Historic windows with passive heat loss reduction strategies and their effect on indoor thermal comfort

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Abstract

Ireland's ambitious goal of achieving net-zero emissions by 2050 necessitates significant reductions in operational emissions from its building sector, prompting the government to target the energy retrofitting of a quarter of its building stock by 2030. However, retrofitting historic buildings poses substantial challenges stemming from concerns related to architectural conservation, cost, and technical complexities. In this context, focusing specifically on addressing heat loss through single-glazed historic windows, this study revisits traditional heat loss mitigation techniques that were once prevalent in historic buildings but have since fallen out of common use. With in-situ tests, we investigate the thermal performance of curtains, blinds and shutters on single-glazed wooden sash and case historic windows. We present variations in heat loss through the window and its associated thermal comfort in response to each strategy. Test results show significant heat loss reduction from a combination of traditional strategies which is on par with secondary glazing. These strategies offer viable solutions for energy efficiency and thermal comfort in historic buildings without major interventions on the protected historic fabric.

Keywords - Historic windows, Experimental U-value calculation, Thermal comfort, Historic buildings, Passive retrofit strategies.

1. Introduction

It is estimated that 37% of all the Greenhouse Gas emissions in Ireland are attributed to the operation and construction of the built environment with operational emissions accounting for 2/3rd of these emissions [1]. Ireland's Climate Action Plan 2021 sets out to reduce emissions in the building sector by 44-56% by 2030. Among the proposed key actions in the building sector, the National Retrofit Plan targets to retrofit 500,000 homes (one quarter of the building stock) to higher energy efficiency and to reduce 50% of emissions from public sector buildings. Traditional buildings in Ireland constitute 16% of the total housing stock in Ireland [2]. Historic buildings are rarely considered in retrofit policy dialogues due to the architecture conservation agenda and the lack of technically feasible solutions [3,4]. Such impediments often render historic buildings less energy efficient and impact the occupants' thermal comfort. A study based in England estimated 3.2 million tons of avoidable carbon per year due to the preservation of the unique characteristics of neighbourhoods with conservation area status [5]. On the other hand, architecture conservation contributes to maintaining the unique identity of a place and acting as a tangible representation of cultural heritage.

Windows are often considered the weakest part of a building envelope in terms of thermal performance. A previous study reported that a double-pane window could allow as much as 10 times the amount of heat to escape the house compared to the same area of a typical wall [6]. The single-glazed period windows in historic buildings are less energy efficient with low U-values by a factor of 3 compared to Ireland's national building guidelines [7]. In cold climates, they lead to indoor thermal asymmetry and create draughts that reduce local thermal comfort. The colder inside surface of windows creates stronger radiant asymmetry and causes thermal discomfort to the occupants. Retrofit of periodic buildings and windows is often challenging due to the lack of technically feasible solutions aligned with conservation characteristics, expertise, and associated costs. In this context, we revisit a range of traditional passive heat loss reduction strategies to investigate their performance related to heat loss reduction and associated thermal comfort.

Previous studies on the thermal performance of windows with a range of heat loss reduction strategies were carried out in lab-based [8,9] and simulation-based [10] tests. Both the lab-based study report reduced heat loss through the window and an associated thermal comfort improvement for single-paned timber sash and casement windows with shutters, curtains, blinds, and secondary glazing. Secondary glazing provides better insulation overall. However, closed wooden shutters are found to be the most effective traditional strategy to reduce heat loss [8,9]. Another study, with hot box tests, used corrected empirical equations for the effects of window frames and outdoor wind velocity to estimate the U-value of a practical window with a cloth curtain [11].

In this study, we present in-situ tests conducted in the winter months of 2022 and 2023 on single-glazed period windows from 5 different historic buildings of varying typologies and scales across Greater Dublin, Ireland. Tested traditional strategies include the use of blinds, curtains, and shutters. We also compare their performance with modern passive strategies used in historic buildings like secondary glazing and slimline glazing fixed to the existing timber frame. In this study, we primarily test for the change in U-values and conductive heat loss through the centre of the glazing with/without other heat loss reduction options. We also report the interior room facing surface temperature variations associated with it. The implications of such variations on thermal comfort, convective heat loss, and radiative heat loss are also discussed.

2. Methods

2.1 Windows and strategies assessed

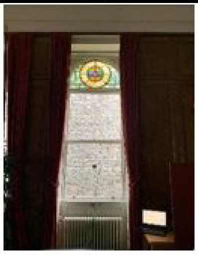
Table 1 reports the summary of the in-situ tests conducted on five different case studies. The windows were tested as found and are not draught proofed. Previous studies have reported that draught-proofing has no significant effect on conductive heat loss [9]. Case studies 1, 2, and 3 explore the performance of the single-glazed period window with/without closed blinds, curtains, and shutters. In case study 4, the impacts of these strategies, if the period window is retrofitted with a secondary glazing system (that was mounted within the staff beads of the period window), were analysed. Finally, case study 5 investigates the thermal performance of a commonly used slimline double-glazed pane that can be retrofitted into the existing timber window frame.

2.2 Experimental test method

The effect of passive heat loss reduction strategies in varying combinations is investigated with the experimental test methods previously outlined by these authors [12]. In-situ thermal transmittance values (U-value) are obtained using the quasi-steady average Heat Flow Meter (HFM) method. All the test scenarios have a Hukseflux Type HFP01 heat flux sensor and type-T thermocouples affixed to the centre of the glass measuring the heat flux through the glass and the indoor room-facing surface temperature. The ambient air temperatures in both the interior and exterior space were also measured using type-T thermocouples. For all the tests, the room heating radiators, except the one below the tested windows, were kept on for the entire duration of the tests. To monitor the exterior air, the thermocouple sensor was carefully probed out through the ventilation duct. The sensors collect data at 1-minute intervals and are stored as 10-minute averages in the datalogger.

Except for the fifth case study, all the tests comprised continuous observation of the thermal performance of the windows in response to various heat loss reduction strategies. For example, after all the sensors are in place, case study 1 starts with blinds and curtains closed. After 72 hours of monitoring, the readings were collected from the datalogger, and the curtains were opened to continue the test. Similarly, the test continued with the blinds closed for another 72 hours. In the third test, blinds were opened and the performance of the single glazing without any strategies was monitored. Now, this third test is used as the baseline for the previous tests. The tests are reported in reverse order (starting from single glazing alone, blinds down and then both blinds and curtains down) to make it easier to understand the heat loss reduction upon adding various options. This procedure is repeated for other windows. In the fifth case study, we investigate the performance of slimline glazing (double-glazed pane that can be retrofitted into the existing timber window frame). Here, we do not have a baseline single glazing as it was retrofitted a few years ago. Therefore, we compare its performance with a U-value averaged from previous single-glazing tests.

Table 1: Summary of the case study windows, and the tested heat loss reduction strategies.

No.	Test site	Case study windows and the test strategies			Notes
1	Dun Laoghaire-Rathdown (DLR) County Hall building				Tests conducted- single glazed; closed Roman blinds; closed Roman blinds and curtains. Room function- Assembly Hall, public events.
2	DLR Harbour Master building. (office space)				Tests conducted- single glazed; closed wooden shutters; closed curtains; closed shutters and curtains. Sensors placed on both glazing and shutters. Room function- Board room.
3	Leeson Street Upper (residential building)				Tests conducted- single-glazed; closed wooden shutters. Sensors placed on both glazing and shutters. Room function- Home office space.
4	Grove Park, Rathmines (residential building)				Tests conducted- single glazed; double glazed secondary window; secondary window with closed curtains; secondary window with closed blinds and curtains. Room function- Living room.
5	Richmond Place, Rathmines (residential building)				Tests conducted- slimline glazing on existing window frame Room function- kitchen.

https://doi.org/10.62744/CATE.45273.1146-514-522

3. Results

3.1 Heat loss reduction

Table 2: Test data for the in-situ experiments conducted on 5 case studies.

Case study	Case	Interventions	Indoor air	Outdoor air	Heat Effective	study
temperature temperature flux U-value Code (°C) (°C) (W/m²) (W/m²K)						
DLR County Hall building	1a	N/A- Single glazed	19.5	11.3	34.5	4.16
	1b	Closed Roman blinds	20.1	10.6	28.9	3.04
	1c	Closed Roman blinds and curtains	20.8	12.8	22.1	2.78
DLR Harbour Master building	2a	N/A- Single glazed	18.3 19.2	8.6	53.0 39.4	5.44 5.02
	2b	Closed curtains	17.0	11.3	23.6	2.40
	2c	Closed wooden shutters	19.7	7.2	26.0	2.69
	2d	Closed wooden shutters and curtains		10.1		
Leeson Street Upper	3a	N/A- Single glazed	15.2	7.6	39.7	5.25
	3b	Closed wooden shutters.	15.5	7.2	26.7	3.22
	3c	Closed wooden shutters, sensors on shutters	15.2	7.6	11.4	1.51
Grove Park, Rathmines	4a	N/A- Single glazed	20.5	11.7	40.6	4.62
	4b	Secondary glazing	20.5	11.7	11.8	1.34
	4c	Secondary glazing with closed blinds and curtains	15.5	8.3	7.0	0.97
	4d	Secondary glazing with closed curtains	16.3	10.5	5.1	0.88
Richmond Place, Rathmines	5a	Slimline glazing on existing frame	16.2	6.7	17.5	1.84

Figure 1: Change in heat loss through the surface and effective U-value for each intervention broken down by case study. All changes are relative to the respective single-glazing baselines.

Table 2 reports the test data for the different interventions considered in this study. Indoor and outdoor ambient air temperatures are tabulated alongside. Figure 1 illustrates the variation in heat loss and the effective U-value for the considered interventions relative to the baseline. The performance analysis baseline for each strategy is set by the performance of single glazing without any heat loss reduction strategies in their respective case studies. For example, code 1a is the baseline for 1b and 1c. In-situ tests report U-values of the single-glazed period windows ranging from 4.16W/m2K to 5.44W/m2K. Conductive heat loss through a surface area of 1m2 at the centre of the period window glazing is impacted by all the tested strategies. A reduction ranging from 87% to 33% is observed when a combination of strategies is tested (tests 1c, 2d, 3b, 3c, 4c, and 4d). Secondary glazing alone reduced heat loss to 71% followed by closing wooden shutters (55% to 33%), curtains (26%) and Roman blinds (16%). A baseline value of 4.85W/m2K U-value and heat flux of 42W/m2 averaged from the previous single glazing are assumed for case study 5. Based on this assumption, the heat loss reduction by the slimline glazing is 58% compared to the single glazing.

3.2 Thermal comfort

In this section, we compare the surface temperature of the single glazing with the surface temperature of the shutters (case studies 3b and 3c) and secondary glazing (case studies 4a and 4b) to understand the thermal comfort improvement achieved upon using them.

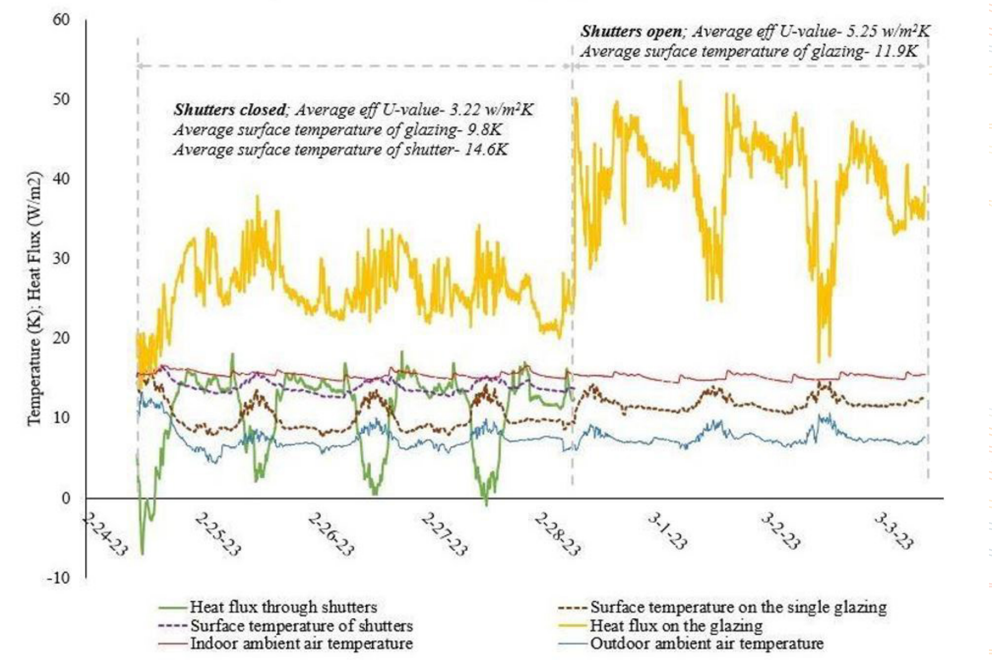


Figure 2: The impact of opening and closing wooden shutters on the surface temperature and heat flux through a single glazed period window.

Figure 2 illustrates the test data from 3c and 3b in a 7-day continuous test. The test started with heat flux and thermocouple sensors fixed on both the single-glazing and closed shutters. The figure summarises the increased heat loss through the glazing when the shutters are opened on the fourth day. On opening the shutters on the fourth day, the heat flux through the glazing increased and the average surface temperature of the glazing increased to 11.9°C when the shutters were open. When the shutters are closed, the average surface temperature of the shutters is 14.6°C, which is 2.7°C lower than the single glazing.

Figure 3 reports the test data from case studies 4a and 4b, a 3-day test conducted side by side on two-period windows but one affixed with a secondary glazing. The results show a reduction of heat loss through the secondary glazing as 71% less than that of the single glazing. While the average interior room-facing surface temperature of the single glazing is 16.6°C, the secondary glazing achieved an average interior room-facing surface temperature of 19.4°C. A 2.8°C temperature difference between single glazing and secondary glazing.

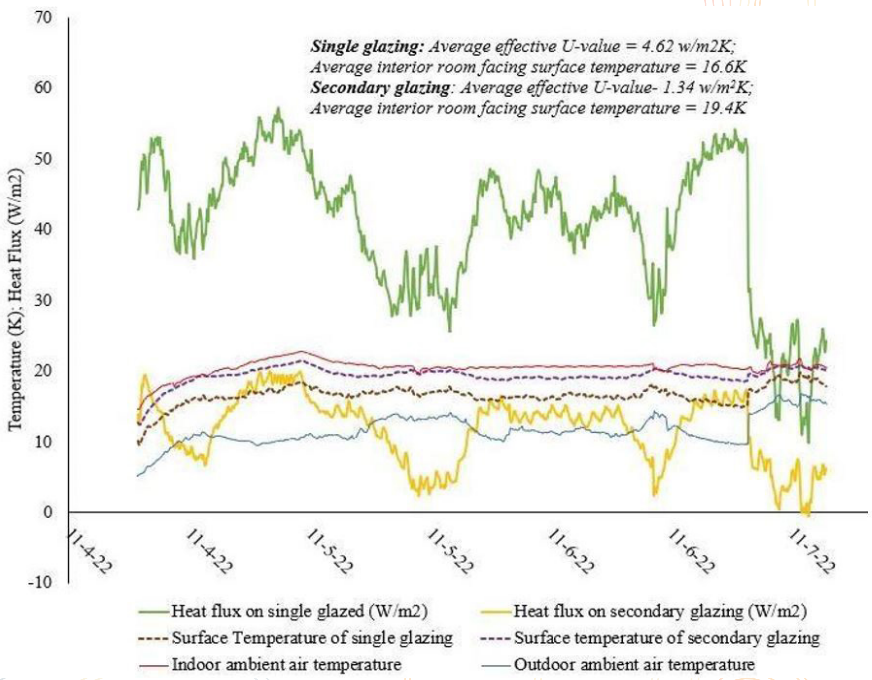


Figure 3: Test data on the performance of single glazing and secondary glazing analysed side by side.

4. Discussion

4.1 Heat loss reduction

This study presented results from in-situ tests conducted on period windows with a range of heat loss reduction strategies. The results imply that simple techniques like curtains, blinds, and shutters can substantially reduce heat loss through single-glazed period windows. Shutters are the most effective traditional solution with conductive heat loss reduction ranging from 55%- 33%. A similar trend in U-value reduction ranging from 56-39% is observed. Previous studies have reported a heat loss reduction of 61-64% [9] and 51% [8] associated with closed shutters. Closing the shutters alongside curtains and blinds can further improve the performance and achieve an effective U-value of as low as if it were retrofitted with secondary glazing. Similarly, employing secondary glazing on periodic windows can significantly reduce the U-value lower than 1.4 W/m2K, required by the Irish regulation for new builds [7]. The results also show that the secondary glazing's performance can be further improved if curtains, and more if shutters are used alongside.

Although the study illustrated a heat loss reduction trend with a range of traditional strategies, there are some exceptions when we compare them. This is primarily due to variations in the sensor placement. Unlike secondary glazing, the rest are not representative of the actual heat flow through the curtains, blinds, and shutters, but the heat loss through the single glazing after the insulation provided by those strategies. While sensors are placed on the surface of the secondary glazing and shutter facing the warm interior air, sensors placed on the single glazing face the colder buffer created behind the curtains, blinds and shutters measure the performance of the rest. The variation in the results is clear from tests 3B and 3C. Tests 3B and 3C are conducted together with two heat flux sensors placed on the centre of the single glazing and closed shutters respectively of the same window (Figure 2). With the performance of the same single glazing tested without shutters closed (3A) as baseline, 3B (on glazing) records a 33% less heat flux and 3C (on shutter) records a 71% less heat flux. Therefore, we cannot numerically compare the results of curtains, blinds, and shutters with secondary glazing and slimline glazing.

4.2 Thermal comfort

All the tested strategies create an insulating buffer zone between the heat transfer from the warmer interior to the colder exterior. The room-facing surface temperature of the wooden shutters was recorded as 18% higher than that of the centre of the single-glazed period window. A similar figure of 17% improvement is recorded with secondary glazing. The improved surface temperature impacts thermal comfort in two ways. A colder single window pane cools the interior air in contact with it, creates downdraughts and enhances the convective heat loss from the human body. A warmer surface, shutters, for example, reduces the downdraught in comparison with a colder single window and reduces thermal asymmetry. Similarly, increased surface temperature will also reduce the radiation heat losses. The lower the difference between the two surfaces, the lower the radiative heat transfer between them [13]. So the thermal asymmetry is reduced by the reduction of radiative heat transfer towards shutters, for example. Radiative heat transfer is also significantly reduced if a grey body, regardless of the surface temperature differences between the heat source, is placed parallel to the transfer as shown in a numerical study by these authors [13(p. 125)]. Therefore, all the tested options reduce conductive, convective and radiative heat losses and are expected to improve the thermal comfort.

4.3 Implications and limitations

For historic buildings where energy retrofit has technical, economic, and policy-related challenges, these simple traditional strategies could reduce a significant amount of operational energy, cost, and carbon by maintaining thermal comfort. Recent research on Net Zero Energy Buildings (NZEB) reveals that, despite achieving an annual net-zero or surplus energy balance through on-site renewable sources, these buildings depend on carbon-intensive energy imported from the grid to meet the elevated energy demands during the winter months [14]. Making use of simple strategies that are often forgotten like curtains, blinds, and shutters can further reduce their grid dependency. Similarly, in older town centres with heating-dominated climates, especially in Europe where the urban fabric has a significant number of inefficient historic buildings, these simple strategies can create a huge impact. Most of the historic buildings in Europe are equipped with these traditional strategies. Utilising them effectively is a leap towards climate action without any additional embodied carbon. The authors acknowledge that these strategies are not always ideal especially, as they can block daylight. Considering the shorter daylight and higher energy consumption during the winter months in Ireland poses a huge potential for these strategies to be used as a nighttime strategy. Lisa Heschong in her book, argues that when thermal comfort is a constant condition, it becomes so abstract that it loses its potential to focus affection [15(p. 36)]. Similarly, the curtains, blinds, and shutters not only provide thermal comfort at night but also a 'sense' of thermal function during the day as well. This is because we appreciate the variability in its thermal function [15(p. 37)] like we open or close the curtains, blinds and shutters. The authors also acknowledge that further research on infiltration and other parameters is essential for a truly conclusive study.

5. Conclusion

This paper presented a comprehensive analysis of a range of heat loss reduction strategies for single-glazed historic windows. In-situ tests on period windows with and without traditional options like curtains, blinds and shutters were tested. Their performance was compared with conventional retrofit strategies used in historic buildings such as secondary glazing and slimline glazing. The results indicate that seemingly simple strategies such as curtains, blinds, and shutters can significantly improve the thermal performance of single glazing. Using all the strategies in combination results is the most effective way to reduce the conductive heat loss through the centre of the glazing. For example, employing shutters, blinds and curtains together on a period glazing improves its thermal performance and can achieve an effective U-value of as low as if it were retrofitted with secondary glazing. Further, the introduction of these strategies to already retrofitted windows, for example, secondary glazing, can enhance its performance. Wooden shutters were identified as the most effective traditional strategy in this study. However, the study also argued that the comparison between those tests cannot be numerically compared due to the variations in the sensor placement. By creating an insulating buffer, all the strategies positively impact thermal comfort by reducing conductive, convective, and radiative heat losses. For historic buildings facing challenges related to energy retrofitting, these traditional strategies offer a cost-effective means of improving energy efficiency by maintaining thermal comfort without any additional embodied carbon. Considering the impact they have on the daylight and solar heat gain, it is advisable a nighttime strategy. These simple strategies with their benefits if advocated properly to the public can have a butterfly effect across the occupants, buildings, neighbourhoods, districts, national and global scale. This research is part of a wider project which aims to further address such impacts of these strategies across different spatial scales.

6. References

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