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Thermal performance of retrofitted secondary glazed windows in residential buildings – two cases from Australia

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Abstract

Purpose: This study presents the results of empirical measurements of the thermal performance of retrofitted secondary glazed windows, involving installation of an additional windowpane, in a residential context in Australia.

Methodology: In-situ temperature measurements were collected from the surfaces of retrofitted secondary glazed windows in two residential buildings in the Australian Capital Territory. The heat loss savings, and subsequently the electricity savings, were then calculated were based on these temperature measurements.

Findings: Heat loss reductions of up to 60.8% and electricity savings of up to 9.96% could be achieved by retrofitting single glazed windows with secondary glazing. The findings suggest that the thermal performance of retrofitted secondary glazed windows are comparable to double glazed windows.

Originality: This research is a first attempt to measure empirically the thermal performance of retrofitted secondary glazed windows in residential property in Sydney Australia. Secondary glazing is the provision of an additional windowpane to the original single glazed window. Previous studies in Australia have focussed on performance of double glazed windows.

Practical implications: Multiple glazed windows provide better energy efficiency, thermal and acoustic performance compared to single glazed windows. It is estimated, however, that 85% Australian buildings still have single glazed windows. Secondary glazing has emerged as a cost-efficient and easier-to-install alternative to double glazed windows. The results of this research can contribute to a wider market uptake of secondary glazed windows in Australia by showing that they have similar thermal performance to double glazed windows.

1. Introduction

The built environment accounts for over a third of global energy use through construction and building operation (IEA, 2019). Energy use results in greenhouse emissions which contribute to climate change, and improving energy efficiency in buildings will lower those emissions (Diakaki et al, 2008, IEA 2014). In Australia, it is posited that energy efficiency measures in buildings can deliver more than 25% of the national target to reduce overall emissions by 26-28% on 2005 levels by 2030 (Department of the Environment and Energy, 2015; Australian Sustainable Built Environment Council, 2016). However, only 1-2% is added to the total stock of buildings annually (Popescu et al, 2012) and therefore to achieve emissions reductions requires an active programme of energy retrofits in all buildings (Kumbaroğlu et al, 2012).

Many countries including Australia (through the Building Code of Australia Part J Energy in effect since 2005) impose minimum energy efficiency requirements on new buildings (Brounen and Kok, 2011; Eichholtz, Kok and Quigley, 2013). Australia was very slow however to legislate minimum energy efficiency in buildings, for example, the UK initiated their energy standards in 1984 (Bell, 2004) some 21 years ahead of Australia. As such, Australia has a higher proportion of housing stock that lacks any minimum energy efficiency standards. Given the long life-cycle of buildings and the tiny annual addition to the total stock, retrofitting existing buildings is crucial to improve the energy efficiency of the built environment and to reaping the multiple social, economic and environmental benefits (McDowell *et al.*, 2016). Such benefits include emission cuts, creation of jobs, stimulation of economic growth, improvement of health and well-being of building occupants, higher energy security, reduced energy costs and local emissions, and higher asset values (IEA, 2014).

Retrofits can range from minor to major and involve adaptations to the building envelope and services (Hoicka et a, 2014). The goal is typically how to achieve the most energy efficiency for the least capital cost and disruption to building occupants, with a low perceived risk (Hirst and Brown, 1990). Accordingly, low-cost and low-risk energy efficiency measures that result in minimal disturbance to occupants would be preferable to house owners.

In residential buildings, between 25-35% of heat is lost through the roof and ceilings of buildings, 10-20% through the walls, 10-20% through the floor, 15-25% through general air leakage and 11-25% through windows (Bell, 2004). Efforts to reduce heat loss and improve thermal performance therefore focus on these areas. Depending on the design and materials, some windows are leakier than others, for example louvre windows perform very poorly whereas fixed casement windows perform better. Van Den Bergh et al (2013) analysed four glazing frame materials; timber, aluminium, vinyl and fibreglass, and the seals specified, to determine which specifications had best thermal performance and structural functionality. The

Norwegian study examined moisture vapour and gas transmission as well as durability and life expectancy of mateirals and found the design of spacers and specification of the edge seals had a significant impact on performance (Van Den Bergh et al, 2013). Some designs facilitated greater transmission of heat loss and improvements are possible where designs consider heat transfer and positions of space bars and secondary sealants at the edge of the glass. Over time, buildings settle and move and this can cause openings to occur and leakage of heat and energy (Barreira et al 2017), and therefore the thermal performance of older buildings is even worse.

Multiple glazed windows are being increasingly used in new construction and retrofits as they provide better energy and indoor comfort performance compared to traditional single glazed windows (Arici & Karabay, 2010; Cox-Ganser, 2015; Jaber & Ajib, 2011; Jones et al., 2007). Windows can be double or even triple glazed to enhance energy performance (Michaut, 2019). Triple glazing is used in extremely cold climates, such as Canada. The history around the introduction of double glazing is contested with some claiming Scotland to be the first, introducing the technology during the 19th Century. Nevertheless, in Australia adoption has been slow with an estimated 85% of all windows still being single glazed (O'Dea, 2017). Replacing inefficient single glazed windows with multiple glazed windows can incur considerable costs as it requires the replacement of the whole window unit by a professional, which can be costly and cause disturbances to occupants. In comparison, adding an additional layer of glazing to an existing window, called secondary glazing, is a lower cost alternative, as it does not require replacing the whole window frame and can be installed by the occupant. There are several secondary glazing products available, ranging from "stick-on" PVC layers to additional windowpanes (Dowson et al, 2012, Smith et al., 2009). Studies undertaken in Texas and New Zealand show that secondary glazing can save energy, cut energy use peaks and enhance thermal comfort (*Smith, 2009;* Smith *et al.*, 2012; *Smith et al., 2009*; Fitton *et al.*, 2017; Kim and Felkner, 2018).

Windows should have a good light transmittance, reducing the need for artificial lighting, while providing effective resistance to heat transfer. Optimising the thermal performance of windows in colder climates can be achieved by minimising the conduction and convection heat transfer losses, while maximising radiation heat transfer gains through solar energy (Rubin, 1982). The conduction occurs when heat passes through the solid material of a whole window, with certain materials such as metals allowing for higher transmittence and have less insulative properties. The convection in the case of a window is when warm air comes in contact with a cold window and creates a current by sinking and when the wind blows on the outer surface of a window. It increases the conduction of the material, such as the glazing, and negatively impacts the thermal performance of a window. The radiative heat transfer through windows is mainly from solar energy which penetrates into the building through the window glazing.

Multiple glazed windows create thermal barriers by filling the gaps located between two or more panes with materials that have insulative properties, such as low conductivity, with the most common being dry air (Arici and Karabay, 2010). Thermal, and accordingly energy, performance of multiple glazed windows depend on various factors, such as the climate, the surface area and the orientation of the windows, the gap between the panes, if there is coating on the surfaces, among others (Gan, 2001; Arici and Kan, 2015).

A recent study by Bulut *et al.* (2020), reporting the results of a post-retrofit survey in Australia, found strong satisfaction and significant perceived indoor comfort by the respondents as a result of the retrofits with secondary glazing. In this study, over 80% of respondents felt their home had better thermal and noise insulation, nearly 79% found a positive impact on their property value and 77% answered that they would retrofit their new home with secondary glazing if they moved. Despite the growing interest for secondary glazing products in Australia, which could be related to the perceived indoor comfort and energy savings benefits, there are no Australian studies on their measured thermal performance in a residential setting. This research seeks to complement the perceived benefits with empirical measurements and address this knowledge gap by presenting the results of an analysis based on in-situ measurements from two houses retrofitted with secondary glazing in the Australian Capital Territory (ACT). Once the positive outcomes are known, more retrofits should follow.

2. Methodology

This is quantitative research (Sukamolson, 2007. Holton and Burnett, 2005) which sought to measure the performance of retrofitted secondary glazing in the ACT, Australia. Best practices for quantitative data collection outlined by Sukamolson (2007) and Holton and Burnett (2005) were adopted for the experiment.

As noted above, minimising heat losses and maximising solar energy gains allow for improved energy performance in colder climates such as the climate of the ACT. The ACT is deemed a suitable location to conduct the measurements as it experiences relatively cold winters with temperatures often dropping below 0°C, requiring heating and heat conservation in buildings (Australian Bureau of Meteorology, 2020). The data collection for this study was done in two residential houses, which were both retrofitted with secondary glazed windows provided by the company Magnetite (Australia) Pty Ltd (2021). The secondary glazing panes were made of acryclic and had magnetic attachments for the ease of installation.

Property 1 was a 3-bedroom, 1 bathroom detached property sited on a 928 m^2 block built in 2010. The total surface area of the window system of Property 1 was 11.33 m^2, with 2.17 m^2 (1.81*1.20) facing east, 4.82 m^2 (2.41* 2.00) facing west, 2.89 m^2 (2.41*1.20) facing north, and 1.45 m^2 (1.21*1.20) facing south. ACT is in Australia, where the north facing elevation gets most exposure to the sun.

Property 2 was a 4-bedroom, 2 bathroom detached property sited on a on 759m^2 land size built in 1999. In Property 2, the total area of the window system is 7.73 m2, with equal window areas of 2.58 m^2 (1.44*1.79) facing west, north and south.

Given that no coating was applied to the glazing of the secondary windowpane, the reduction in solar energy gains as a result of the additional glazing blocking solar energy in this study was considered negligible. The impact of convection before and after the retrofit was also assumed to be the same. The thermal performance of retrofitted window was then calculated by the heat loss reduction through improved conductivity that the additional windowpane provided on all orientations of the windows. Due to the limitations associated with the data collection, measurements could be conducted from mid-winter to mid-spring.

Fixed thermometers were placed on the internal surfaces of the original single glazed windows and the secondary windowpanes in the properties (See Figure 1). Hourly temperature data was collected from Property 1 for 56 days, from 00:00 on 16 August 2017 to 23:00 on 10 October 2017. For Property 2, the data collection lasted 44 days, from 00:01 on 29 August, 2017 to 23:01 on 11 October 2017. The reason for the shorter data collection period for Property 2 was due to challenges in accessing the property. Data collection took place at the end of the winter and start of the spring season. It should be noted that towards the end of the data collection period days would have been longer with higher temperatures. .

Figure 1: Fixed thermometers installed on the internal surfaces of the secondary glazing windowpane and the original windowpane. (Source: Authors).

The heat flow through the window, H_t, is calculated using Equation (1):

$H_t = U*\Delta T*A$ Equation (1).

where U is the U-factor ($W/m^2.K$), the rate of heat transfer, ΔT is the difference in temperature between internal and external surfaces of a window system and A (m^2) is the window area. In the case of this study, U_{nM} is the U-factor of the original single glazed window and U_M is the U-factor of the secondary glazing frame. In Property 1, the single-glazed window comprised of clear glass sheet in a timber frame and was assumed to have a U-factor of 5.4 $W/m^2.K$ (U_{nM1}) based on the information gathered from the Building Sustainability Index (BASIX) (New South Wales Government, 2020). The secondary glazed window in Property 1 had a 3mm thick clear acrylic sheet on a timber frame with a 68 mm air fill and an assumed U-factor of 2.6 $W/m^2.K$ (U_{M1}) based on the information obtained from the Window Energy Rating Scheme (WERS) (WERS, 2020). Property 2 had a single glazed clear glass sheet on a sliding aluminium frame with an assumed U-factor of 7.4 (U_{nM2}) and an installed secondary glazed window with a 3 mm clear acrylic sheet on a sliding PVC frame with a 68 mm air fill and an assumed U-factor of 2.9 $W/m^2.K$ (U_{M2}).

The rate of saved heat, or energy efficiency, through reduced heat loss (ΔH), which is presented as a percentage, was calculated using Equation (2):

$\Delta H (\%) = (H_{nM} – H_M) / H_{nM}$ Equation (2)

where H_{nM} and H_M represent the heat flow through the original single glazed window and the secondary glazed window, respectively.

In order to analyse the thermal and energy performance of the window systems, the following two cases were evaluated:

- An actual case with measured indoor and outdoor temperatures
- A hypothetical case with a constant 23.5°C indoor temperature and measured outdoor temperatures.

The reason to investigate the hypothetical case was to understand the thermal performance of the secondary glazed window systems in an optimal thermal environment set at 23.5°C, which is within the preferred indoor temperature range reported in the literature (Humphreys, Nicol & Raja, 2007).

After determining the reduced heat loss through retrofitting with secondary glazed windows, the resulting energy cost savings was calculated. In order to do this, the following assumptions were made:

(1) the electricity price was assumed to be AU $0.28688[1] per KWh;

(2) the heating system selected for the analysis was an LG P09AWN-14 Reverse Cycle Air Conditioner with C2.5kW H3.2kW (Power Input - Cooling: 518W, Heating: 653W; AEER Cooling 4.83 W/W; ACOP Heating 4.90 W/W); and,

(3) the potential saving is on usage cost only, not including connection costs.

3. Results and Discussion

The results from the temperature readings showed that the internal surface temperature readings were higher than the external surface temperature readings for most of the time, demonstrating heat flow from indoors to outdoors. Although, during a total of 17 and 140 hours, for Property 1 and Property 2, respectively, the direction of the heat flow reversed as the internal surface

[1] This was based on the GST inclusive Smart Meter Home Time-of-Use tariff for Peak Usage provided by the utility company ActewAGL in 2018. www.actewagl.com.au

temperatures were measured to be lower than outdoor temperatures. Given the short duration of these heat gains, however, they were neglected in the calculations.

Table 1 presents the calculated heat losses through the layers of the secondary glazed window system installed in Property 1, resulting in a total heat savings of 101,358 Wh for the period of 56 days based on the actual indoor and outdoor temperature readings. The findings mean that retrofitting with secondary glazing resulted in 51.9% less heat losses, which can be translated into financial savings of 5.93 AU$ through improved energy efficiency for the time period. Greater savings would be achieved during winter periods.

Assuming a constant indoor temperature of 23.5ºC, the results (Table 2) show greater heat loss savings of 339,618 Wh for the same time period and measured outdoor temperatures, resulting in a total energy cost savings of 19.88 AU$ for the time period.

Table 1 - Heat loss reduction and potential savings in energy use (based on the observed indoor and outdoor temperatures) – Property 1.

	Gross Heat Loss (Wh)					***Daily Heat Loss (Wh)***				
	Non-M	**M**	**Diff**	**% diff**	**$**	**Non-M**	**M**	**diff**	**% diff**	**$**
South	63227	30443	32784	51.9	1.92	1129	544	585	51.9	0.03
West	79283	38173	41110	51.9	2.41	1416	682	734	51.9	0.04
North	52965	25502	27464	51.9	1.61	946	455	490	51.9	0.03
Total	195476	94118	101358	51.9	5.93	3491	1681	1810	51.9	0.11

(Source: Authors).

Table 2 - Heat loss reduction and potential savings in energy use (based on the assumed indoor temperature at 23.5º C and observed outdoor temperatures) – Property 1

Gross Heat Loss (Wh) ***Daily Heat Loss (W)***

	Non-M	M	Diff	% diff	$	Non-M	M	diff	% diff	$
South	235653	113462	122190	51.9	7.15	4208	2026	2182	51.9	0.13
West	225642	108642	116999	51.9	6.85	4029	1940	2089	51.9	0.12
North	193683	93255	100428	51.9	5.88	3459	1665	1793	51.9	0.10
Total	654978	315360	339618	51.9	19.88	11696	5631	6065	51.9	0.36

(Source: Authors).

Table 3 presents the calculated heat losses through the layers of the secondary glazed window system installed in Property 2, resulting in a total heat savings of 231,489 Wh for the period of 44 days based on actual indoor and outdoor temperature readings. The findings mean that retrofitting with secondary glazing resulted in 60.8% less heat losses, which can be translated into financial savings of 13.55 AU$ through improved energy efficiency.

Assuming a hypothetical constant indoor temperature of 23.5°C, the results (Table 4) represent greater heat savings of 491,103 Wh for the same period and measured outdoor temperatures, resulting in total energy cost savings of 28.75 AU$.

Table 3 - Heat loss reduction and potential savings in energy use (based on the observed indoor and outdoor temperatures) – Property 2

	Gross Heat Loss (Wh)					***Daily Heat Loss (Wh)***				
	Non-M	**M**	**Diff**	**% diff**	**$**	**Non-M**	**M**	**diff**	**% diff**	**$**
North	119770	46937	72833	60.8	4.26	2722	1067	1655	60.8	0.10
South	65860	25810	40050	60.8	2.34	1497	587	910	60.8	0.05
West	135476	53092	82384	60.8	4.82	3079	1207	1872	60.8	0.11
East	59566	23343	36222	60.8	2.12	1354	531	823	60.8	0.05

Total	380672	149182	231489	60.8	13.55	8652	3391	5261	60.8	0.31

(Source: Authors).

Table 4 - Heat loss reduction and potential savings in energy use (based on the assumed indoor temperature at 23.5°C and observed outdoor temperatures) – Property 2

	Gross Heat Loss (Wh)					***Daily Heat Loss (Wh)***				
	Non-M	**M**	**Diff**	**% diff**	**$**	**Non-M**	**M**	**diff**	**% diff**	**$**
North	198899	77947	120952	60.8	7.08	4520	1772	2749	60.8	0.16
South	125384	49137	76247	60.8	4.46	2850	1117	1733	60.8	0.10
West	321199	125875	195324	60.8	11.44	7300	2861	4439	60.8	0.26
East	162110	63530	98581	60.8	5.77	3684	1444	2240	60.8	0.13
Total	807592	316489	491103	60.8	28.75	18354	7193	11161	60.8	0.65

(Source: Authors).

When compared with 22 kWh ($2394.43/year), which is the benchmark daily usage of similar homes during winter in ACT and is based on two people living in a home with the household use electricity only, without using gas and without having a swimming pool (Independent Competition and Regulatory Commission, 2019), these reductions in heat loss, due to installing a secondary glazing window system, resulted in daily reductions in electricity usage of 1.62% for Property 1, and of 4.70% for Property 2. If indoor temperature is heated to 23.5-degree Celsius for the entire period of observation, the reductions in heat loss, due to installing the secondary glazing window system, result in daily reductions in electricity usage of 5.41% for Property 1, and; of 9.96%, for Property 2.

Given the lack of research on the measured thermal performance of secondary glazed windows involving the installation of an additional windowpane, it is challenging to make a comparison between the obtained results and the information available in the literature. The findings of our study suggest that the achieved heat savings of 51.9% and 60.8% in Property 1 and Property 2, respectively, are in line with the reported savings through the use of double-glazed windows. An early study Selkowitz, (1979) suggest heat loss reductions around 50% through the use of double glazed windows compared to single glazed windows. Arici & Karabay (2010) showed in their study that, based on calculations obtained from four cities located in different climate zones of Turkey, heat losses of up to 60% can be prevented by using double glazed windows. Our results appear reasonably aligned to these findings.

4. Conclusions

Buildings contribute significantly to greenhouse gas emissions and there is great scope to reduce this through energy efficient building adaptation and retrofit. The existing building stock often performs poorly in respect of energy efficiency, with their construction predating minimum energy efficiency standards embodied in building regulations. Australia is lagging in the instigation of minimum energy standards in its building codes, compared to other countries, initiating standards in 2003 some 19 years after the UK for example. The case for retrofitting existing buildings is considerable.

There are many ways to retrofit buildings to enhance energy efficiency and secondary glazing retrofit is one option. This study investigated the thermal performance of retrofitted secondary glazed windows with an additional windowpane in two residential buildings in Australia. While most Australian buildings have single glazed windows, the use of multiple glazing, secondary, double and triple glazing, can improve the energy and indoor comfort performance of buildings. The results of this study show that secondary glazed windows, which involves installing an additional windowpane inside an existing window, can reduce heat transmittance by up to

60.8% in the ACT, Australia. It can be concluded, based on our results, that secondary glazed windows constitute a lower-cost and easier to install viable retrofit alternative to double glazing and make a positive contribution to efforts to cut greenhouse gas emissions from the buildings sector in Australia. Given that no studies have been undertaken to date this research is a contribution to knowledge of the scale of energy savings possible in the ACT from retrofitted secondary glazing.

Due to the limitations associated with the data collection in this study, however, further research is needed to measure the thermal performance of secondary glazed windows over longer periods of time, ideally for a year, in a residential setting. Finally, glazing coatings were not part of this study and do impact window performance; therefore, future empirical studies should evaluate impact on thermal performance of different glazing coatings.

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