Author/s:
Crawford, R;Paton-Cole, V;Turnbull, R;Fitzgerald, E;Michalewicz, A;Garber, J

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Trends in residential sustainability measures in the state of Victoria

R H Crawford[1], V Paton-Cole[1], R Turnbull[2], E Fitzgerald[2], A Michalewicz[2] and J Garber[2]

[1] Faculty of Architecture, Building and Planning, The University of Melbourne, Parkville 3010, Australia
[2] Melbourne Data Analytics Platform, The University of Melbourne, Parkville 3010, Australia

rhcr@unimelb.edu.au

Abstract. Buildings require a significant quantity of energy and water during their operation. Solar water heaters and rainwater tanks have become increasingly common to reduce the demand for fossil-fuel based energy and mains water within buildings. Since 2006, the Victorian Building Authority has required either a rainwater tank or solar water heater to be installed in any new house built in Victoria, Australia. This research analyses the trend in adoption of these two systems using data from building permits issued from 2006 to 2019. This shows that despite an initial preference for rainwater tanks, solar water heaters have been the preferred choice. This preference was found to be greatest for projects costing from $200k-$600k and for allotment areas smaller than 500 m^2. Preference for rainwater tanks tended to increase in line with an increase in project cost and allotment area, and this preference was found to be most common in metropolitan areas. This study provides insight into the opportunities for further adoption of solar water heaters and rainwater tanks, including using information at the LGA level to develop specific business opportunities or to inform policy, such as alternative water efficiency solutions for households where allotment area may limit rainwater tank adoption.

1. Introduction

Households account for around 26% of Australia's energy demand and 13% of its national distributed water demand [1]. This demand is increasing, further exacerbating existing concerns around resource depletion, greenhouse gas emissions and air pollution. In addition, droughts have caused major water supply issues in Australia and are expected to become more frequent and intense [2]. Thus, the need to reduce energy and water demand within our buildings is of critical concern for the long-term resilience and sustainability of society.

The energy and water efficiency of Australia's buildings has improved substantially over recent decades [1], bolstered by the energy crises of the 1970s and increasing environmental awareness throughout the 1980s until the present day. Regulatory requirements under Australia's National Construction Code [3] have contributed significantly to these improvements, setting minimum performance requirements for buildings. This has led to substantial energy and water savings for individual households [1].

While geographic variations across Australia can be significant, for the state of Victoria, energy use for hot water supply represents, on average, 13% of a household's total energy demand, second only behind heating (38%) [4]. The main uses of water in households include bathing/showering (45%), clothes washing (22%) and garden watering (19%) [5].

Acknowledging the considerable potential of residential buildings to help mitigate supply and environmental concerns, in 2005 the state of Victoria mandated the installation of a solar water heater or rainwater tank for all new Class 1 buildings (i.e., single, standalone single houses and horizontally attached houses). Rainwater tanks were a critical solution to addressing water supply issues at this time as southern Australia was in the midst of the Millennium Drought, which spanned from 1996 to 2010, causing significant decline in water storages [6]. Rainwater tanks were in high demand during this period as they enabled householders to maintain gardens amid an extended period of tight water restrictions [7].

Solar water heaters reduce demand for grid-based electricity (which in Australia is predominately produced using fossil fuels [8]) and natural gas. They use the sun as an alternative, renewable energy source to heat water, thus reducing a household's reliance on fossil fuels and the associated environmental effects. While boosting from grid-sourced electricity or natural gas is typically required during periods of low solar availability, these systems can reduce fossil fuel-based energy demand by up to 88% [9]. This can also result in substantial financial savings for householders [9].

Installation of rainwater tanks allows householders to collect rainwater that falls on their roof and use this water within the household, subject to regulatory restrictions. Water can generally be used for toilet flushing, clothes washing, bathing and showering, car washing, and garden watering. The collection and use of rainwater reduces reliance on mains water and pressure on catchment water storages, increases water security and decreases utility costs for householders. Installation of rainwater tanks could potentially reduce mains water demand by up to 100%, depending on tank size, rainfall and household water demand.

An analysis of the correlation between the adoption of solar water heaters and rainwater tanks and a range of different factors, such as geographic dispersion, socio-economic status, and housing characteristics would provide useful insight into understanding key factors influencing their uptake, market gaps, future maintenance and replacement requirements, and policy.

1.1. Aim
The aim of this study was to analyse the historical trends in the adoption of solar water heaters and rainwater tanks in the state of Victoria, Australia, identifying correlations to key household characteristics, including geographic dispersion, social-economic status of householders, project cost and allotment area.

2. Residential Sustainability Measures
Australia's National Construction Code [3] combines the Building Code of Australia and the Plumbing Code of Australia, setting out the technical design and construction provisions for buildings. These codes include provisions for energy efficiency which aim to reduce building energy demand. Buildings must meet performance requirements in relation to heating and cooling loads, glazing, building sealing, air movement, services, and artificial lighting. These provisions are now part of the 6 Star Standard, introduced in 2010 [10], which is a progression from the less stringent 5 Star Standard introduced from 2006 [11], and the first mandatory building energy efficiency standards introduced in 2003 [12]. The state of Victoria developed a variation to these provisions which also requires the installation of either a solar water heater or a rainwater tank for any new Class 1 buildings, taking effect from 1 July 2005. These variations replace Part 3.12.0a in Volume 2 of the National Construction Code 2019 [3] and are detailed further in Practice Note 55-2018 [13].

The solar water heater option allows two different systems, either a gas boosted solar water heater or a heat pump system. The system must be gas boosted if reticulated gas supply is available. If a heat pump system is installed, mains electricity must not be used to heat the water. Where the rainwater tank option is chosen, the Plumbing Regulations 2018 [14] require that the rainwater tank is installed so that it receives rainfall from a minimum catchment area of 50 square metres, has a minimum capacity of 2,000 litres, and is connected to all toilets in the building for the purpose of sanitary flushing [15].

2.1. Adoption and benefits of residential sustainability measures

A study by Harrington [9] evaluated the benefits and costs generated by the implementation of the 6 Star Standard in Victoria, including those associated with the requirement for a solar water heater (but excluded any analysis of rainwater tanks). The study considers the benefits and costs from 2006 to 2019, based on ABS building activity data, Victorian Building Authority (VBA) building permit data and several other data sources. Based on the data obtained from the VBA (for 2008 to 2017) an average of 52% of new Class 1 buildings selected a solar water heater and 23% a rainwater tank, where data exists. In their evaluation, Harrington [9] indicates that 20–30% of building permit records held by the VBA do not report whether or not a solar water heater or rainwater tank has been installed. The two reasons for this may be non-reporting of the choices made (rather than non-compliance) or building permits covering multiple dwellings where the choice may be recorded under the permit for an associated dwelling [9]. Assuming a similar trend in uptake for projects where data is not reported, Harrington [9] showed that from 2008 to 2017, a solar water heater was chosen by around 70% of new homeowners, with an increasing share over the study period. The peak annual benefits of all measures were shown to include 3.7 PJ of avoided energy consumption and 341 ktCO_2-e of avoided greenhouse gas emissions. The energy savings from the uptake of solar water heaters alone were predicted to peak at over 1.6 PJ per annum in 2019. Since this study, data from 2018–2019 has become available, but is yet to be analysed. Several other studies have also looked at the costs and environmental benefits of housing energy and water efficiency measures, further highlighting the considerable environmental and economic benefits (e.g., Morrissey and Horne [16], Crawford, Bartak [17]).

2.1.1. Adoption of solar water heaters. Studies that have considered the adoption of solar water heaters in residential buildings have tended to focus on the key barriers and motivators for their adoption (inter alia, Urmee, Walker [18] in Australia; Wang, Xiong [19] in China; Sanguinetti, Outcault [20] and Sharma [21] in the United States) as well as broader public perceptions (inter alia, Nasirov, Carredano [22]). These studies have found that there is a wide variety of barriers and motivators to the adoption of solar water heaters, involving technical, social, economic and policy factors [23].

In their evaluation of the significance of different predictors of the adoption of solar water heaters, Ghaboulian Zare, Hafezi [24] found that certain attitudinal attributes (such as individual perceptions of the technology) have a stronger influence on the adoption of solar water heaters than factors such as electricity cost. In their analysis of 100 studies on the adoption decision for residential solar water heaters, 123 predictors were identified. 'Financial incentives' and 'perceived attitude towards government policies' were among the most popular economic predictors. 'House type' and 'geographical location' were among the top five. While the correlation between the identified predictors and the adoption decision was investigated, correlation between actual housing characteristics and adoption of solar water heaters was not analysed.

A study by Higgins, McNamara [25] developed a model to predict future adoption of solar water heaters which was implemented in the state of New South Wales, Australia to estimate future water heater options at geographical units of 250 households and was able to effectively identify high versus low adoption locations. This study considered factors such as housing type, home ownership, household income and number of bedrooms and found a strong correlation between solar water heater adoption and higher household income.

2.1.2. Adoption of rainwater tanks. Over a third of all Australian households have a rainwater tank installed [26]. As per the studies on the adoption of solar water heaters, those studies to have considered the adoption of rainwater tanks in the residential context have tended to focus on key barriers and motivators for their adoption. Examples include studies by Staddon, Rogers [27] in Uganda, Tapsuwan, Cook [28] in Australia, and Hameed, Javed [29] in Pakistan. Mankad and Tapsuwan [30] conducted a review of the social and economic drivers for decentralised water systems, including rainwater tanks, in a broad review of the literature on the topic, finding that the key drivers are socio-cultural issues, health concerns, institutional factors, and cost. A further study, conducted by Blackburn, Morison [31], found that while owner-occupied family households of detached houses appear most likely to incorporate rainwater tanks, demographic and socio-economic data does not appear to be an effective predictor of adoption. Furthermore, Gui and Gou [32] analysed the regional differences in the adoption of household water technologies, including rainwater tanks, in the state of New South Wales, Australia. The study used data from the Building Sustainability Index (BASIX) for the period 2011–2019 and found significant differences in the adoption of water technologies between housing in metropolitan and rural areas. However, analysis of the distribution of rainwater tanks at a more refined geographical scale was not found within any existing studies.

Despite the large number of studies that have considered the adoption of solar water heaters and, to a lesser degree, rainwater tanks, they have tended to focus on the key barriers and motivators to adoption. To the authors' knowledge, there have been no studies that have analysed the correlation between adoption of these measures in the residential context and specific project characteristics (physical, geographic, and economic), including trends over time, for a large number of households. With the installation of one of these systems having been mandatory in all new houses for over 15 years in the state of Victoria, Australia, and the availability of relevant housing data, this provides an ideal opportunity to conduct a detailed analysis of the trends in their adoption, building upon the preliminary work of previous studies on the adoption of these technologies.

3. Research Approach

This section describes the steps involved in collecting and analysing the data on solar water heater and rainwater tank adoption in Victoria, Australia.

3.1. Data collection

As the installation of either a solar water heater or rainwater tank is mandatory for new homes in the state of Victoria as part of the state's Residential Sustainability Measures, information on which of these systems is proposed to be installed in a new building project is collected and reviewed at the time of applying for a building permit. Installation of the system must then be confirmed by the Relevant Building Surveyor (RBS) upon completion of the project by sighting a copy of the plumber's compliance certificate before an occupancy permit can be issued. Building permit data was obtained from the VBA. This data includes a separate field indicating whether a solar water heater was installed and one indicating whether a rainwater tank was installed for every project in Victoria that applied for a building permit. In addition to this, further information on each project is provided, including the project location, building classification, construction cost, builder, main construction materials, allotment area, floor area etc.. Building permit data is available in electronic format for projects where a permit application was submitted from 1997 to present. While the installation of solar water heaters or rainwater tanks for Class 1 buildings became mandatory from 2005, some projects had these systems installed prior to this date. However, the building permit data only includes data for these fields from June 2006 and so this study only considers projects that were granted approval from this date.

To better understand the socio-economic drivers of the uptake of residential sustainability measures, Socio-Economic Indexes for Area (SEIFA) data published periodically by the Australian Bureau of Statistics (ABS) aggregated at the suburb level, was collected, and integrated with the building permit data. SEIFA data has been computed every five years from ABS census data since 1986 and includes metrics such as those pertaining to economic resourcing, education/occupation and socio-economic dis/advantage based on socio-economic variables collected during each census. These indices are aggregated statistically to define spatial units at a census district spatial aggregation (from 1986–2006) or a mesh scale (2011–2016). These statistical geographies are redrawn after each census complicating the change in socio-economic conditions in a given area. To address this, and to provide an accurate assessment of socio-economic indices for each building record in the VBA dataset, the SEIFA indices were aggregated to the boundaries of current suburb boundaries. SEIFA data for each suburb was linearly interpolated between each census year to add a detailed estimate to each building permit record. The six socio-economic indices added to the dataset are the:

- Index of Education and Occupation (IEO),
- Index of Economic Resources (IER),
- Index of Relative Socio-economic Disadvantage (IRSD),
- Index of Relative Socio-economic Advantage and Disadvantage (IRSAD),
- Urban Index of Relative Socio-economic Advantage (UIRSA), and
- Rural Index of Relative Socio-economic Advantage (RIRSA).

The IEO, IER, IRSD, and IRSAD indices were interpolated between the values published in 2006, 2011 and 2016 with the values after 2016 remaining constant. The UIRSA and RIRSA values were taken from the last publication of these indices in 1996.

3.2. Data processing
The data from the VBA came in a structured format, however still required extensive cleaning to be useful for the analyses. The data collated by the VBA had been gathered across eighty-six local government areas over a period of twenty years, and as such there was a wide variety in the style and formatting of the data. For geocoding, the Data61-GNAF Geocoder was used, built, and made available by the Australian Urban Research Infrastructure Network (AURIN) using address and coordinate data made available by the Australian Commonwealth government in the Geoscape Geocoded National Address File (G-NAF). The geocoder requires addresses to be ordered correctly and extraneous information removed to correctly geolocate the address, necessitating detailed data cleaning for the most accurate results. This included standardising formatting, particularly case, spacing, blank values, spelling, punctuation, and location names. New columns were inserted to capture additional or incorrect data included in the lot number, street number, street, suburb, and postcode columns, and for the geocoded addresses and co-ordinates, and address details in the wrong columns were corrected. The data was filtered and moved using the Pandas.loc method and regular expressions. This needed to be done iteratively to account for the different delimitators and other formatting choices made when the data was entered. The G-NAF, AURIN Data61-GNAF Geocoder web interface, and Google Maps were used to check individual address details while cleaning. In total, 685,313 of the 1,454,312 individual records were changed during this process (47%). The 1,028,400 unique addresses were geocoded, and a new parquet file was created with the clean data, including co-ordinates, which was used for the analysis. Monetary values were adjusted for inflation according to the quarterly Consumer Price Index issued by the Australian Bureau of Statistics [33] and given in values at 1st December, 2021.

3.3. Data analysis
Relevant data for the different parameters compared was filtered from the larger dataset of processed building permit records. Any projects that were not required to comply with the Residential Sustainability Measures (i.e., not new Class 1 buildings) were excluded from the analysis. Only private sector buildings with permits issued from 2006 to 2019 were included, which resulted in 541,357 records. The study presents data on the number of solar water heater and rainwater tank installations, proportion of projects with one or both systems installed, as well as an analysis of the correlation between the installation of each system and geographic distribution, socio-economic indices, project cost, and allotment area.

4. Findings and Discussion

4.1. Adoption of residential sustainability measures

The total number of projects with either a solar water heater (SWH), rainwater tank (RT) or both is shown in Table 1 and Figure 1, by year of permit application. In any one year, more than 30% of projects report neither system being installed. This, along with the main reasons likely being non-reporting of the choices made or building permits covering multiple dwellings, as also highlighted by Harrington [9]. The proportion of projects adopting a rainwater tank peaked in 2008 and has consistently declined since. Conversely the proportion of projects adopting a solar water heater has remained constant since 2009. This phenomenon may be a result of the perceived reduced benefit of rainwater tanks towards the end of the Millennium Drought. The ratio of projects adopting solar water heaters to rainwater tanks was around 1:1 in the first two years but steadily shifted to 3:1 by 2019.

Table 1. Number and proportion of solar water heaters and rainwater tanks installed in new Victorian Class 1 buildings from 2006 to 2019.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
SWH only (%)	15.5	24.9	30.8	41.8	43.6	45	45.6	41.2	44	45.4	39.3	36.7	43.5	45.4
RT only (%)	19.7	26.8	26.2	20.3	19.5	19.2	18.2	17.7	15.9	16.1	13.7	13.5	13.5	14.4
Both (%)	1.0	1.4	2.5	2.6	2.3	2.6	2.5	2.6	2.3	2.7	2.2	2.2	2.6	3.3
Neither (%)	63.8	46.9	40.6	35.3	34.7	33.2	33.6	38.5	37.9	35.8	44.7	47.6	40.4	36.9
Total new Class 1 buildings	20,967	36,008	37,065	41,790	44,867	38,768	35,459	34,903	39,402	41,309	43,979	46,558	46,297	20,374

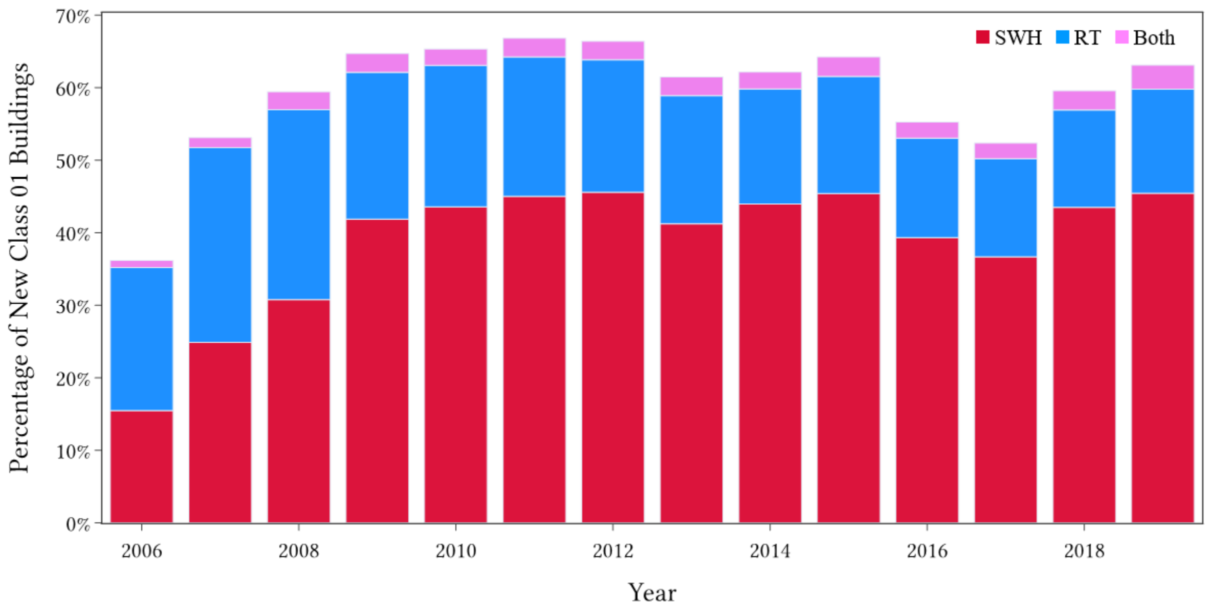

Figure 1. Proportion of solar water heaters and rainwater tanks installed in new Victorian Class 1 buildings from 2006 to 2019.

The adoption of solar water heaters and rainwater tanks has not been uniform across the state. Figure 2 shows the proportion of projects with rainwater tanks or solar water heaters for each local government area (LGA) restricted to permits which have one or other measure but not both. There is a similar number of LGAs preferencing solar water heaters and rainwater tanks (45 v 41), however LGAs in metropolitan Melbourne have a higher occurrence of rainwater tanks (17 v 12). A greater preference for solar water heaters in rural areas may be due to rainwater tanks being more common prior to 2006 due to lower instances of mains water access than in metropolitan areas [1].

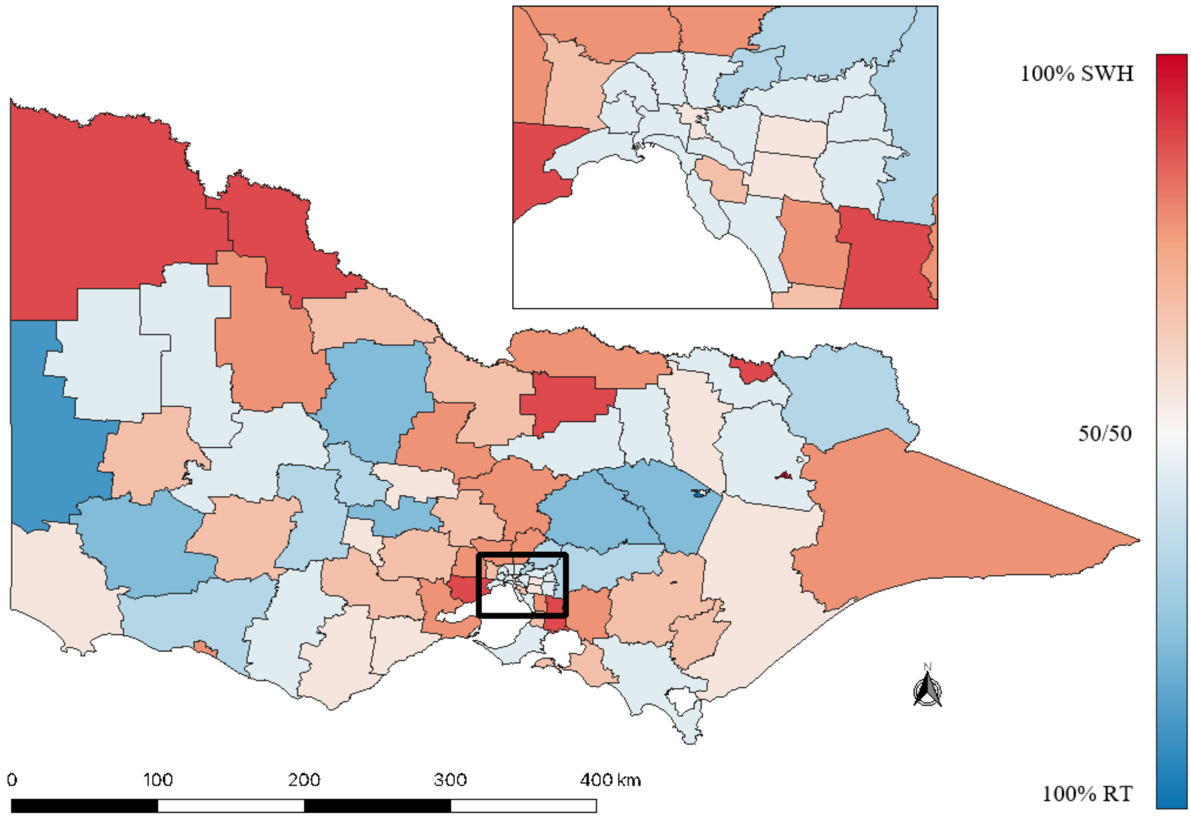

Figure 2. Relative proportion of new Victorian Class 1 buildings with a solar water heater or rainwater tank (but not both) by LGA.

4.2. Correlation with project characteristics

Figure 3 shows the correlation between project cost and adoption of solar water heaters and rainwater tanks. This shows that projects costing under $200k preferred rainwater tanks, possibly related to the lower cost of installing a rainwater tank. Projects costing between $200k-$600k preferred solar water heaters. Projects over $600k preferred rainwater tanks, with this preference increasing slightly in line with project cost.

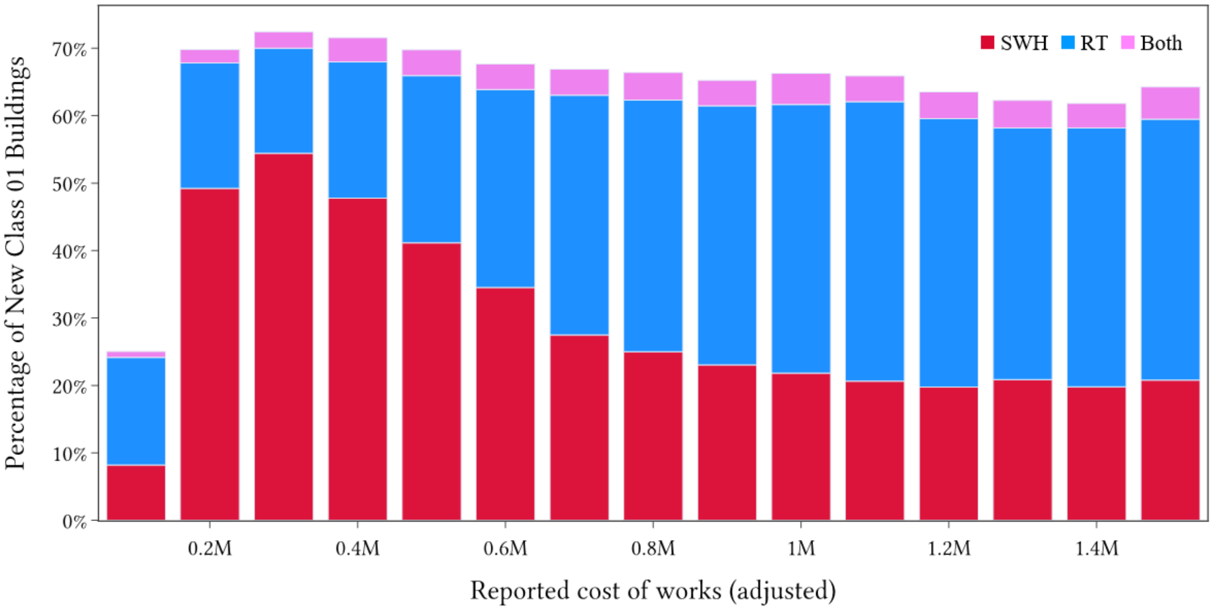

Figure 3. The proportion of new Victorian Class 1 buildings having solar water heaters or rainwater tanks by project cost.

Figure 4 shows the correlation between project allotment area and adoption of solar water heaters and rainwater tanks. This shows that there is a strong preference for solar water heaters for allotments under 500 m^2, but this shifts more towards rainwater tanks as allotment area increases. This is likely due to greater availability of space required for rainwater tanks on larger allotments. A trend towards smaller allotment areas post Millennium Drought may also explain this shift.

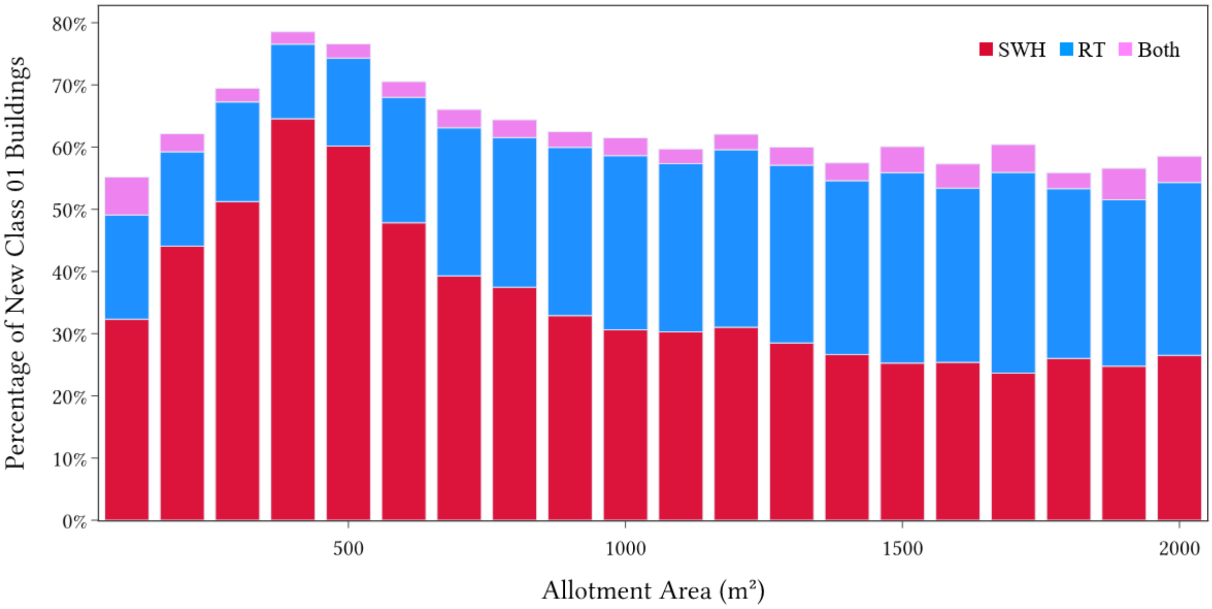

Figure 4. The proportion of new Victorian Class 1 buildings having solar water heaters or rainwater tanks by allotment area.

Figure 5 shows the Pearson correlation coefficients of rainwater tanks with a range of socio-economic indices. This shows a weak correlation except for the UIRSA and RIRSA indices indicating that there was a small positive correlation between urban settings and adoption of rainwater tanks and conversely between rural settings and adoption of solar water heaters. This aligns with the findings from Figure 2, but the small correlation is also supported by Blackburn, Morison [31] findings that socio-economic data does not appear to be an effective predictor of adoption.

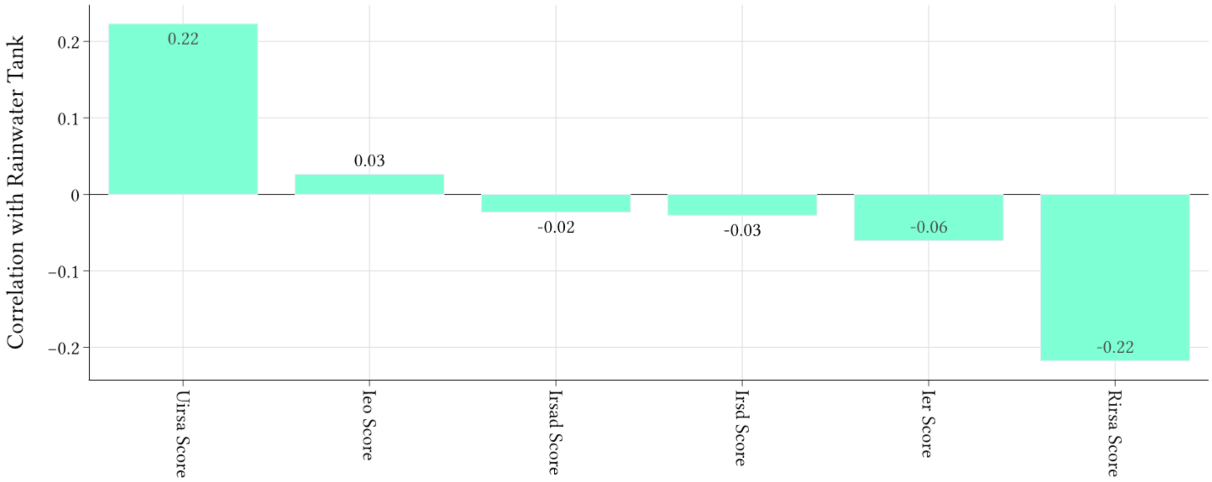

Figure 5. Correlation of rainwater tanks with socio-economic indices.

5. Conclusions and Further Research

The aim of this study was to analyse the historical trends in the adoption of solar water heaters and rainwater tanks in the state of Victoria, Australia, identifying correlations to several key household characteristics and socio-economic indices. Using building permit application data from the VBA, it was found that since the introduction of residential sustainability measures in 2005, after an initial preference for rainwater tanks in 2006-07, most likely due to an alignment with the timing of the Millennium Drought, solar water heaters have been the preferred measure adopted. The subsequent decline in adoption of rainwater tanks, compared to solar water heaters may also be due to the decline in allotment area. This is supported by the analysis, which shows that solar water heaters are preferred for projects on allotments of less than 500 m^2, and above this the preference for rainwater tanks increases in line with allotment area. Rainwater tanks were found to be more common in metropolitan areas and for projects with a higher cost, supported by the comparison with socio-economic data. Preference for solar water heaters was found to be particularly strong for projects with a cost between $200k-$600k, which may correlate strongly with smaller allotment areas and the subsequent limited space available for rainwater tanks.

This study provides insight into the opportunities for greater adoption of solar water heaters and rainwater tanks. For example, information at the LGA level could be used to develop specific business opportunities for maintenance or future upgrades of solar water heaters and rainwater tanks. This could be further enhanced by data at the individual household level, such as building age. The study may also provide guidance to inform policy, such as alternative water efficiency solutions for households where allotment area may limit adoption of rainwater tanks, including consideration of differing socio-economic contexts.

The accuracy of the findings is limited by, and reliant on the completeness and accuracy of the data collected during the building permit application process. It is possible that a lack of data, inaccurate data or changes during construction could alter the overall findings.

Further research would provide even greater insight into the factors affecting the adoption of solar water heaters and rainwater tanks. This may include an analysis of the correlation with other project characteristics, as reported in the building permit database, such as floor area, builder, construction materials, number of storeys etc.. The data analysis tool developed for this study would be useful for supporting these and other data analysis and visualisation tasks.

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