SB10 Conference

Paper Number: 60

A COST BENEFIT ANALYSIS OF SECONDARY GLAZING AS A RETROFIT ALTERNATIVE FOR NEW ZEALAND HOUSEHOLDS

Scientific Paper, Student Paper

ABSTRACT

Houses with single glazing represent a large majority of the New Zealand housing stock. With the recent changes to the NZ Building Code Clause H1 Energy Efficiency, new houses require higher glazing thermal performance. This will lead to an increased need for cost effective methods to improve window thermal performance in existing single glazed houses without completely replacing the windows.

There are several secondary glazing options available including 'stick-on' plastic glazing as well as aluminium framed glass solutions that are installed inside the existing joinery. Secondary glazing is marketed as a cost effective alternative to insulated glazing units, providing both improved acoustic and thermal insulation to existing windows. There is little information regarding the in-use performance and cost benefits of secondary glazing in New Zealand. This paper will explore the efficacy of the secondary glazing products when installed in existing single pane frames.

A guarded hotbox was used to make thermal transmittance measurements on a typical single glazed aluminium window. Four common secondary glazing systems were retrofitted into the window – (1) thin plastic film; (2) magnetically-attached acrylic sheet; (3) aluminium framed secondary glazing; and (4) aluminium framed low emissivity (low-E) secondary glazing. Models of 'typical' New Zealand houses created in the ALF building thermal simulation programme were used to explore the heating energy savings and cost benefits provided by the different secondary glazing systems in a range of locations.

Of the tested products, the low-E secondary glazing produces the largest cost-benefits. Secondary glazing was found to not be a financially viable solution in warmer climates such as Auckland. In cooler climates such as Christchurch and Dunedin, secondary glazing was found to be a cost effective retrofit alternative for existing single glazed households.

KEYWORDS: Secondary glazing; double glazing; fenestration; cost benefit; retrofit

INTRODUCTION

With the recent New Zealand wide introduction of higher domestic glazing insulation requirements in the New Zealand Building Code (DBH, 2007) and the introduction of a Household Energy Rating Scheme (HERS) (EECA, 2007), there is a need to provide an economic means to upgrade the window thermal performance in existing housing without the need to completely replace windows. Windows are a thermally weak point of the envelope, responsible for between 26% and 48% of the heat lost from a building, depending on the insulation levels in the roof, wall and floor (Pollard, 2005). Existing single glazed houses make up a large percentage of the New Zealand housing stock – in 2005, 87% in Christchurch and 99.7% in Auckland.(Clark et al. 2005) Research has shown that these houses often struggle to reach acceptable temperatures during the winter season (French, 2007). Many of these houses lose much of their heat through the single glazed windows.

There is little information regarding the cost benefits of secondary glazing in New Zealand. Secondary glazing is marketed as a cost effective alternative to double glazed windows, providing acoustic and thermal insulation but using existing windows. With no research on the in-use performance of secondary glazing systems, it is difficult to make any comparisons or well based recommendations.

This paper examines the efficacy and cost benefit of a variety of secondary glazing systems under New Zealand conditions. Four secondary glazing systems were tested under laboratory conditions and then modelled using specialist software. The results from these investigations were then used to explore the cost benefits of the different systems, in order to develop recommendations for future retrofitting of existing single glazed houses.

METHOD

An international literature review found the most suitable method was a physical measurement of the thermal transmittance of the window using a guarded hotbox (GHB). This method is able to accurately provide thermal transmittance measurements and allows a fair comparison between the various secondary glazing systems. Due to the small expected variations in R-value between some of the secondary glazing products, both precision and accuracy of the measurements were crucial. Once the guarded hot box is set up, it is possible to conduct a number of tests in a short time, particularly with secondary glazing where the changes only involve the replacement of the internal glazing onto a fixed window.

To test the secondary glazing units a primary single glazed window is required which fairly represents windows currently used in New Zealand. A survey of New Zealand houses conducted in 2005 found that the proportion of homes with timber windows have decreased from more than 60% in 1999 to 44% in the 2005 survey. That decrease reflects the increased numbers of newer houses in this survey, along with the number of older houses replacing some or all of their old timber windows with aluminium (Clark et al., 2005). Aluminium windows made up 49% of the 2005 sample with the remaining 7% comprised of all other types of windows (Clark et al., 2005) being composite materials, PVC and steel. Therefore a typical aluminium window frame was used for the testing.

Secondary Glazing Selection

A variety of secondary glazing products were tested. A key difference between the products was the cost, with the products ranging from low-cost temporary solutions to more expensive permanent systems.

The most basic and lowest cost solution to be tested was the thin plastic film window kit. While this simple DIY solution can be achieved in a variety of ways, an off-the-shelf kit was chosen for investigation. The kit consists of a large clear, heat-shrink plastic sheet and a roll of double sided tape. These kits are produced by a variety of manufacturers; however most are comprised of similar materials.

The second product is magnetically-attached acrylic sheet, a middle cost, permanent solution. It consists of an acrylic sheet with edge-clipped magnetic strips which are used to attach it to the existing window frame which has been fitted with adhesive backed magnetic strips. While acrylic sheet could be purchased and installed using a DIY method such as screw fixing, the magnetic sealed system was chosen for the ability to easily remove and open the existing window, aesthetic appearance and the market availability.

The final product to be tested was a typical aluminium secondary glazing unit. It consists of aluminium tracks installed inside the timber reveal of the window. These tracks house two sliding sash aluminium windows. The windows can be opened by sliding along the track to access the inter-pane space for cleaning or ventilation, or they can be lifted out of the tracks outside of the heating season, and stored. The product is very durable and designed to be a long term solution, however the cost to produce and install these windows is higher. Different glass types can be used – for this study 6 mm clear glass and high performance low-E glass units were tested.

Physical Testing

The BRANZ Guarded Hotbox (shown in *Fig. 1*) has a 1.2 x 1.2 m meter box on the warm side of the box. This permits the hotbox to test fenestration systems up to 1.2m x 1.2m. For this project a 1m x 1m window was tested.

Fig. 1: The Guarded Hotbox Opened Between Tests

Around the window and separating the two sides of the hotbox was the surround panel. This panel is comprised out of timber studs forming a 1030mm x 1030mm opening. The open areas of this surround panel frame are filled in with 100mm thick expanded polystyrene (EPS) as recommended in Note 4 of ASTM C 1199 – 2000 (ASTM, 2000).

Once the wall is in place, then the window is positioned with 15mm timber packers used to ensure it is centred in the opening. The timber reveal is then firmly screwed to the timber surround. Finally any potential areas of air leakage are closed off by sealing the edge of the aluminium frame to the timber stud of the surround using masking tape. Care was taken to ensure that there were no air leaks and that the tape did not cover more that 13 mm of the test specimen frame or edge as specified by Section 7.1.3 'Air Leakage' of ASTM E 1423 (ASTM, 1999).

Next the 16 temperature sensors are wired up on the 'outside' (cooler) side of the window. A 4 x 4 grid of thermocouples are then suspended 100 mm from the window at equal 300 mm intervals to align themselves with the corresponding thermocouples in the heat metering box. Due to the transparent nature of the test specimens, a radiant shield with a low emissivity coating was positioned on the cold side of the GHB to minimise any radiant heat transfer through the window. Once this was complete, the warm half of the guarded hotbox was closed. The heat metering box is centred over the warm side of the window covering an equal 100 mm of the surround on each side of the window. The environmental conditions on each side of the hotbox are then established at an inside temperature of 25°C and an outside temperature of 18°C. The guarded hotbox was able to stabilise and produce reliable results with a 7°C temperature difference between the two sides.

The hotbox measures the thermal transmittance of the 1.2m x 1.2m area covered by the heat metering box. It does this by simultaneously measuring the temperatures on the cool and the warm sides of the box, the wattage used to sustain the set temperatures and the air temperatures on each side of the window being measured as the heat flow. These measurements are collected by a computer with a purpose-built software analysis program which records the measurements at 1 minute intervals and calculates the R-value.

The hotbox is switched on and left until the temperatures are stable. It is then left overnight to run. If the GHB temperatures have been stable and it is giving a consistent R-value result, the test can be stopped. The data is exported into a spreadsheet, the GHB switched off and opened up to remove the tested secondary glazing and prepared for the next test.

Computer Simulation

In order to evaluate the window R-value, it was necessary to calculate the thermal resistance of the surround panel. A combination of two separate programs was used for this purpose, The software combination was of Window 6 (LBNL, 2009a) and Therm 6 (LBNL, 2009b), provided by Lawrence Berkley National Laboratories (LBNL), are able to model each of the five fenestration systems both with and without the surround panel. The 1.2m x 1.2m modelled whole window and GHB surround was simulated with the GHB environmental conditions in Window 6, producing results very close to those measured in the GHB. The process was then repeated with the surround removed, enabling the calculation of the final whole window R-values.

Once the whole window thermal resistance was known, the potential energy savings could be calculated using the program AFL 3.1 (Annual Loss Factor) (BRANZ, 2009).

Ten ordinary New Zealand houses were modelled in ALF. The houses were randomly selected middle income single and two-storeyed households from a range of designs, sizes and construction materials. The houses were all constructed prior to 1978 and as a result are generally uninsulated throughout. The average window area for these houses was 40.5m^2, only 0.5m^2 more than the household average in 1996 (Burgess, 1998).

ALF was used to simulate the houses in four specific climate zones; Auckland, Wellington, Christchurch and Dunedin. The winter heating season for these climates was; June to August for Auckland, May to September for Wellington and Christchurch, and May to October for Dunedin. The houses were simulated using a typical NZ heating schedule of morning (7am-9pm) and evening (5pm – 11pm) heating, at a set point of 18°C. This is the minimum temperature recommended for thermal comfort by the World Health Organisation (WHO, 2007) and was the closest set point available to the average winter heating temperature of 17.3°C as measured by HEEP (Isaacs at al. 2002).

Each of the ten houses was modelled 5 times, once with the primary windows installed and then four more times with each of the secondary glazing units. This resulted in a total of 50 different models. These 50 models were each then simulated with the 4 different climates resulting in a total of 200 heating energy simulations. Not all windows in the houses were able to be secondary glazed. Many of the houses contained a glazing inset within doors, ranch slider doors, and conservatory style areas which, for the purposes of this study have not been secondary glazed. In the thermal models these windows retain the R-value of the single glazed primary window for all five models.

Cost Benefit Calculations

Quotes to provide and install were obtained from each of the manufacturers to secondary glaze two of the ten houses. Averaging these two provided a fair approximate cost for the remainder of the households. This allowed the quoted prices to be calculated for the remaining eight houses using a simple average cost per window, multiplied by the amount of windows. These prices were used alongside the ALF heating energy costs for the cost benefit calculation.

For the purpose of analysis, it was assumed that the heating for the houses was provided by electric resistance heating distributed around the houses and operating at 100% efficiency. The cost to provide the heating energy was calculated by multiplying the current price of electricity ($/kWh) by the annual amount of energy required to heat the house. The electricity cost was determined from the schedule of domestic electricity prices provided by the Ministry of Economic Development (MED, 2009). Electricity price escalation was assumed to be 2% per annum. As energy costs vary depending on the location, region specific energy prices were used.

The cost calculation for the thin plastic film secondary glazing required a different process. As the thin film is marketed as do-it-yourself, there are no installation costs. The most affordable price to purchase the tested thin plastic film kit was selected. The total price to secondary glaze the possible windows was calculated for each house from these costs. The windows were arranged so that there was as little unnecessary waste from the window film packs as possible, allowing for the lowest possible cost per m^2 for each house. Due to the kits typically only lasting one heating season, the cost benefit calculation determines the annual saving made by installing the film. Rather than producing an expected payback period for the product, the result was the household annual energy cost savings for the year minus the cost of the window kits for that household.

The three remaining systems; magnetically attached acrylic, aluminium and aluminium low-E secondary glazing needed to have the simple payback period calculated. The payback period was the number of years required for the annual heating energy savings to match the cost of purchasing and installing the units. The annual energy cost savings were added assuming an annual energy cost escalation of 2% until the sum totalled the capital cost of the secondary glazing. The total purchase and installation costs of the secondary glazing options for each household were divided by the annual energy savings to determine the payback period of each system for the various households in each of the four climates. The simple payback results are presented on table 4.

There are also non-energy benefits (NEBs) provided by secondary glazing such as noise insulation and improved health and thermal comfort from increased room and mean radiant temperatures and condensation reduction. While it may be possible to quantify the economic value of these benefits to the consumer, this study has not included the value of these NEB's in the cost-benefit results.

RESULTS

Table 1: Final Whole Window R-values

Fenestration Unit	U-Value (W/m².K)	R-Value (m².K/W)	Improvement (%)
Window	6.92	0.145	Ø
Magnetic Acrylic	2.75	0.364	152%
Thin Plastic Film	2.85	0.351	143
Aluminium	2.98	0.335	132
Aluminium Low-E	1.77	0.565	291

Table 1 presents the final whole window R-values for the both the primary single glazed window and for the window fitted with each of the four secondary glazing systems. These were the results measured by the GHB with the effects of the surround panel removed by calculation.

The thermal transmittance R-value for the primary aluminium framed window was 0.145 m² K/W. This was within 4% of the typical R-values for a generic aluminium 4mm clear single glazed window which is 0.15 m² K/W (New Zealand Standard, 2009).

The R-value for the window more than doubles once a secondary glazing unit was attached. These are significant improvements for the windows. With the exception of the low-E coating, the secondary glazing units all produce similar R-values when retrofitted on to the same window. This was expected as it is the air gap rather than the type of secondary glazing which provides the majority of the retrofitted window's thermal resistance (BRANZ, 1999). While there were variations in the air gap between the secondary glazing units, this would not have had a noticeable influence on the thermal transmission. This was because all the cavities were larger than 20mm wide; variations in spaces wider than this create very little difference in the R-value of the window (Godfrey, 1972).

In many cases these results were better than others previously measured and calculated for various secondary glazing units. The New Zealand manufacturer MagicSeal, calculated their product to have an R-value of 0.37 m² K/W (MagicSeal, 2007). WERS simulations found Magnetite able to produce R-Values as high as 0.37 m² K/W with a timber window or 0.22 m² K/W when installed over an aluminium window (WERS, 2008). The GHB measured magnetically attached acrylic R-value of 0.36 m² K/W was similar to the WERS result when using a timber framed window. The 152% improvement measured in the GHB testing however was much larger than the improvements found by the WERS simulations. WERS simulation found attaching magnetite provided an 18% improvement over the WERS single glazed aluminium window (0.18 m² K/W) and a 41% improvement over the WERS single glazed timber window (0.22 m² K/W) (Magnetite, 2006). With the GHB results producing an R-value 0.1 m² K/W higher than what was calculated for a timber window (rather than aluminium) with a similar secondary glazing system, the WERS result does seem high for the product.

Thin plastic film secondary glazing has been claimed by a manufacturer to improve the R-value of a window by 90% (3M, 2006). The testing found the product to go further than this and improve the R-value of the window by 143%.

The aluminium framed secondary glazing provided the least additional thermal resistance of the four secondary glazing systems. This was primarily due to the large amount of aluminium, (which has a high conductivity), in the framing. Aluminium was also used for the tracks and sash of the sliding-sash design. Despite this, the measured performance was still very similar to the two previous solutions. A difference of less than 0.02 m² K/W is very difficult to measure accurately and would provide little difference in the total amount of heating energy saved. Calculated R-values for aluminium framed secondary glazed products ranged from 0.34 to 0.38 m² K/W (Selectaglaze, n.d.). These R-values were just slightly higher than the results found by the GHB physical testing.

The low-E glazing gave a particularly impressive performance in testing, providing a 291% improvement over the primary window. The performance advantages of low-E secondary glazing over standard secondary glazing have been highlighted in an earlier USA study which found the payback period was half that of standard secondary glazing (Drumheller et al. 2007). The measured result of 0.565 m² K/W was just slightly higher than the results of manually calculated R-values of 0.51 – 0.56 m² K/W for similar low-E secondary glazing units (Selectaglaze, n.d.). A test cell study on Low-E secondary glazing found it to have an R-value of only 0.42 m² K/W when used in conjunction with a 0.23 m² K/W primary window (Klems, 2003). It is important to note that low-E coatings are not constant among various glass products and the properties of low-E windows can vary dramatically as shown in Appendix C of NZS4218 (New Zealand Standard, 2009). The emissivity can vary across the window and is typically influenced by factors such as climate, cost and tint. The surface of glass which receives the low-E coating can also vary, giving different results.

The GHB testing should be considered a best case scenario as it was tested under laboratory conditions, with both the window and each of the secondary glazing systems carefully installed to ensure that there were no air leaks or imperfections, and the test was of such short duration there was no time for any deterioration. The product was also installed over an airtight, fixed aluminium window with little thermal resistance, allowing for a large potential for improvement.

Energy Simulation

Table 2: Household Heating Energy Simulation Savings

	Auckland		**Wellington**		**Christchurch**		**Dunedin**	
	(kWh)	**Savings**	**(kWh)**	**Savings**	**(kWh)**	**Savings**	**(kWh)**	**Savings**
Window	5060		10810		12825		14830	
Magnetic Acrylic	4310	15%	9380	13%	11090	14%	12800	14%
Thin Film Plastic	4330	15%	9410	13%	11100	14%	12850	13%
Aluminium	4350	14%	9450	13%	11180	13%	12910	13%
Aluminium Low-E	4140	18%	9050	16%	10700	17%	12340	17%

These results present the average heating energy consumption from each of the ten houses simulated. The installation of secondary glazing provided heating energy savings of 13 to 18%. Despite the reduced Solar Heat Gain Coefficient (reducing the availability of solar energy), the higher R-value of the low-E secondary glazing resulted in an increased reduction in heating energy. On average, the low-E secondary glazing resulted in heating reductions approximately 3% larger than the other secondary glazing systems tested.

Cost Benefit Calculations

The heating energy savings were then converted to dollar savings using regional electricity costs, assuming an electric heat source with an efficiency of 100%.

Table 3: Regional Heating Energy Savings for Secondary Glazing Systems

		Auckland	**Wellington**	**Christchurch**	**Dunedin**
	Capital Cost	**22.88 c/kWh Savings**	**22.85 c/kWh Savings**	**21.43 c/kWh Savings**	**21.95 c/kWh Savings**
Magnetic Acrylic	$6,663	$172	$326	$376	$438
Thin Film Plastic	$246*	$167	$318	$374	$427
Aluminium	$6,720	$163	$310	$357	$416
Aluminium Low-	$7,643	$210	$401	$461	$538

*Annual Capital Cost

The average capital cost of each system was then divided by the regional savings to give an estimated payback period in years. This is displayed on Table 4. As the thin film plastic secondary glazing is replaced annually, the payback is calculated as an annual return and is presented on Table 5.

Table 4: Regional Simple Payback Periods for Secondary Glazing Systems

	Auckland (Years)	**Wellington** (Years)	**Christchurch** (Years)	**Dunedin** (Years)
Magnetic Acrylic	29.0	17.3	16.2	13.9
Aluminium	30.4	18.2	17.0	14.6
Aluminium Low-E	28.0	16.5	15.5	13.2

The average payback period for these products ranged from between 29 years for Auckland down to only 13 years in Dunedin. A 29 year payback is a significant amount of time to seek a return on an investment of around $7000. It is important to note that this study did not take any means to measure the life expectancy of the products. There was no evidence to suggest that the products would not last for more than 30 years. However, it is known that acrylic sheets are subject to scratching from wear and tear, and have been known to degrade from long term exposure to UV radiation. With well formulated material and good design, acrylic glazing can have a service life of 20 or more years (BRANZ, 1994). To seek a return within 20 years the product would generally have to be retrofitted into houses within climate zones 2 and 3. In these cooler climates the magnetic acrylic secondary glazing has the ability to pay itself off within the estimated lifespan.

While very similar, the additional aluminium window cost on average 1% more than the magnetic acrylic windows but was found to have approximately 6% poorer thermal resistance. Hence the payback period was inevitably going to be longer than for the magnetic acrylic windows. These small differences in thermal performance and price result in an average payback period approximately one year longer. The differences between the two systems were very small and are only a general representation of the payback period. The proportion, area and number of windows within a household could result in these systems having very similar paybacks or slightly larger than represented.

While the magnetic acrylic unit does manage to outperform the aluminium framed glass unit, there was only a very small performance difference between the two. As the two designs are quite different, it would be sensible to choose a unit based on durability, aesthetic and functional preference rather than purely economic reasons when the payback period is so similar. These choices would ultimately be down to the individual consumer.

Use of the low-E secondary glazing resulted in the shortest average payback period of the three permanent secondary glazing systems. It was able to produce these results in all four climates in which the products were tested. Despite having the largest cost to manufacture and install, the significant energy savings provided by the low-E secondary glazing were enough to result in the largest savings, even when the energy consumption was lower, such as in the warmer Auckland climate.

The average expected payback period in Auckland, as with the other units was still rather high. The average for the other three climates; Wellington, Christchurch and Dunedin, was below 20 years. This was below what would be the life expectancy of aluminium framed glass secondary glazing. Provided the low-E coating was not heavily scratched or damaged with chemicals during cleaning or storage, then it would remain effective throughout its full life. The average payback period for houses tested within Dunedin was below 14 years. This was a significant reduction in the payback period over other units.

Table 5: Annual Return for Thin Film Secondary Glazing Systems

	Annual Cost	**Auckland** Annual Return	**Wellington** Annual Return	**Christchurch** Annual Return	**Dunedin** Annual Return
Thin Plastic Film	$247	-$79	$71	$123	$187

This table shows the annual savings provided by the thin plastic film secondary glazing. In Auckland the average savings did not outweigh the capital cost but in all other locations, including Wellington, there were positive returns. Whether these returns are acceptable will depend on the value placed by the homeowner on the time taken to install the DIY system.

This rapid payback would be suitable for someone who is only seeking a short term solution. Examples of this could be tenants of a rental property, an owner who is looking to replace the windows before other secondary glazing systems would be able to provide a return on the initial investment or someone with future plans to sell the house. The product could also be used as a trial for homeowners contemplating a permanent secondary glazing system.

CONCLUSION

The measured R-values of the secondary glazing units indicated significant improvements over the single glazed window. The low-E glass secondary glazing produced a significant R-Value of 0.57 m^2 K/W. The remaining three secondary glazing units all had similar measured R-values, ranging from 0.34 m^2 K/W to 0.36 m^2 K/W. The small differences were caused by the different framing and glazing materials used. A key finding was the significant improvement these systems were able to provide over the existing single glazed window. The windows R-value increased from 132% through to 291%.

Low-E aluminium-framed glass secondary glazing provided the shortest payback of all the systems tested, although at the highest capital cost. This shorter payback period was the case for all the houses modelled in each of the four New Zealand climates. The additional energy savings outweighed the higher initial capital investment in all climates.

Based on the thermal simulations with the 10 different houses, secondary glazing is not a cost effective retrofit alternative within the Auckland region. Wellington, Christchurch and Dunedin all provided much shorter payback periods than in the Auckland climate. Wellington averaged a payback period of approximately 17 years depending on the system. When used in a Wellington climate, low-E secondary glazing produces a mean payback of 16.5 years.

Christchurch and Dunedin were both capable of producing much faster returns. Both climates were able to provide a mean payback period of 17 years or less for all systems. Low-E secondary glazing produced a mean payback just above 13 years when used in Dunedin.

As thin film plastic secondary glazing restricts the opening of operable windows and requires the homeowner to install it themselves, it may not be a suitable solution for many households. As it is typically a seasonal product it also requires replacement annually, although in some locations it can last longer. This also means that it is able to provide similar annual returns to the more expensive secondary glazing options, making it suitable for short term solutions. The low cost of thin plastic film secondary glazing allows it to provide a positive annual payback of more than half the capital cost in Christchurch and Dunedin. In Wellington the return was over one quarter of the purchase price and as it is a DIY system that requires time to install, it may not be suitable for many homeowners. In Auckland the energy savings did not outweigh the cost of purchasing the materials.

This work has for the first time measured the performance of four different secondary glazing systems. It found the basic systems to have similar thermal performance, with only the low-E glass system providing additional benefit. Although the analysis has focus on capital and running costs, it is possible that home occupants will receive other benefits from the installation of secondary glazing systems. Given the high window areas found in many New Zealand homes, these systems offer a realistic method to reduce heating energy use while also improving temperatures for the comfort benefit of the occupants.

ACKNOWLEDGEMENTS

Nigel Isaacs was primary supervisor and John Burgess the secondary supervisor. We would like to thank Building Research for the scholarship supporting Nick Smith, and to Beacon Pathway for funding the laboratory testing. We would like to thank BRANZ for the use of their test facilities, and Ian-Cox Smith, Mark Hearfield and Roger Stanford of BRANZ for their assistance in the assembly and testing.

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