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Energy efficiency of housing for older citizens: Does it matter?

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ABSTRACT

Global population ageing has significant implications for public policy in areas such as health, housing and economic security. The notion of housing as a public health issue is not new, yet very little research has examined the links between housing specifically built for older people, energy performance and occupant health and economic security. Utilising a case study approach, this research examined the interplay between the energy efficiency of housing explicitly designed for this demographic, the thermal efficiency of their dwellings, and the impact on internal temperatures and monthly energy costs. The study shows that the thermal efficiency of the dwellings is not the same across all dwellings, impacting the internal temperatures experienced by the elderly occupants and their finances. This has implications for energy efficiency policy, policy governing the energy performance of buildings specifically designed for older people, as well as the mandatory disclosure of building performance. The study highlights in particular the need for energy policy to be further refined to link the thermal performance requirements of buildings to the broader health care plan and specific needs of older people.

1. Introduction

There is a global phenomenon of a numerical and structural ageing of the population. This impending global ageing phenomenon represents a fundamental and dramatic evolutionary shift and signifies a social, health and economic issue for at least another 30 plus years with the number and percent of older people continuing to grow into the middle of the 21st century (Olshansky et al., 2011; United Nations Department of Economic and Social Affairs Population Division, 2013). The Australian Bureau of Statistics acknowledges that the nation's ageing population has significant implications for public policy and the economy in areas such as health, housing and economic security (Australian Bureau of Statistics, 2012). This paper explores age-specific living environments for older Australians (65 years and older), in particular examining if, and to what extent, the approach to energy services in these environments impacts on the health and economic security of their occupants. This Australian case study adopts a place based approach and focuses on the everyday functioning of the living environment for older people. This study has international relevance given worldwide population ageing and the importance of a healthy, functional and affordable living environment for the everyday needs of older people (Howden-Chapman et al., 1999; Oswald et al., 2007; World Health Organisation, 1984). This current research was initiated on a premise that designated age specific living environments for this demographic are based on and delivered through established and conventional design processes rather than processes which consider both the specific energy service needs of the intended occupants and the global move towards a de-carbonised energy system. Specifically this paper explores early research on the interplay between housing designed for this demographic, energy efficiency and thermal comfort and the impact this interplay has on older people's ability to successfully age in place. We argue that the good health and economic capacity of this demographic is challenged by the thermal efficiency of their living environment and the severity of the rising cost of energy. In considering the importance of energy policy for sustainable housing for older citizens, the following section is divided into discussion of the global demographic change currently taking place, the notion of ageing in place and the interplay of climate and the energy efficiency of buildings on the thermal comfort on older people.

2. Background

2.1. The impact of an ageing population

Internationally, it is expected that the number of older people (those over 60 years of age) will continue to grow as a proportion of the world population, reaching 21.1 per cent by 2050 and exceeding the number of young people for the first time by 2047 (United Nations Department of Economic and Social Affairs Population Division, 2013). This is due to a rapid increase in life expectancy in the 20th century;

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associated reductions in infectious diseases and declining early age and maternal mortality (Olshansky et al., 2011). The birth rate is also declining with the largest low-fertility countries being China, the United States, Brazil, Russia, Japan and Viet Nam (Gerland et al., 2014; United Nations Department of Economic and Social Affairs Population Division, 2015). Older people, in the main, are healthier and living longer than previous generations due to public health and medical advances that have led to declining middle and old age mortality (Olshansky et al., 2011). Also fuelling this phenomenon is the ageing of the baby boomer generation, defined in Australia as those born between 1946 and 1965. In 2011, the first of the baby boomers turned 65 commencing a rapid growth in the over 65 cohort, four to five times faster than the total population (Australian Bureau of Statistics, 2012). By 2021, the baby boomers will start turning 75 and will likely substantially increase their use of ageing support and health services (Access Economics (Firm), 2001). However, current and future cohorts of older persons are not homogeneous and their diversity is expected to grow as the size of elderly cohorts swells (Olshansky et al., 2011).

While older people are not homogeneous, with many not requiring any special consideration, as a group they have some distinct population characteristics including a higher incidence of disability (Stone, 2014). Age related disability increases the possibility of housing and health problems with their associated stress and costs to older people, their family, community and government (Howden-Chapman et al., 1999). Affordable and appropriate housing plays a fundamental role in assuring quality of life and active and independent living, which can result in a lessening of demand on health and aged care systems (Oswald et al., 2007; World Health Organisation, 2002). A better understanding of the living environment required for quality of life and active, independent and affordable living for older people is important for future development of housing and lifestyle environments and services. From a government perspective there is a need to better understand the situation of the living environment for older people in order to consider appropriate policy and practice solutions now and into the future. From a business perspective an ageing population represents expansion and new market opportunities with both housing policy and product implications (Stimson and McCrea, 2004).

2.2. Ageing in place

Ageing in place (growing older in one place without the need to move as a result of health impacts) is broadly recognised to be desirable for both older people and the government (Judd et al., 2010). Older people enjoy greater independence and well-being through ageing in place and there is a reduced economic burden on government for institutionalised aged care. While affordable and appropriate housing plays a fundamental role in assuring quality of life and a good quality of life is a right requiring no empirical justification, housing and social policy and social change needs to be driven by a better understanding of what constitutes an 'affordable and appropriate' environment in which older people are committed to ageing in place. The need to better understand older people's experiences is in part driven and supported by research that suggests that the living environment matters (Australian Bureau of Statistics, 2013; Howden-Chapman et al., 1999; Judd et al., 2010; Pinnegar et al., 2013; World Health Organisation, 2007).

Older people in Australia live in private or non-private dwellings including semi-detached and detached houses, apartments, units, flats, granny flats within the grounds of a family member's home, boarding houses, institutions, retirement villages and aged care facilities (including self-contained living units, supported living units and institutional accommodation) (Australian Bureau of Statistics, 2013). [Table 1] Those aged 65–74 were most likely to live with a partner (67%) compared to those aged 85 and older who were least likely to live with a partner (23%) (Australian Bureau of Statistics, 2013). Similarly, the percentage of people in non-private dwellings increases with age (e.g. 26% of people aged 85 years and over), supporting the hypothesis that people's choices about where they live in old age (e.g. in a private or non-private dwelling) are influenced by their need for assistance with everyday activities such as medical, personal care or communication needs.

2.2.1. Retirement villages and residential aged care facilities

These two types of living environments for older Australians vary in housing tenure and operation. Retirement villages are housing estates for predominantly healthy, mobile and independent people aged 55 and over, to support their social and recreational needs amongst peers. Individual dwellings are privately owned or leased, and a range of community facilities and services are provided. Minimal daily personal care and support services are provided. Around 5.3% of those aged 65 years and over are currently housed in retirement villages in Australia and this figure is expected to rise to 7.5% by 2025 (Productivity Commission, 2011). The reasons given by this small but growing number of residents for moving to a retirement village are related to health or physical abilities, changing lifestyle, closeness and security of relatives or friends, challenges of property maintenance, need to be independent of family members, physical support and financial situation (Stimson and McCrea, 2004). At the 2011 consensus, almost 136,000 people lived in retirement villages and almost two-thirds of this group were women.

In contrast, residential aged care facilities cater to the needs of older persons who have low to high level of care needs, including lower levels of mobility and independence. Whilst these facilities may outwardly look very similar to retirement villages, the number and type of services provided to residents is high, for example scheduled meal times and 24 h nursing on call. The average age of occupants of these facilities tends to be higher, and their health care needs tend to result in lower levels of personal mobility. These types of residential facilities are strongly regulated by national laws, in terms of occupancy and associated charges.

2.3. Energy efficiency of housing, thermal comfort and occupant health

A range of physiological, psychological and environmental factors influence thermal comfort for members of a household during the day and over time (Howden-Chapman et al., 1999). These factors may be variable for the individual and household members and include the level of humidity and ventilation, air temperature, temperature of surrounding surfaces and air movement. Thermal comfort is also affected by the clothing worn and activity undertaken as well as the age, health status, gender and adaptation to the climate and local environment of the individual and the household (Vandentorren et al., 2006; World Health Organisation, 1984). Household crowding and under-occupation will also influence thermal comfort (Ormandy and Ezratty, 2012). These factors do not remain stable within the home and it may be difficult to assess some factors especially if attempting to determine the level of comfort for an older person as studies propose that older people do not judge temperature as well as younger people (Roelofsen, 2015; Van Hoof et al., 2010). Older people with multiple co-morbidities are unable to appreciate high temperatures and protect themselves effectively which is largely a result of poor thermoregulation (Dalip et al., 2015).

However, levels of older people's comfort may not only be a useful factor in explaining their use of energy but also be an important part of a holistic view of well-being. For example, Hovmand et al. (2012) have suggested that an intervention can increase comfort and reduce energy bills thereby increasing disposable income which may have a positive effect on well-being. Ormandy and Ezratty (2012) have suggested that any assumptions on the thermal comfort of older people require guidance to give safe limits and that ambient air temperature be the

Table 1
Dwelling types and occupancy for Australians 65 years and older.

Dwelling type and occupancy	Private dwelling with partner/family	Private dwelling alone	Non private dwelling with meals provided
Percentage of the older population in each dwelling type	69%	25%	6% total, made up of 67% in nursing homes (high care needs); and 25% in retirement or residential aged care facilities (low care needs)

main focus of guidance and of thresholds to protect health. The WHO (World Health Organisation, 1984) has determined that there is minimal risk to the health of sedentary people in houses where the ambient temperature is between 18 and 24 °C although a subsequent report (World Health Organisation, 1987) recommended a minimum temperature of 20 °C for the very old (but no maximum temperature).

High temperatures, particularly for prolonged periods of time such as in a heat wave, impact on human health. In Australia, for example, heatwaves have caused more deaths over the past 200 years than floods or cyclones, and heat waves are expected to become more severe and frequent in the future (Steffen et al., 2014). Older people are particularly vulnerable to heat related morbidity (Dalip et al., 2015) and mortality (Banwell et al., 2012; Rikkert et al., 2009) which can be exacerbated by high humidity and lack of air-conditioning (Kravchenko et al., 2013). The excess mortality and morbidity attributed to heat, however, are considered preventable (Banwell et al., 2012; Dalip et al., 2015).

What does this mean in terms of energy policy, housing and the elderly? Studies on the increased health risks of excessive heat (Klenk et al., 2010) and cold (Geddes et al., 2011) affecting mainly old and very old people reveal a number of vulnerable cohorts within this age demographic:

(i) Women;
(ii) People with psycho-geriatric and neurological conditions such as dementia (which alters their thermoregulation mechanisms);
(iii) People with high levels of dependency (e.g. immobility that restricts their capacity to modify their environment or position as a coping mechanism);
(iv) People with a physiological inability to transfer heat from skin (typical response) because of cardiovascular disease, drugs or water depletion;
(v) People who live alone or have low socioeconomic status (Stafoggia et al., 2006)

Weatherising and modifying homes could improve thermal comfort for older people (White-Newsome et al., 2012) as can air-conditioning, however both have capital and operational cost implications (Klenk et al., 2010). In New Zealand this area of research has focused on the health impacts of cold housing and has drawn a link between fuel poverty and energy inefficiency in housing (Howden-Chapman et al., 2012), citing three main factors that impact on unhealthy indoor temperatures, including:

- Low level of thermal efficiency of the housing;
- High levels of income inequality; and
- Increases in real price of residential electricity.

Whilst deaths from cold have tended to be based on investigation of temperatures inside houses, the link between mortality and heat waves has been based primarily on analysis of external ambient temperatures. Very few investigations have examined the relationship between heat waves (outdoor ambient temperature extremes), indoor temperatures and morbidity (i.e. non-fatal effects of heat on chronic illness or on health indicators such as sleep and anxiety), leading to a call for more studies on the urban environment and housing and their effect on mortality and morbidity (Åström et al., 2011).

The research presented in this paper is part of a long term project that is exploring the relationship between housing construction specifically for elderly people, occupants' health, comfort and economic security, and the implications for policy makers and industry. This paper specifically presents early findings on the interplay between housing designed for this demographic, internal temperatures and associated operational energy costs. The purpose of this paper is to initiate discussion on possible energy policy implications of these early findings.

3. Methodology

3.1. Case study of a subtropical residential aged care facility

A case study approach was used to examine in more detail the relationship between buildings, internal temperatures and electricity consumption for older citizens in an aged care facility. This facility consists of 110 one and two bedroom apartments within a community setting that also includes a heated swimming pool, community centre, dining room, library and gardens [Fig. 1]. Onsite nursing care is provided 24 h/day and a full range of nursing and home help services, from low to high care to palliative care, is available to residents in their own home within this estate. The average age of residents is reported by management to be about 80 years and most residents live alone. This facility is located in coastal south-east Queensland (Lat. 27.6°S; Long. 153°E) which has a subtropical climate of warm humid summers and mild dry winters [Table 2].

The single and two storey apartment blocks were constructed in four stages over a period of approximately 3 years (2005–2007). Individual apartments, based on 13 'standard' designs, range in size from 36 m^2 to 74 m^2, with the typical floor area 55–60 m^2. Fig. 1 shows the prevalence of particular apartment designs, indicated by letters A-I, throughout the facility. The estate has its own electricity distribution network (micro-grid) and is connected to the main electricity grid through two gate meters. Residents are charged for their metered electricity use by the site managers. 110 kW of PV (equivalent to 1 kW system for each residence) were installed in 2012 in an attempt to limit spiralling electricity charges [Fig. 2]. Electricity general kW h charges increased 180% from July 2008 to June 2015 whilst the feed-in tariff (FiT) for excess solar sent to the network (net tariff, not gross) decreased from AUD$0.44 kW h to 0.06 kW h over the same timeframe. The embedded PV system allegedly caused problems for the main network and, at the instigation of the network service provider, is currently not fully operational. It was this situation – spiralling energy costs, disconnected PVs and decreased FiT – that lead to the research to evaluate the whole energy system: occupant energy service needs, the buildings and appliances, and the energy forms available. Technical analysis of the interplay between the PV system, the microgrid and the main grid is the subject of further research.

3.2. Data collection

For this study, two sources of data were used: historical energy consumption data and onsite experimental data. The historical consumption data consisted of monthly electricity consumption data, per apartment, for the period of three years and four months (01-July-2011 to 31-Oct-2014). This data was correlated to a number of building

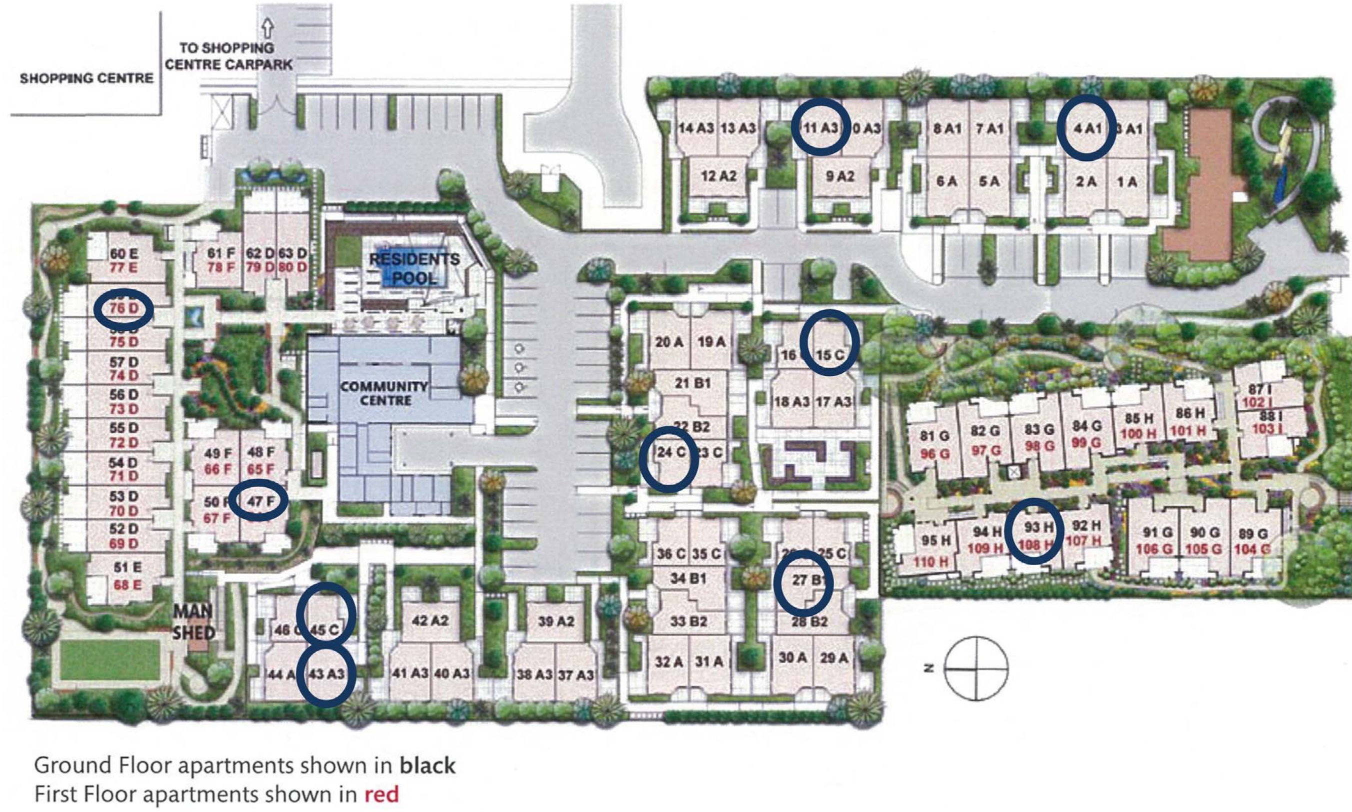

Fig. 1. Site layout of the aged care facility showing apartments under study.

Table 2
Climatic conditions of case study site.

Parameter	Winter (Jun, Jul, Aug)	Spring (Sep, Oct, Nov)	Summer (Dec, Jan, Feb)	Autumn (Mar, Apr, May)
$T_{max-mean}$	21.3 °C	25.5 °C	28.7 °C	25.8 °C
$T_{min-mean}$	9.8 °C	15.6 °C	20.9 °C	19.6 °C
RH_{mean} 9 am	65%	60%	66%	67.7%
RH_{mean} 3 pm	51.7%	58%	62.7%	58.3%
Solar radiation$_{mean/daily}$	13.6 MJ/m^2	21.6 MJ/m^2	22.9 MJ/m^2	16.3 MJ/m^2
Sunshine Hours$_{mean/daily}$	7.6	9.0	8.2	7.7

Fig. 2. Aerial view of Aged Care Facility showing solar power systems.

characteristics, such as the size, design and orientation of each apartment.

To evaluate the impact of building design and construction on occupant thermal comfort and energy consumption, internal and external temperatures of 11 apartments were measured (refer to Fig. 1 for map of units under examination). In these apartments, temperature sensors (Maxim ibuttons) were installed in the main bedroom, bathroom, open plan kitchen/living room and outdoor patio, recording temperature data every 30 min, at a resolution of half a degree Celsius. A relative humidity sensor was also placed in the kitchen/living room. This paper reports on the first period of measured data (82 days): the 2014/2015 Australian summer. Data collection, however, will continue for at least 12 months. All 11 apartments were unoccupied at the time of commencement of data collection, with three apartments becoming occupied halfway during this data collection period. This enabled the researchers to study the effect of building design on internal temperatures (unoccupied units) and the impact of occupants on internal temperatures (units that became occupied during this period). The monitored apartments varied in age, layout, size and orientation of the patio [Table 3]. The wall leading to the patio has the largest glazing ratio of all external walls, resulting in this wall potentially having a significant impact on heat exchange with the interior spaces. Refer to Fig. 1 for the site context of each apartment under study.

4. Results

4.1. Comparison of electricity consumption and costs

Electricity consumption for each unit for the period 01-July-2011 to 31-Oct-2014 was analysed to determine if there were any correlations between consumption and building characteristics such as construction stage, apartment size, orientation or location of apartment in relation to the roof. Table 4 shows the average monthly electricity

Table 3
Characteristics of apartments under examination.

Apartment	Construction stage	Apartment design	Roof exposure	Internal area	Patio area (m^2)	Patio orientation
4	1 and 2	A1 (2 bedroom)	Yes	56	17	North
11		A3 (2 bedroom)	Yes	55	18	North
43			Yes	55		South
27		B1 (2 bedroom)	Yes	55	12	North
15		C (1 bedroom)	Yes	36	15	South
24			Yes	36		North
45			Yes	36		South
76	3	D (1 bedroom)	Yes	60	12.25	North
47		F (1 bedroom)	No	58.5	13.75	West
93	4	H (1 bedroom)	No	56	15.8	West
108			Yes			West

consumption and range of monthly consumption, compared to apartment design type and internal area. The mean monthly electricity consumption across all apartments was 145 kW h/month (range of 28.2–410 kW h/month), 79% of the consumption of a 'representative single person household' (a low energy consumption household) as represented by the Queensland Competition Authority (2015). The monthly consumption, per square meter of internal space, ranged from 1 to 7 kW h/m^2/month, with an average of 3 kW h/m^2/month. Comparison of apartments of the same size (55–56 m^2) still revealed a consumption range of 1–7 kW h/m^2/month. Interestingly one of the smallest apartments (type C) had the highest usage per m^2, whilst the largest apartments (74 m^2) were amongst the lowest consumers per m^2. This would seem to indicate that apartment size is not, of itself, an indicator of energy consumption. Apartments constructed in stage 3 and 4 of the development had a lower monthly electricity consumption per m^2. This is likely due to hot water services: apartments in stages 1 and 2 have electric hot water services whilst those in stages 3 and 4 have gas water heating. The energy for gas water heating is not included in the electricity consumption data. If we apply the current price of electricity (AUD$0.2545 kW h) to the consumption, we get a clear picture of the financial impact of the differences in energy consumption (Table 4). For example, monthly electricity costs (consumption component only) for residents in type A and B apartments account for 1–6% of the monthly aged care pension (2015 rates). What could account for these large differences in electricity consumption, given the seeming homogenous nature of the occupant demographic?

There did appear to be some correlation between energy consumption and the location of the apartment compared with the roof (i.e. if the apartment was directly under the roof, or was on the lower floor of a 2 storey building). Apartments without direct exposure to the roof had an energy consumption range of 1–5 kW h/m^2/month (average of 2 kW h/m^2) whilst those with direct exposure to the roof had an energy consumption range of 1–7 kW h/m^2/month (average 3 kW h/m^2). Eighteen of the top twenty consuming apartments were exposed to the roof, i.e. their ceilings were exposed to the buildings' roof space.

There was also evidence of seasonal differences in energy consumption for some apartments, as shown by the examples in Table 5. Some units showed little variation in energy consumption from month to month (e.g. apartment 16) whilst others showed significant differences between summer and winter consumption. For example, July and February usage in apartment 56 (highest single occupant usage) was 60–70% higher than shoulder seasons. In apartment 32 (highest dual occupant usage), February consumption was 4–5 times higher than shoulder seasons, with no significant winter heating load. This would seem to indicate electricity consumption being effected by the climate and the manner in which the building characteristics protect the occupants from the climate. There did not appear to be a clear correlation between the orientation of the patio (and hence the largest area of glazing) and energy consumption. Further investigation would be required to account for other possible variations, such as occupancy rates per month (e.g. were residents on holidays or hospitalised), number of general household appliances, or the combined effects of window orientation, floor area and roof exposure.

4.2. Comparison of thermal performance of unoccupied apartments

An indication of the impact of construction on internal temperatures can be found by comparing apartments 93 and 108 (refer to Fig. 1

Table 4
Comparison of monthly electricity consumption and costs.

Apartment design type	Internal area	Construction stage	Range of monthly kW h	Average monthly kW h	Average monthly kW h/m^2	Range of monthly electricity costs[a] AUD$
A, A1, A2, A3, B1, B2	55–56 m^2	1 and 2	64.5–410.8	122	3	$16.42 $104.55
C	36 m^2	2	64.5–243.9	161.8	5	$16.42 $62.07
D	60 m^2	3	52.7–306.1	129.8	2	$13.41 $77.90
E	74	3	99.2–147.8	132.8	2	$25.25 37.87
F	58.5	3	40.9–216.1	105.8	2	$10.41 $57.54
G	70.7	4	40.8–276	141.2	2	$10.38 $70.24
H	56	4	28.2–211.5	112.3	2	$7.18 $53.83
I	55.75	4	96.3–117.8	104.9	2	$24.50 $29.98

[a] Costs indicative, assuming 25.45c/kW h, the current retail charge in QLD; includes Goods and Services Tax (GST) but excludes metering charges and daily network connection charges.

Table 5
Seasonal energy consumption of a selection of apartments.

Apartment	Orientation of patio (largest glazing area)	Winter (July) average kW h/day	Summer (Dec/Jan) average kW h/day
16	North	3.9	3.8
18	North	9.2	3.8
104 (5th highest user)	West	7.3	4.2
98 (in top 20 highest users)	East	15	6.4
32 (highest user)	North	3.5	8.6
83	East	5.3	11.2

Fig. 3. Unit floor plan.

Fig. 4. Unit interior.

for their location in the estate). These apartments have an identical orientation, floor plan and interior (Figs. 3 and 4), and were both unoccupied during the study period. The thermal characteristics of the built structure were uniform for both units, with the exception of the ceiling. For these two units the only difference between the apartments is their building position (i.e. ground floor or upper floor), resulting in different thermal characteristics of the ceiling due to separation or exposure to the building's roof space.

The average daily temperatures of these apartments during the 2014/15 summer data collection period are presented in Figs. 5 and 6. A comparison of these graphs shows a much more consistent and lower internal temperature gradient in the lower floor apartment (25–27 °C) than the upper floor apartment (26–29 °C). Internal temperatures of

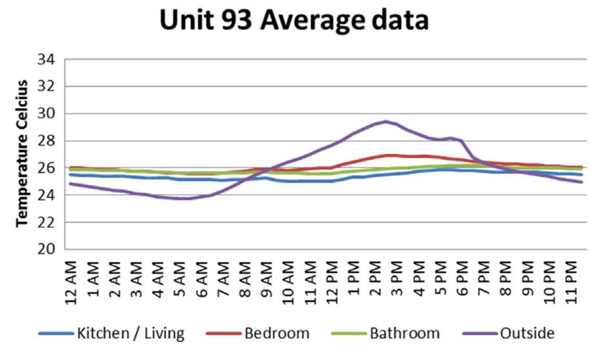

Fig. 5. Temperature data apartment 93.

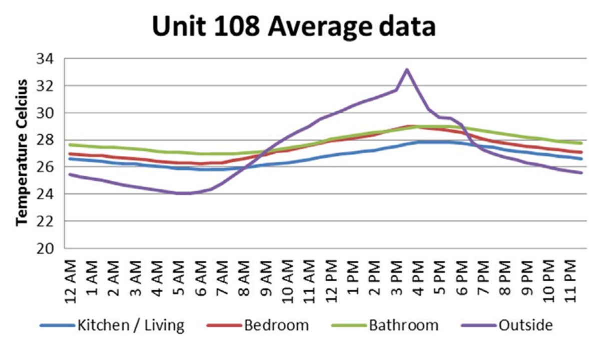

Fig. 6. Temperature data apartment 108.

the upper floor apartment respond much more to the external temperatures, with a thermal lag time (the time for inside temperatures to respond to outdoor temperatures) of approximately one hour. This would seem to indicate that the thermal comfort levels of the upper floor apartment are being influenced by the roof of the building, suggesting possible poor levels of ceiling and/or roof insulation. Both apartments show relatively high external temperatures on the west facing outdoor patio during daylight hours. The lower temperatures recorded in the lower storey patio would suggest that it receives a higher level of shading (possibly from the upper storey and from external landscaping) than the upper storey patio. Both patios exhibit temperatures that would likely not be comfortable for occupants, likely making these spaces predominantly un-useable during summer days.

Presenting this data in a histogram is even more revealing. Figs. 7 and 8 show the percentage of time that each monitored zone spent in different temperature bands, with green representing the acceptable summer 'comfort band' of 20–26 °C assumed by the Australian building regulations for this climate and supported by adaptive comfort research (Nationwide House Energy Rating Scheme, 2014; Tuohy et al., 2010). These graphs clearly show that each zone of the upper floor apartment (108) is outside of the comfort band for a much larger proportion of the time compared to the ground floor apartment, and that the temperature range in these zones is greater than those

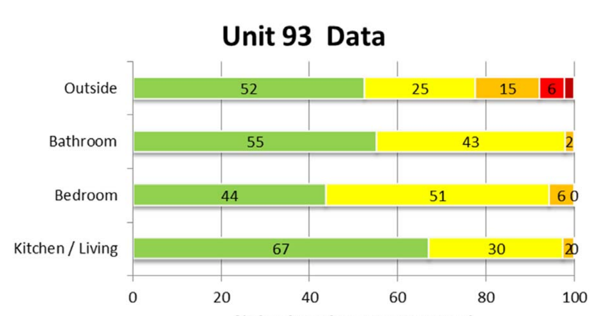

Fig. 7. Temperature histogram of apartment 93.

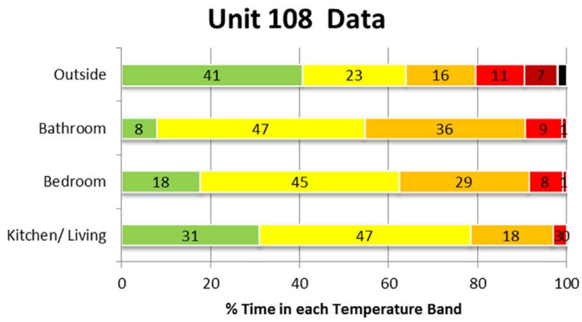

Fig. 8. Temperature histogram of apartment 108.

experienced in the lower floor apartment.

This data shows that although the two apartments share the same design plan and orientation, there is a vast variation in internal temperatures. These temperature differences would likely impact the thermal comfort and health of occupants (if no mechanical heating or cooling was utilised) and impact the energy costs occupants would need to pay to achieve acceptable thermal comfort (because more heat needs to be pumped out of the upper floor apartment, for longer periods of time). It is possible that neither potential occupants nor building owners/operators are aware of these differences in the thermal performance of apartments. One could perhaps presume that, psychologically, occupants may tend to favour upper storey apartments because of access to better views and access to breezes to aid in thermal comfort. This data, however, suggests that upper floor apartments are not as thermally comfortable as their lower floor counterparts. Consequent physical inspection of the attic space revealed that the only insulation in the roof cavity was reflective foil under the metal roof. There was no bulk insulation on the ceiling cavity.

4.3. Comparison of impact of occupancy on thermal performance

The impact of occupants on the thermal performance of apartments can be seen by comparing apartments 27 and 93. Both of these apartments were unoccupied at the commencement of the monitoring period but became occupied during the monitoring period. Occupancy rates during the study period are indicated in Table 6.

Fig. 9 shows the temperature histograms of the two apartments before and after occupancy. In its vacant condition, apartment 27 had a good proportion of hours (61%) in the 'comfort band' of 20–26 °C. With occupants, there was almost no variation in temperatures, implying that occupants were comfortable with the temperatures of the apartment. The slight increase in the percentage of time in the temperature range 28–30 °C could be attributed to internal heat gains from appliances. In apartment 93 it appears as if occupants have utilised cooling devices (an air conditioner) to increase the proportion of time within the comfort band and to ensure the temperature does not exceed 28 °C.

These observations would suggest that the more thermally comfortable an apartment is, the less action is required by aged occupants to manage their comfort. The implications of this will be discussed in the next section.

Table 6
Occupancy rate of apartments 27 and 93 during study period.

	Unoccupied	Occupied	Occupancy rate
Unit 27	27/11/2014 to 5/01/2015	6/01/2015 to 17/02/2015	50.7%
Unit 93	27/11/2014 to 5/02/2015	6/02/2015 to 17/02/2015	13.6%

5. Discussion and policy implications

This study demonstrates that, for this residential aged care facility, the standard of energy efficient housing in terms of thermal comfort levels and performance provided to residents of similar demographic profile is not evenly distributed across the residences within the village. Retirement villages and residential aged care facilities are purpose-built accommodation for older people to successfully age in place with appropriate support within a community environment. The findings of this current study are significant in informing energy efficiency policy in general and in the development of policy governing the energy performance of buildings designed for older people.

Excess heat related morbidity and mortality has been associated with poor thermal efficiency of housing (Vandentorren et al., 2006; World Health Organisation, 1984). In the French study, Vandentorren et al. (2006) found five significant risk factors for the heat related deaths of older people living at home including:

1. Lack of mobility;
2. Some pre-existing medical conditions (mental disorders, cardiovascular diseases and neurological diseases;
3. Housing characteristics: e.g. construction date as an indication of presence/absence of insulation; living on top floor (closest to the roof); number of windows per 50 m^2; location of bedroom (location directly under roof and sun exposure/orientation);
4. Temperature (outdoor ambient temperature) - which can be higher than reported ambient temperatures due to a heat island effect in local urban neighbourhoods (e.g. lots of hard surfaces absorbing the heat and re-radiating it); and
5. Occupant behaviour (e.g. opening windows in the afternoon, level of clothing, ability to use cooling devices and techniques).

This current study supports these international studies, confirming that poor building thermal characteristics impact on internal temperatures that in turn present a potential risk to elderly occupants. In particular, this study has found quite significant thermal comfort differences between dwellings on the top floor immediately under the roof (i.e. a roof cavity with an un-insulated ceiling) and those on the ground floor, thereby ostensibly putting residents living in top floor dwellings in greater risk of heat related morbidity and mortality. Results show that residents in top floor dwellings also have increased energy costs with eighteen of the top twenty electricity consuming apartments having direct exposure to the roof. These differences raise significant concerns in terms of policy development, in particular the need to integrate building energy efficiency regulations with residents' health, the refinement of building rating tools and outputs, and consideration of the implications for equity and affordability.

5.1. Implications for energy policy linking building regulations and health

This study highlights two specific energy policy 'black holes' in Australia that may have implications for energy policy internationally. First, the energy efficiency standards required for housing in general (detached and semi-attached housing and apartments) do not currently apply to purpose built accommodation for an older population (considered to be a different class of buildings, not 'housing' per se). Second, many 'health protection' regulations apply to purpose built accommodation for this demographic, yet the thermal performance of the buildings is not considered as part of their overall health care plan.

Energy policy that generates the re-examination and refinement of building regulations to reflect and integrate current knowledge of healthy aging and energy efficient housing is urgently needed. The notion of housing as a public health issue is not new (Howden-Chapman et al., 1999; Krieger and Higgins, 2002). Information on the impact of building efficiency standards on internal temperatures

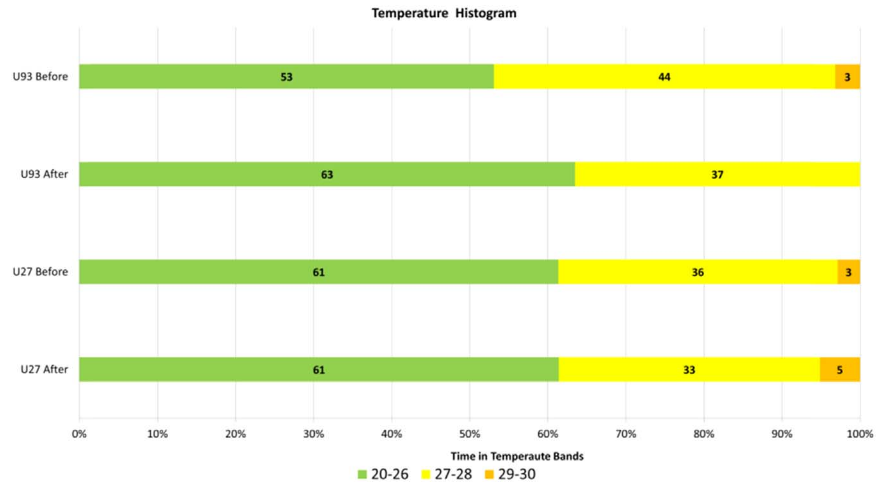

Fig. 9. Temperature histogram in Apartments 27 and 93 before and after occupancy.

needs to be disseminated to everyone involved in the care of older people so strategies can be put in place to adjust and manage routines in the event of heat waves or extended periods of hot and humid weather. For example, Vandentorren et al. (2006) found opening windows in the afternoon (when outdoor temperatures begin to drop), dressing in light clothing and the ability to use cooling devices and techniques to be important protective factors in avoiding heat-related mortality. In the middle to longer term, energy policy that governs more stringent regulation of the thermal performance of the building envelope must be adapted to provide protection from possible heat waves and extended periods of hot weather. This applies to all housing types in the general community (e.g. to support ageing in place within existing communities) as well as energy policy that establishes higher thermal performance standards for accommodation specifically designed for older people. Enhanced national energy policy establishing uniform codes or guidelines that address factors affecting morbidity and mortality such as thermal comfort performance is needed. Such policy could be applicable for both new and existing housing stock of all types and would be a valuable asset for a number of stakeholders including the retirement village and residential aged care industry, older people and their family and friends as well as public health agencies.

5.2. Implications for energy policy relating to building rating tools

The apartments in this study have very different levels of thermal performance with the findings based on a range of internal temperature measurements within the studied apartments. The findings from this study raise questions and issues that need to be addressed by energy policy to establish what should be rated to determine the thermal efficiency of buildings to best inform housing codes for healthy housing. Questions and issues include:

- Should dwellings be rated for 'average' weather as well as for extreme weather conditions such as heat waves and cold spells? Ratings based on average weather conditions could mask the thermal performance on extreme weather days when the older person is particularly at risk of heat or cold related morbidity or mortality.
- Should information about a building's performance be communicated per room rather than an average across the dwelling (or across a whole building)? Should each dwelling have a rating for different climate conditions (e.g. summer, winter, shoulder seasons)? Ratings per room and under different climate conditions could potentially be more useful for older people 'at risk' of heat related morbidity and mortality. Average ratings for an individual residence may hide poor thermal performance rooms where the older person/s spend/s the majority of their time, e.g. their bedroom and lounge room. Average ratings for apartments within one building (the typical practice in Australia for standard housing) are equally meaningless in communicating the likely thermal performance of specific apartments within a building.
- Should the 'comfort set point' of building simulation tools for regulatory purposes be adjustable, to account for the different comfort needs of older people? As people age, they often suffer from poor thermoregulation as a result of multiple co-morbidities which makes it difficult for them to appreciate high temperatures and protect themselves effectively (Dalip et al., 2015). It would be valuable to have the flexibility to adjust the 'comfort set point' in such circumstances.

5.3. Implications for energy policy addressing equity and affordability

This study demonstrates the disparity between apartments within the one residential complex in terms of thermal performance and the implications this disparity has on energy consumption and hence operational costs across a group of residents of similar demographic profile. This raises issues of equity and affordability. The major disparity was that the apartments were not equal in terms of thermal comfort and associated running costs. There was a significant difference between upper level and ground floor residences with the ground floor apartments outperforming those of the upper level. This raises an interesting ethical question of whether the thermal performance of apartments should be disclosed to potential residents and/or their families at the point of tenancy or sale.

The cost of cooling and heating increases exponentially as the variance between temperatures outside and inside surge (Howden-Chapman et al., 1999). To conserve costs, some older people may keep the temperature at uncomfortable levels which Vandentorren et al. (2006) found to be a major risk factor of heat related mortality. In their study, Howden-Chapman et al. (1999) found anecdotal evidence that many older people overly economised on heating during the oil crisis due to an increased sense of civic responsibility. Keeping indoor temperatures at uncomfortable levels is a significant health risk to older people (World Health Organisation, 1984, 1987) whether it be to conserve costs or because of civic consciousness. The mandatory disclosure of the energy efficiency (thermal performance) of individual units, at the point of sale/lease/occupancy, would enhance transparency and consumer knowledge of the links between building performance, health and operational costs. Whilst some level of mandatory disclosure of building energy performance exists in some countries (not

Australia), the authors of this paper could find no evidence of any energy policy requiring this level of energy performance disclosure for individual units.

6. Conclusion

This study has established the importance of understanding the thermal performance characteristics of dwellings for older people, the impact that thermal performance has on their health and their living costs, and the implications of these findings on energy policy development and refinement. Whilst the paper deals with the preliminary findings from only one aged care facility, the findings have implications for all accommodation for older people whether it be private or non-private, national or international.

The study has highlighted the need for energy policy, in particular building regulations, to continue to enhance minimum standards for thermal efficiency as a matter of occupant health and safety and to link the thermal performance requirements to the broader health care plan of older people. It also presents an argument supporting mandatory disclosure of the thermal performance of dwellings, and individual rooms within dwellings, as a means of ensuring that occupants (older people, their families and/or their carers) can adapt strategies for ensuring occupant health is not put at risk. This study makes a significant contribution to the continuing development and refinement of energy policy that acknowledges the links between the thermal comfort efficiency of purpose built accommodation for older people and its impact on the good health, active ageing in place and economic capacity of older people.

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References

Access Economics (Firm), 2001. Population ageing and the economy. Australian Department of Health and Aged Care. Accessed from: ⟨http://nla.gov.au/anbd.bib-an46130134⟩.

Åström, D.O., Forsberg, B., Rocklov, J., 2011. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. Maturitas 69, 99–105. http://dx.doi.org/10.1016/j.maturitas.2011.03.008.

Australian Bureau of Statistics, 2012. Who are Australia's Older People?: 2071.0 – Reflecting a Nation: Stories from the 2011 Census. ABS. Accessed 21/6/2015 from: ⟨www.abs.gov.au⟩.

Australian Bureau of Statistics, 2013. Where and How do Australia's Older People Live? 2071.0 – Reflecting a Nation: Stories from the 2011 Census ABS. Accessed 17/4/2015 from: ⟨www.abs.gov.au⟩.

Banwell, C., Dixon, J., Bambrick, H., Edwards, F., Kjellström, T., 2012. Socio-cultural reflections on heat in Australia with implications for health and climate change adaptation. Glob. Health Action, 5. http://dx.doi.org/10.3402/gha.v3405i3400.19277.

Dalip, J., Phillips, G.A., Jelinek, G.A., Weiland, T.J., 2015. Can the elderly handle the heat? A retrospective case-control study of the impact of heat waves on older patients attending an inner city Australian emergency department. Asia-Pac. J. Public Health 27, 1837–1846. http://dx.doi.org/10.1177/1010539512466428.

Geddes, I., Bloomer, E., Allen, J., Holdblatt, P., 2011. The Health Impacts of Cold Homes and Fuel Poverty. Friends of the Earth and Marmott Review Team, University College London. Accessed 24/9/2015 from: ⟨https://www.foe.co.uk⟩.

Gerland, P., Raftery, A.E., Sevcikova, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B.K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G., Wilmoth, J., 2014. World population stabilization unlikely this century. Science 346, 234–237. http://dx.doi.org/10.1126/science.1257469.

Hovmand, P.S., Andersen, D.F., Rouwette, E., Richardson, G.P., Rux, K., Calhoun, A., 2012. Group Model-Building 'Scripts' as a Collaborative Planning Tool. Syst. Res. Behav. Sci. 29, 179–193. http://dx.doi.org/10.1002/sres.2105.

Howden-Chapman, P., Signal, L., Crane, J., 1999. Housing and health in older people: ageing in place. Soc. Policy J. N.Z., 14–30.

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivant, K., Taflar Barnard, L., Lloyd, B., 2012. Tackling cold housing and fuel poverty in New Zealand: a review of policies, research, and health impacts. Energy Policy 49, 139–142. http://dx.doi.org/10.1016/j.enpol.2011.09.044.

Judd, B., Olsberg, D., Quinn, J., Groenhart, L.A., Demirbilek, O., 2010. Dwelling, Land and Neighbourhood use by Older Home Owners. Australian Housing and Urban Research Institute. Accessed 21/4/2015 from: ⟨http://www.ahuri.edu.au/research/final-reports/144⟩.

Klenk, J., Becker, C., Rapp, K., 2010. Heat-related mortality in residents of nursing homes. Age Ageing 39, 245–252. http://dx.doi.org/10.1093/ageing/afp248.

Kravchenko, J., Abernathy, A.P., Fawzy, M., Lyerly, H.K., 2013. Minimzation of heatwave morbidity and mortality. Am. J. Prev. Med. 44, 274–282. http://dx.doi.org/10.1016/j.amepre.2012.11.015.

Krieger, J., Higgins, D.L., 2002. Housing and health: time again for public health action. Am. J. Public Health 92, 758–768.

Nationwide House Energy Rating Scheme, 2014. Nationwide Home Energy Rating Scheme. Accessed 06/07/2016 from: ⟨http://www.nathers.gov.au/owners-and-builders/star-rating-scale-overview⟩.

Olshansky, S.J., Biggs, S., Achenbaum, W.A., Davison, G.C., Fried, L., Gutman, G., Kalache, A., Khaw, K., Fernandez, A., Rattan, S., Guimaraes, R.M., Milner, C., Butler, R., 2011. The Global Agenda Council on the ageing society: policy principles. Glob. Policy 2, 97–105.

Ormandy, D., Ezratty, V., 2012. Health and thermal comfort: from WHO guidance to housing strategies. Energy Policy 49, 116–121. http://dx.doi.org/10.1016/j.enpol.2011.09.003.

Oswald, F., Wahl, H.W., Schilling, O., Nygren, C., Fänge, A., Sixsmith, A., Szeman, Z., Tomsone, S., Iwarsson, S., 2007. Relationships between housing and healthy aging in very old age. Gerontologist 47, 96–107.

Pinnegar, S., van den Nouwelant, R., Judd, B., Randolph, B., 2013. Understanding housing and location choices of retiring Australians in the 'baby boom' generation. Scoping Report prepared for the National Housing Supply Council. City Futures Research Centre, University of New South Wales. Accessed October 2015 from: ⟨www.cityfutures.net.au⟩.

Productivity Commission, 2011. Caring for Older Australian, Final Enquiry Report. Australian Government. Accessed September 2015 from: ⟨http://www.pc.gov.au/inquiries/completed/aged-care⟩.

Queensland Competition Authority, 2015. Electricity Prices - Residential Tariff. Accessed 04/07/2015 from: ⟨http://www.qca.org.au/Electricity/Electricity-Prices-2015%E2%80%9316/Electricity-prices-2015-16/Electricity-Prices-Residential-Tariff⟩.

Rikkert, M.G.M.O., Melis, R.J.F., Claassen, J.A.H.R., 2009. Heat waves and dehydration in the elderly (Editorial). Br. Med. J. 339, 119–120. http://dx.doi.org/10.1136/bmj.b2663.

Roelofsen, P., 2015. Healthy Ageing: differences between elderly and non-elderly in temperature sensation and dissatisfied. Intell. Build. Int., 1–15. http://dx.doi.org/10.1080/17508975.2015.1063474.

Stafoggia, M., Forastiere, F., Agostini, D., Biggeri, A., Bisanti, L., Cadum, A., Caranci, N., de'Donato, F., De Lisio, S., De Maria, M., Michelozzi, P., Miglio, R., Pandolfi, P., Picciotto, S., Rognoni, M., Russo, A., Scarnato, C., Perucci, C., 2006. Vulnerability to heat-related mortality. A multicity, population-based, case-crossover analysis. Epidemiology 17, 315–323.

Steffen, W., Hughes, L., Perkins, S., 2014. Heatwaves: Hotter, Longer, More Often. Limited, C.C.o.A. Accessed March 2014 from: ⟨https://www.climatecouncil.org.au/heatwaves-report⟩.

Stimson, R.J., McCrea, R., 2004. A push-pull framework for modelling the relocation of retirees to a retirement village: the Australian experience. Environ. Plan. A 36, 1451–1470. http://dx.doi.org/10.1068/a36206.

Stone, S.D., 2014. Age-related disability: believing is seeing is experiencing. In: Kriebernegg, U., Maierhoger, R. (Eds.), The Ages of Life: Living and Aging in Conflict?. transcript Verlag.

Tuohy, P., Roaf, S., Nicol, F., Humphreys, M., Boerstra, A., 2010. Twenty first century standards for thermal comfort: fostering low carbon building design and operation. Archit. Sci. Rev. 53, 78–86. http://dx.doi.org/10.3763/asre.2009.0112.

United Nations Department of Economic and Social Affairs Population Division, 2013. World Population Ageing 2013. Nations, U. Accessed August 2014 from: ⟨www.un.org/en⟩.

United Nations Department of Economic and Social Affairs Population Division, 2015. World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. Accessed April 2016 from: ⟨www.un.org/esa/population⟩.

Van Hoof, J., Kort, H., Hensen, J., Duifnstee, M., Rutten, P., 2010. Thermal comfort and the integrated design of homes for older people with dementia. Build. Environ. 45, 358–370. http://dx.doi.org/10.1016/j.buildenv.2009.06.013.

Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C., Riberon, J., Siberan, I., Declercq, B., Ledrans, M., 2006. August 2003 heat wave in France: risk factors for death of elderly people living at home. Eur. J. Public Health 16, 583–591. http://dx.doi.org/10.1093/eurpub/ckl063.

White-Newsome, J.L., Sánchez, B.N., Jolliet, O., Zhang, Z., Parker, E.A., Dvonch, T., O'Neill, M.S., 2012. Climate change and health: indoor heat exposure in vulnerable populations. Environ. Res. 112, 20–27. http://dx.doi.org/10.1016/j.envres.2011.10.008.

World Health Organisation, 1984. The Effects of the Indoor Housing Climate on the Health of the Elderly: Report on a WHO Working Group. WHO for Europe, Copenhagen.

World Health Organisation, 1987. Health Impact of Low Indoor Temperatures: Report on a WHO Meeting. WHO for Europe, Copenhagen.

World Health Organisation, 2002. Actuve Ageing: a Policy Framework. WHO, Geneva.

World Health Organisation, 2007. Global Age Friendly Cities: a Guide. WHO, Geneva.