temperature scenarios. As mentioned above, to consider the uncertainties in future global carbon emissions, the analysis can also be made for the future years under the different carbon emission scenarios. It should be noted that the simulation results here project the potential average changes in the energy consumption centred at the future year and should not be viewed as the determinative energy consumption for a specific year in the future.

As shown in Table 4, to maintain the energy consumption of existing and new houses in 2030 no more than current level under high carbon emission scenario A1FI, the 2 star existing 'House 1' is required to be retrofitted to 5 stars and the 5 star new 'House 2' be upgraded to 7 stars. This building envelope improvement of 'House 1' can still be applied to achieve the targeted energy consumption in 2050. For the new 'House 2', to achieve the targeted energy consumption in 2070, the three options (built 7 stars, high energy efficient air-conditioning and appliances, and installing smaller PV) are required.

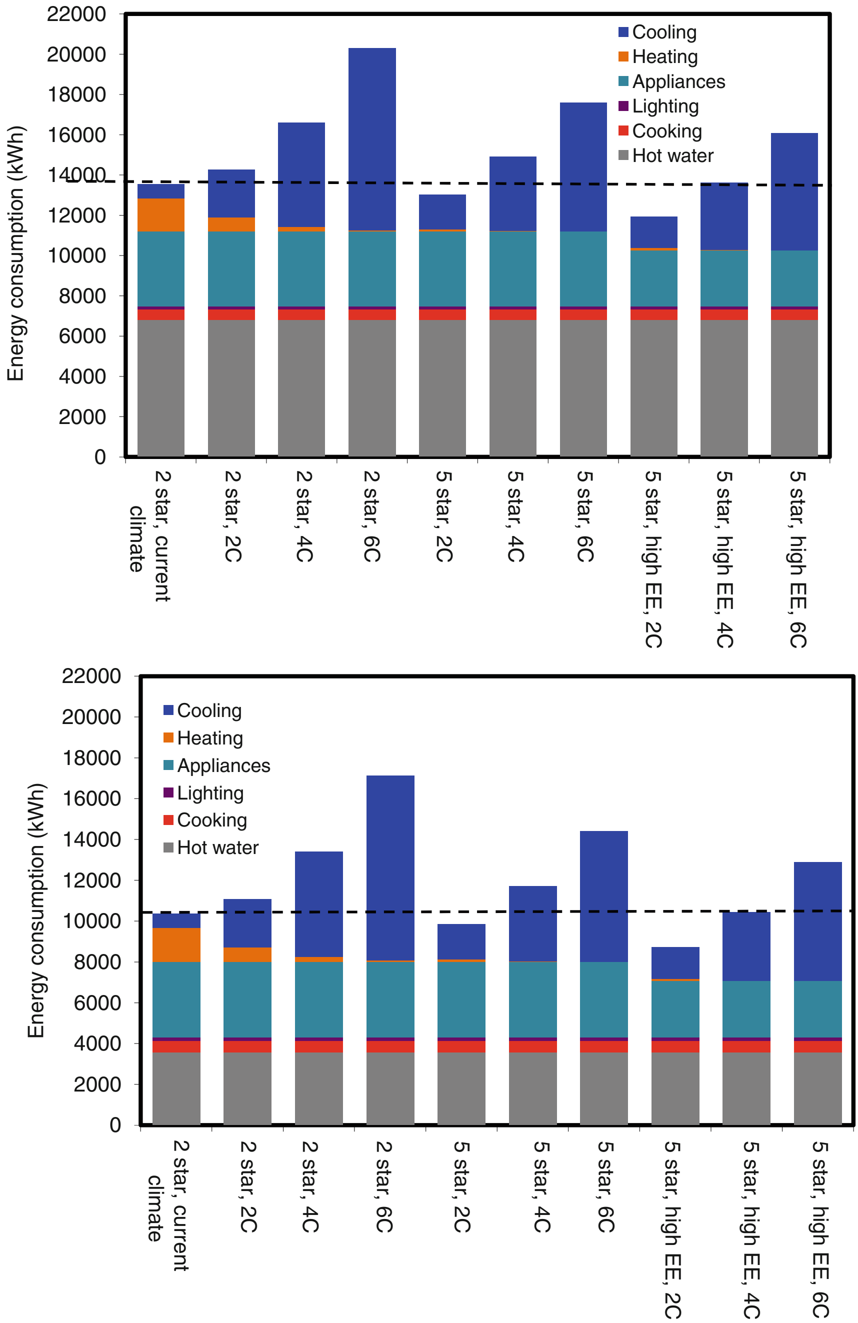
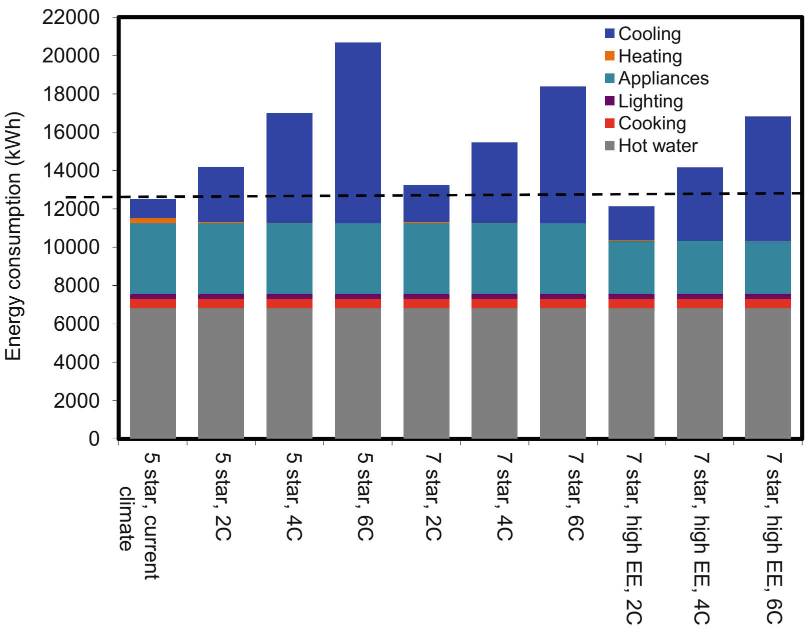


Fig. 6 Evaluation of the total energy consumption to global warming through the measures of building energy efficiency, high EE (air-conditioning and appliances) and on-site solar PVs for House 1 and House 2



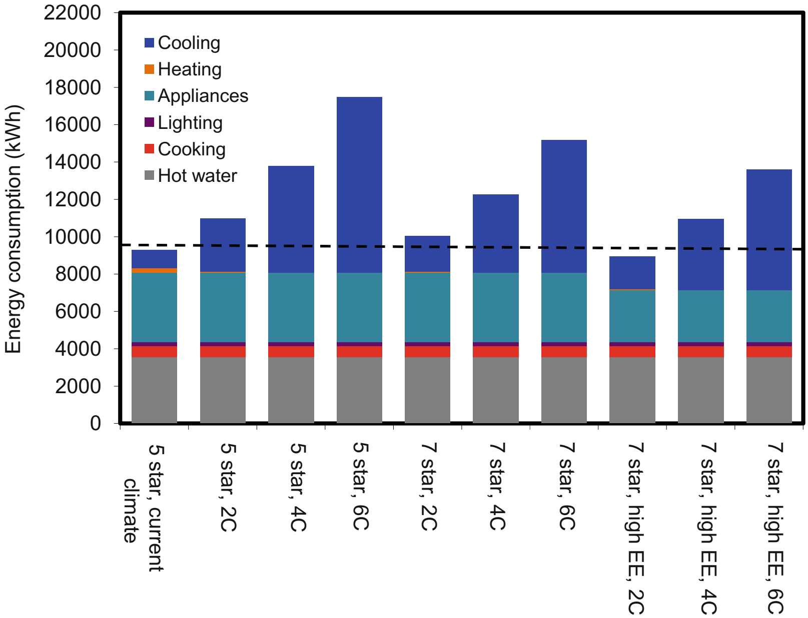


Fig. 6 continued

Table 4 The adaptation options to maintain housing energy consumption no more than current levels for years 2030, 2050 and 2070 under high carbon emission scenario A1FI

Emission scenario A1FI	House 1 (2 star)			House 2 (5 star)		
	Retrofitted to 5 stars	High energy efficient appliances	PVs (kW)	Upgrade to 7 star	High energy efficient appliances	PVs (kW)
2030	√	No	0	√	No	0
2050	√	√	0	√	√	0
2070	√	√	0	√	√	0.3

As shown in Figs. 4 and 5, even under high carbon emission scenario A1FI, the energy consumption of houses in 2100 is lower than the values when global temperature increases up to 6 °C.

4 Conclusions

This study investigated climate change impacts and potential pathways for climate change adaptation in terms of the total energy consumption and related carbon emissions of housing in Brisbane which represents the climate zone with balanced heating and cooling.

It was found that in Brisbane, slight global warming of 1.0 °C causes insignificant increase in the energy consumption of lower performing houses (such as 2 star 'House 1'). However, as global warming continues to rise, energy consumption will increase rapidly. In particular, as temperatures rise more than 4 °C, energy consumption will increase regardless of improving energy performance of building envelops and using higher energy efficient equipment and appliances. On the other hand, global warming causes immediate increase in the energy consumption of higher performing new houses (such as 5 star 'House 2'). As temperatures rise more than 2 °C, energy consumption will continue to increase regardless of the improved performance of their building envelops and installing higher energy efficient equipment and appliances.

Considering the uncertainties in future carbon emissions, the total energy consumption for the existing and new houses will increase apparently starting from 2030 given the high carbon emission scenario A1FI and medium emission scenario A1B, and increase linearly after 2050.

It was also demonstrated that in heating and cooling balanced regions such as Brisbane current mitigation techniques such as building envelop and appliances upgrade at current global temperatures may only maintain current levels of energy consumption and carbon emissions as temperatures increase, and therefore may no longer serve for carbon mitigation in the future. Other technologies may be required to boost the adaptive capacity. These may include the installation of on-site renewable energy such as solar PVs and solar hot water.

Acknowledgments This research was funded by CSIRO Climate Adaptation Flagship.

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Author Biographies

Zhengen Ren is research scientist in the Urban Systems Program of CSIRO Ecosystem Sciences. His research interests include energy efficient and healthy buildings, urban heat island and heat stress.

Xiaoming Wang is a Senior Principal Research Scientist in the Urban Systems Program of CSIRO Ecosystem Sciences, and a senior research leader of built environment research in the program. He is currently leading the Sustainable Cities and Coasts Theme of the CSIRO Climate Adaptation Flagship. Xiaoming has extensive experiences working on climate impact and adaptation related projects of national significance. He has published more than 200 journal and conference papers, book chapters, and technical reports with collaborations in multi- and inter-disciplines.

Dong Chen is a Principal Research Scientist in the Urban Systems Program of CSIRO Ecosystem Science. Dong is a member of Australian Nationwide House Energy Rating Scheme (NatHERS) technical adversary committee. He is currently leading the research in building indoor environment, urban heat island and green infrastructure for climate adaptation in the program.