1. Introduction

Buildings and the building construction sector together represent 36% of the global energy demand, accounting for nearly 40% of the total global CO_2 emissions (IEA 2019). In Australia, energy efficiency measures in buildings has the potential to deliver more than one quarter 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). Accordingly, energy retrofits in existing buildings can play a key role to cut emissions both globally and in Australia.

Windows are an important element of the building envelope, allowing for ventilation and access to daylight (Chen et al., 2015; Shin 2007). Their relatively large surface area, however, creates a significant heat flow through conduction, radiation and convection, which can result in energy losses of up to 60% depending on various conditions (Cuce and Riffat 2015; Jelle et al., 2012; Grynning et al., 2013). Windows, on the other hand, can also help save energy by letting solar energy through, reducing the demand for heating and lighting. Several factors impact the energy efficiency of windows, such as their design and orientation, surface area, airtightness and the materials used (Cuce 2017; Grynning et al.,, 2013; Jelle et al.,, 2012).

Well-designed windows enhance indoor thermal and acoustic comfort and, as a result, improve the health and well-being of building occupants (Menzies and Wherrett 2005). The link between indoor comfort and occupant health and well-being is established in the literature (Bonnefoy et al.,, 2004; Jantunen et al.,, 1998; Bluyssen et al., 1995). Poor indoor thermal comfort and lighting can result in the so-called; Sick Building Syndrome (SBS) causing upper-respiratory problems, headaches, fatigue, and rashes (Redlich, Sparer, and Cullen 1997). Good indoor

comfort, on the other hand, can lead to positive changes in behavioural patterns[1] of occupants in relation to occupants' health, well-being and productivity (Nikolopoulou, Baker, and Steemers 2001; Kolcaba and DiMarco 2005; Ali, Chua, and Lim 2015).

Given the above mentioned benefits they offer, windows are often one of the first elements of a building to be addressed in an energy efficiency retrofit. Although most buildings in Australia have single glazed windows, there is, however, a strong increase in the number of installed double glazed windows (Mediaedge Communication Australia 2009). Double glazed windows, which have two sheets of glazing with a sealed air gap, offer numerous benefits over single glazed windows, such as improved energy efficiency and enhanced thermal, noise and UV control (Bluhm et al.,, 2007; Menzies and Wherrett 2005; Singh, Garg, and Jha 2008).

Replacing existing windows with new ones, however, could be costly and cause disturbances to occupants during retrofit. Secondary glazing - installing an independent window frame inside of an existing window - has therefore emerged as an easier-to install and lower-cost alternative to double glazing. Figure 1 is an illustration of a window retrofit by using secondary glazed window that is attached to the existing window by magnetic edgings.

[1] Behaviour is defined as *'observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions such as temperature or indoor air quality or sunlight'* (Chen et al., 2015).

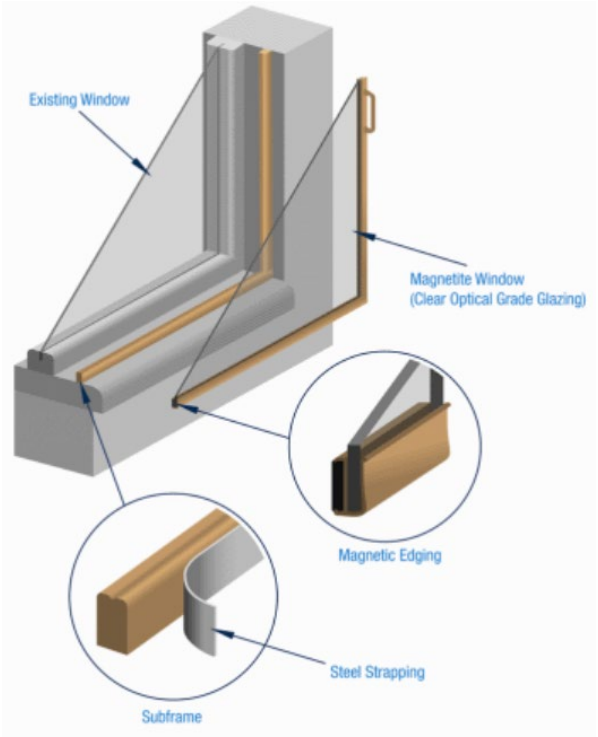

Figure 1 – Retrofit with a secondary glazed window with magnetic edgings

(Copyright by Magnetite Australia Pty. Ltd.)

Despite having been used for a relatively long time, particularly on buildings having heritage value to preserve the original window frames, there is limited research on secondary glazing in the literature compared to double glazing. The available research, nevertheless shows that secondary glazing not only provides considerable energy savings and energy peak use reduction, but also improves indoor thermal comfort by reduced air infiltration and condensation (Kim and Felkner 2018; Fitton et al.,, 2017; Smith et al.,, 2012). Reporting on simulations for different secondary glazed windows in four different locations in New Zealand, Smith et al.,, (2012) and Smith & Isaacs, (2009) found that secondary glazing can improve, compared to single glazing, the R-value of a window from 130% through to 290%, depending on the glazing and materials used. An experimental study from the United Kingdom (UK), showed that an eco-friendly PVC sheet could reduce the thermal transmittance of old single

glazing windows by up to 57% and provide a higher and more stable indoor air temperature (Harjunowibowo et al 2019).

Mainly investigating double glazed windows, post-retrofit surveys suggest improved perceived thermal indoor comfort as a result of multi-layered glazing. A post-retrofit study conducted in the UK report showed improved thermal comfort due to reduced draughts after the installation of double glazed windows, which minimised the need for occupants to control draughts (Walker, Lowery, and Theobald 2014). Another study from the UK show improved perceived enhanced indoor thermal comfort following the installation of double glazed windows as a result of occurrances of extreme temperatures in winter and summer (Chiu et al., 2014). In an Australian context, a study conducted in Victoria, where heat shrink films were used, suggested some indoor thermal comfort improvements were achieved, with reduced draughts and more stable indoor temperatures (Sustainability Victoria 2017).

Retrofit secondary glazed windows are marketed on a range of criteria: overall noise reduction (Schomer et al., 1991), thermal improvement, comfort, lower risk of condensation, daylighting potential, extent of air leakage, cost, ease of operation and a general aesthetic effect (Ariosto and Memari 2012). In spite of their recognised benefits, the adoption of such a window system by Australian residents has been low (Sustainability Victoria, 2017). We argue that it is important to measure occupants' perceptions about these windows, not just as a measure of product evaluation but also because of the role of customers in attracting new buyers.

Satisfied and engaged customers are effective product endorsers. Retrofit windows are a durable good, and are regarded as 'high-involvement', in view of the time, interest and effort invested by customers in the pre-purchase search for such products. In view of the financial expense and psychological commitment made, retrofit windows are seen as an important part of the customers' life (Zaichkowsky, 1985). Customers' involvement with the product is viewed as stable and on-going. Consumer behaviour literature recognises such highly involved buyers

as possessing greater knowledge about a product category than other customers (Corey, 1971). These buyers willingly discuss the product with others (Bloch, 1981). Therefore, it may not be surprising when such involved individuals are called upon to advise others on their purchases (Price and Feick, 1984). Thus, current users of retrofit windows are potentially strong advocates for this product category.

There is, however, a gap in the literature about a post-retrofit evaluation of secondary glazing. This research addresses this gap by presenting the results of an online survey completed by 56 respondents who had retrofitted their home with secondary glazed windows in the Australian Capital Territory (ACT) and New South Wales (NSW), Australia.

2. Research Methodology

This research seeks to ascertain the views and perceptions of home owners and occupants on the levels of comfort following a retrofit of secondary glazing (Patton 2013). The data collection method used in this research was a self-administered online survey targeted at occupants living in a property that had been recently retrofitted with secondary glazing. Self-administered online surveys are a time- and resource-efficient data collection method (Patton 2013). A larger number of potential respondents could be reached by online surveys compared to other methods of data collection, such as face-to-face surveys, where an administrator would be needed (Yin, 2015). In addition to this, respondents may also prefer to answer online surveys over other methods, as they often require less time and planning (Brace 2005).

The online survey used in this study was designed based on best practices and recommendations available in the literature and included multiple-selection, open-ended and 5-point Likert scale questions to collect both quantitative and qualitative data (Brace 2005; Albaum 1997). A list of the survey questions can be found in Annex A. The survey invitation with the link to Google

Forms[2], the online survey administration platform used, was e-mailed to 445 occupants who retrofitted their property with secondary glazed windows in Canberra and Sydney between August 2017 to November 2017. Two reminders were sent to those who did not respond in order to collect further data. A total of 56 respondents, of which 34 were female and 22 were male, answered the survey. Three quarters of the survey respondents lived in a house and the remaining 25% lived in apartment buildings. No other background information about the respondents was collected.

2.1 Limitations

Self-administrated surveys can create sampling problems if the respondent does not belong to the target group or, if they answer the survey more than once (Wright 2006). Sampling risks associated with this study in this regard can be considered low given that the list of recipients included only those who were known to have installed secondary glazing panels, and the survey could not be answered multiple times from the same IP address. It is, however, important to note that the respondents could be more likely to respond to the survey if they were satisfied with the retrofits, which has the potential to create sampling bias.

The responses to the survey produced a response rate of 13%. Given the voluntary nature of the online survey - no incentives were offered - a relatively low response rate was expected. According to the literature, low response rates to online surveys do not necessarily impact the validity of the results (Rindfuss et al., 2015; Morton et al., 2012). Considering this, and a quality check of the data already collected, no further reminders were sent to recipients.

Another limitation of this study is that the survey data was collected from occupants who were located in a relatively small geographic area and installed secondary glazed windows from the

polyvinylchloride (PVC) clear sheet panels which are retrofitted (internally or externally) to improve energy performance of existing buildings.

[2] https://www.google.com/forms/

same manufacturer. Furthermore no questions were asked about any variations in performance that may be experienced across different seasons. It is possible that different climatic conditions and varying specifications and quality of the installed secondary glazed systems could influence the occupant perceptions, hence the findings.

3. Findings

The online survey, provided in Annex A, included questions on occupants' experienced indoor comfort and well-being changes post-retrofit, as well as their views on energy efficiency and its perceived economic benefits.

In line with the findings of the studies on the thermal insulation properties of secondary glazed windows, open ended answers provided by some respondents in our study suggest better indoor thermal stability, and; a reduced demand for heating and cooling (Kim and Felkner 2018; Fitton et al., 2017; Harjunowibowo 2019; Smith et al., 2012). One of the respondents commented on this with the following:

"Both heating and cooling times have been reduced. Our air conditioners are rarely used."

Respondent A

Accordingly, when asked about the impacts of secondary glazed windows on their energy bills, some respondents reported no changes, while others mentioned that their energy bills had been reduced. No respondents reported paying higher energy bills post-retrofit.

Enhanced thermal comfort can be expected to influence the overall comfort and satisfaction of building occupants. The results (Figure 2) show that 78% and 84% of the respondents agreed, or strongly agreed, that they live in a more pleasant and comfortable environment, respectively. When asked to elaborate, the respondents associated the improvement in overall comfort with

enhanced indoor thermal and acoustic comfort post-retrofit. One respondent explained the improved thermal comfort stating:

"Less layers of clothing (are) required in cold weather. More comfort in warmer weather."

Respondent B

The reported overheating issues with multi-layered glazing in the literature were not evident in the results of our study (Walker, Lowery, and Theobald 2014). It should be, however, pointed out that overheating issues are highly dependent on the climate and the orientation of windows in a building. It is, therefore, not possible to draw conclusions on the overheating impacts of secondary glazing based on the results.

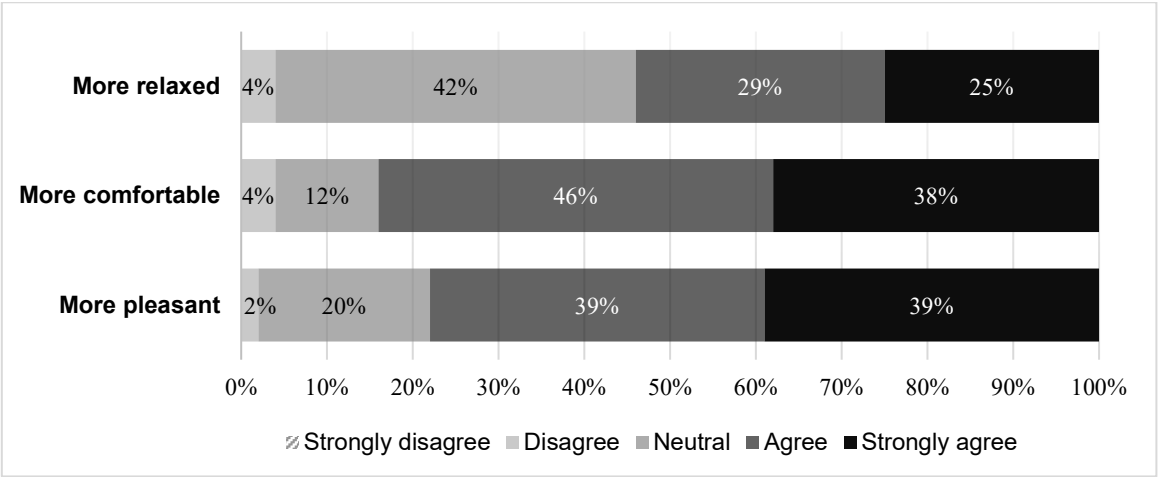

Figure 2 - Internal comfort improvement post installation of secondary glazed windows.

Double glazed windows can reduce condensation and mould growth (Chiu et al., 2014). When asked if there was less condensation and mould growth following retrofit of secondary glazing systems, 45% of the respondents agreed or strongly agreed (Figure 3). One of the respondents mentioned that they installed secondary glazing specifically to target condensation and mould in one of their rooms. The results also suggest that 45% of the respondents neither agreed, nor

disagreed, that secondary glazing reduce condensation and mould. This may suggest an absence of problems with condensation and mould growth pre-retrofit, but it can also be dependent on climatic conditions and building designs and sealings.

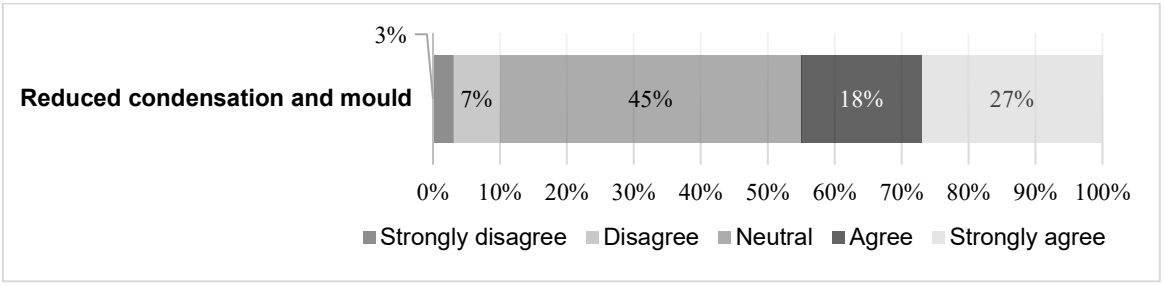

Figure 3 - Condensation and mould reduction post installation of secondary glazed windows.

Multi-layered glazing was found to provide better acoustic protection from outside noise in several studies (Mishra, Parida, and Rangnekar 2010; Kaiser, Pietrzko, and Morari 2003). The open-ended answers from the survey suggest that secondary glazing provides better acoustic insulation in comparison to single glazed windows by blocking out noise from outside. Nearly 54% of the respondents agreed or strongly agreed that they lived in a more relaxed environment post-retrofit (Figure 2), which could be related to better noise insulation, as suggested by results presented in Figure 4. This was pointed out by one of the respondents with the comment: *"noise levels have (been) reduced from neighbours' (houses) which has made it easier to sleep in the mornings and be at home without noise disruptions."*

Respondent C

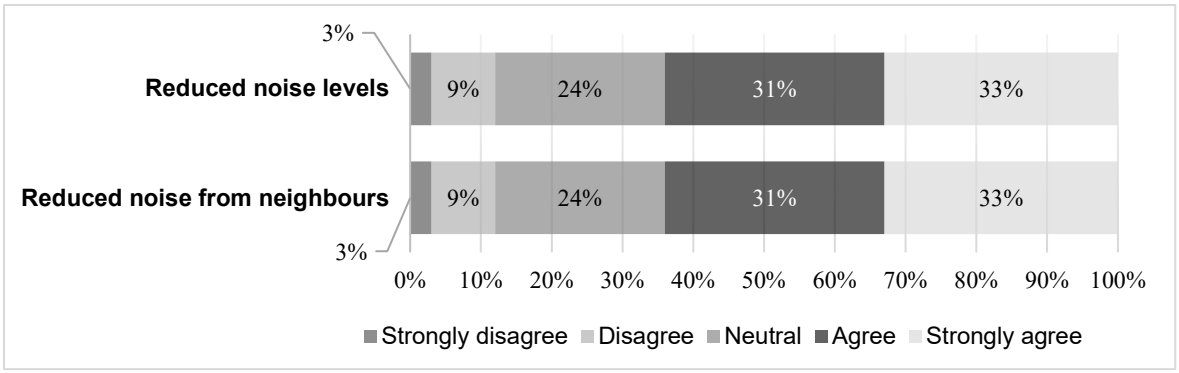

Figure 4 - Noise pollution reduction post installation of secondary glazed windows.

Positive behavioural changes by occupants, such as improved sleep, productivity and focus, as a result of enhanced indoor comfort post-retrofit can be expected based on previous studies in the literature (Bonnefoy et al., 2004; Jantunen et al., 1998; Bluyssen et al., 1995). Around a third of respondents in our study reported improved productivity (34%), ability to focus (36%) and efficiency (31%) post retrofit, as shown in Figure 5. Some respondents reported better sleep post-retrofit as a result of improved sound insulation.

Productivity is often studied in the context of office buildings; however, it can also apply to residential cases as people increasingly work from home. The number of employees working from home has increased dramatically as a result of the COVID-19 pandemic, whose impacts on working culture could be permanent (Kovar 2020). As a result of this, people may consider retrofit measures that have impacts on overall productivity. It should be noted that productivity may not necessarily be related to work, as it is also common to study at home, spend time on hobbies and do housework, such as cleaning and cooking. The results show that only a small percentage of respondents (<4%) felt there was reduced productivity, efficiency and ability of focus after the installation of a secondary-glazed window system. It is not known if this is associated with the retrofit or if there were other factors that contributed to this perception.

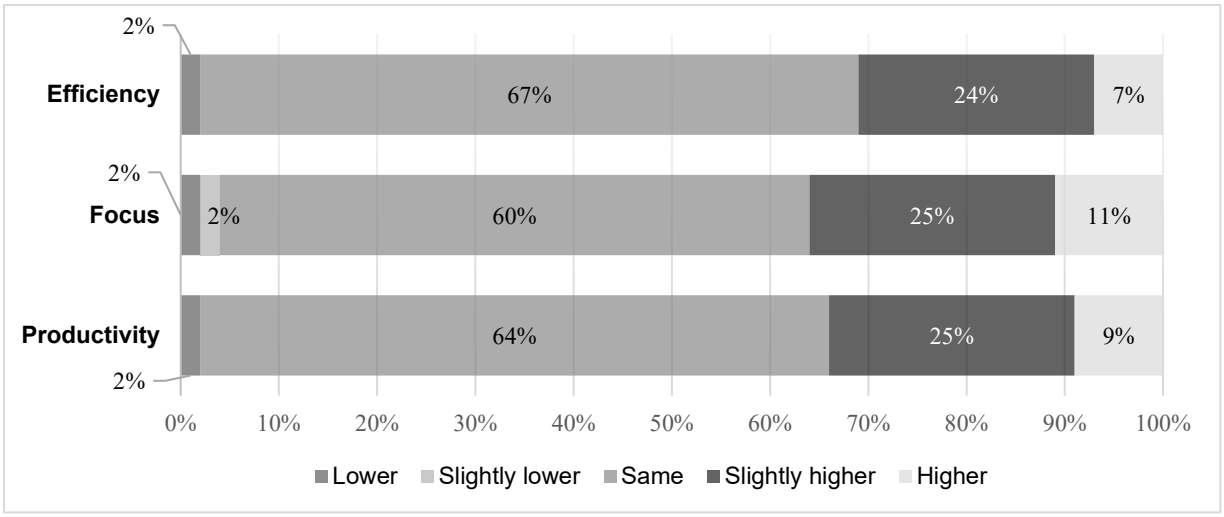

Figure 5 - Ability to focus and think, and personal productivity post installation of secondary glazed windows.

Attitudes to energy efficiency and its associated benefits, particularly economic, are important for increasing the rate of building retrofits. Several questions were included in the online survey to investigate the perceptions and attitudes of the survey respondents on energy efficiency. The results (Table I) suggest a high level of awareness for energy efficiency, with over 90% of the respondents who strongly agreed or agreed that *"responding to an energy conservation program is a good idea"* and, that; *"in Australia, there is a strong need to conserve energy*". In addition, nearly all respondents either strongly agreed (70%) or agreed (27%) that "*everyone has a role to play in energy conservation*" (Table 1), indicating that energy efficiency is considered a shared responsibility. The high level of awareness for energy issues identified in our study, however, could be related to the fact that the occupants have decided on the retrofit themselves, compared to for example cases of retrofit in public housing.

On the perceived benefits of secondary glazing, a vast majority of the respondents in our study strongly agreed or, agreed that; "*additional insulation is worth the effort*" and, "*products that reduce energy use are worth investing in*", as presented in Table 1. The results reflect a high level of satisfaction with the retrofit, as nearly 8 out of 10 respondents thought that installing

secondary glazed windows increased the value of their property (Figure 6). It indicates that the respondents consider the additional windowpane as something that would add value to their property and not the opposite, showing that secondary glazing is considered to be low-risk from a property value perspective. In addition, 77% of the respondents find it likely or very likely that they would get their new house retrofitted with secondary-glazing if they had to move to a new property, which could be interpreted as a strong sign of satisfaction with the retrofit with secondary glazing.

	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)
In Australia, there is a strong need to conserve energy	0	4	0	25	71
Everyone has a role to play in energy conservation	0	0	3	27	70
Responding to an energy conservation program is a good idea	0	0	4	23	73
Products that reduce energy use are worth investing in	0	0	5	18	77
Additional insulation is worth the extra effort	0	3	2	18	77

Table I - Energy conversation attitudes; need to conserve, roles, conservation is good, worth investing in and installing insulation.

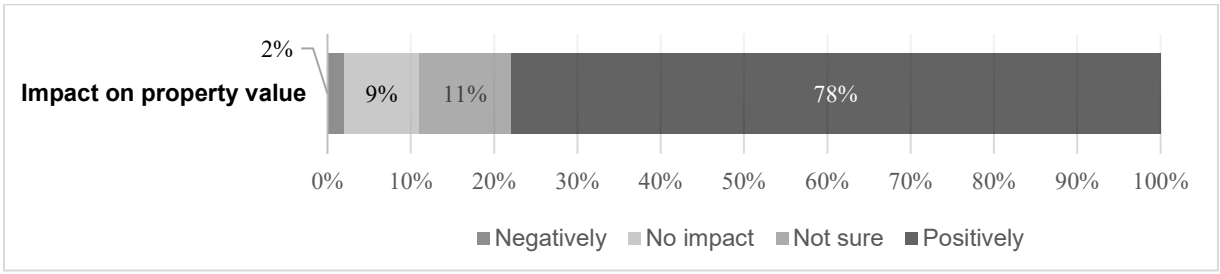

Figure 6 - Secondary glazing impact on my property value

Conclusions

The literature shows that energy retrofits to residental property offers the opportunity to reduce energy consumption and greenhouse gas emissions and to improve thermal comfort. Furthermore a considerable amount of energy leaks from poorly sealed single glazed windows and retrofitting with secondary glazing offers added benefits of reducing external noise pollution. Whilst evidence has been gained from studies outside of Australia of these benefits, they are not widely known or adopted in Australia. This research sought to acertain the views of building occupants who had retrofitted secondary glazing to their homes.

Based on a post-retrofit online survey answered by 56 respondents from Australia, this research addresses a knowledge gap by reporting on occupant perceptions of secondary glazed windows. The key findings from this study are as follows:

- More than 8 out of 10 respondents agree that their residence was more comfortable post retrofit.
- Most respondents felt that retrofitting with secondary glazing improved their wellbeing through better sleep, noise insulation and thermal comfort.
- Regarding energy efficiency awareness, 95% of respondents were willing to invest in products to reduce energy use.
- Approximately 79% stated that the new window systems had a positive impact on their property value. Nearly 77% of the respondents found it likely or, very likely, that they would get their new property retrofitted with secondary-glazing if they had to move.

Based on the results it can be posited that retrofitting existing windws with secondary glazing is considered a low-risk energy efficiency measure that significantly improves indoor comfort, through enhanced thermal and acoustic insulation. In the light of our results and the documented thermal insulation properties of secondary glazed windows in the literature, secondary glazed windows can be promoted as an viable alternative to double glazed windows in retrofits. They

can be particularly useful for retrofits where installing double glazed windows may not be possible for various reasons, such as high costs and inconveniences associated with the replacement of the window frames or heritage listing.

This study is a first attempt to evaluate post-retrofit occupant satisfaction with secondary glazed windows in Australia. Although the results of this study indicate a high level of occupant satisfaction post-retrofit, the survey data was collected from a limited geopraphical area with a relatively similar climate. There is, therefore, a need for further research on post-retrofit evaluations of secondary glazed windows in various climates to draw conclusions on their perceived thermal and acoustic insulation properties and health and well-being benefits. Nevertheless, this study contributes to the further use of secondary glazed windows by informing policy-makers, market actors and occupants on their benefits.

Funding

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Appendix A.

Survey Questions

1. Gender:

- Male
- Female
- Prefer not to say
- Other: _____

2. Do you live in a:

- House
- Unit
- Townhouse
- Other: _____

3. Age: _____

4. Occupation: _____

5. When did you retrofit your window(s) with secondary glazing?

6. How many rooms did you retrofit with secondary glazing?

7. Which rooms were retrofitted?

8. Since installation of your double-glazed windows, how much is your average energy bill in winter?

9. Since installation of your double-glazed windows, how much is your average energy bill in summer?

10. Since installation of your secondary glazed windows, to what extent do you agree with the statements below?

It is more pleasant

Strongly disagree				Strongly agree
1	2	3	4	5

It is more relaxing

Strongly disagree				Strongly agree
1	2	3	4	5

It is more comfortable

Strongly disagree				Strongly agree
1	2	3	4	5

11. To what extent do you agree with the following statements?

Since installation of secondary glazed windows, the noise level in my house/building has reduced

Strongly disagree				Strongly agree
1	2	3	4	5

Since installation of secondary glazed windows, any sounds from the neighbours' house have reduced

Strongly disagree				Strongly agree
1	2	3	4	5

Secondary glazed windows help reduce condensation and mould in the building

Strongly disagree				Strongly agree
1	2	3	4	5

12. Since installation of the secondary glazed windows: How would you rate your personal productivity?

Lower than before				Higher than before
1	2	3	4	5

How would you rate your ability to focus and think?

Lower than before				Higher than before
1	2	3	4	5

How would you rate your contribution to a piece of work?

Lower than before				Higher than before
1	2	3	4	5

How would you rate your overall efficiency?

Lower than before				Higher than before
1	2	3	4	5

13. To what extent do you agree with the following statements?

In Australia, there is a strong need to conserve energy

Strongly disagree				Strongly agree
1	2	3	4	5

Everyone has a role to play in energy conservation

Strongly disagree				Strongly agree
1	2	3	4	5

Responding to an energy conservation program is a good idea

Strongly disagree				Strongly agree
1	2	3	4	5

Products that reduce energy use are worth investing in

Strongly disagree				Strongly agree
1	2	3	4	5

Putting additional insulation in a home is worth the extra effort

Strongly disagree				Strongly agree
1	2	3	4	5

14. How do you think the secondary glazed windows have impacted on the value of your property?

- Positively
- Negatively
- No impact
- Not sure

15. If you had to move house, how likely is it that you would get your new house retrofitted with secondary-glazing?

Not at all likely				Very likely
1	2	3	4	5

16. Due to the window installation, has there been a change in any of the following (choose as many as are relevant, and explain):

- Garments/ dress while in-doors
- Food consumption
- Amount of drinks consumed
- Sleeping
- Entertaining
- Working from home

Please explain in what way have any of the above-ticked behaviours changed?

_____

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