Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 00 (2018) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES18, 19–21 September 2018, Athens, Greece

Comparative performance analysis of Vacuum Insulation Panels in thermal window shutters

Arman Hashemi[a]*, Mahmood Alam[a], Kenneth Ip[a]

[a]*School of Envrionmen and Techmology, University of Brighton, Lewes Road, Brighton, UK, BN2 4GJ*

Abstract

Windows are a major area of heat loss in buildings and can lose up to 10 times more energy than other building elements. In a typical house, around 10% of heat is lost through the windows. Thermal shutters could considerably reduce heat losses through windows and improve the energy performance of buildings. Insulation plays a major role in overall performance of thermal shutters. Advance insulation material such as Vacuum Insulation Panel (VIP) can help in improving the performance of thermal window shutters. VIP with a thermal conductivity of 0.005-0.008 W/mK is a high thermal resistance and energy efficient alternative to conventional thermal insulation materials. In this paper, effect of VIP and conventional insulation has been investigated and compared for enhancing the thermal performance of window shutters using computer simulations. Results indicate significant reduction in heat loss through windows when VIP insulation was employed in internal thermal window shutters. Thermal bridging was found to be the significant factor that deteriorated the performance of the shutter. Reducing heat loss through the frame and surrounding walls could improve the VIP insulated shutter thermal performance by approximately nine times.

Keywords: Energy performance; Heat loss; Vacuum Insulation Panel; Windows; Thermal Shutter.

* Corresponding author. Tel.: +44 (0) 1273 642272.
E-mail address: A.Hashemi@brighton.ac.uk

1. Introduction

Energy efficiency in buildings is one of the significant challenges that need to be addressed for reducing their impact on climate and meeting the emission targets as agreed in the Paris agreement [1]. In the EU, buildings approximately consume 40% of energy and are responsible for 36% of CO2 emissions [2]. Insulating the building envelope is key to achieving savings on building space heat energy and reducing carbon emissions. Window is often the weakest element in the building envelope with regards to offering thermal resistance. According to the Approved document L of the UK Building regulation [3] windows can have overall heat transfer coefficient (U-value) up to 10 times higher compared to that of insulated building walls. Thermal shutters can be installed externally or internally on windows to improve thermal resistance and reduce heat glare and solar shading [4]. Thermal shutters can reduce heat losses through the non-coated and coated double-glazing window 30% and 25% respectively if placed externally [5]. Thermal shutters when applied internally can also provide non-intrusive solution to improve the thermal performance of windows of historic buildings without any impact on the external façade. Well-fitted external or internal wooden shutters can reduce the conduction heat losses by 60% [6]. Application of thermal shutter to improve the thermal performance of timber-framed sash windows can offer potentially low cost option compared to standard double glazing. This is due to the fact that installing standard double glazing would require the replacement of old sash window frame and may also lead to change the appearance of façade.

For traditional windows heat loss can be reduced up to 60% with thermal shutters insulated with conventional thermal insulation material [7]. To further reduce heat loss, traditional thermal insulation material in thermal window shutter application would require greater thickness to achieve the lowest U-value due to their higher thermal conductivity values in the range of 0.020-0.070 W/mK. Increasing the thickness of conventional thermal insulation materials to improve the thermal transmission values of thermal window shutters may be not be appropriate approach for achieving smart window designs. To overcome this challenge, alternative energy efficient materials are required to be investigated. Alawadhi (2012) [8] has theoretically investigated the Phase Change Material (PCM) in the development of a new external window shutter to improve the energy performance of windows and found that in hot climate PCM window shutters can reduce the heat gain through windows by 23.29%. Silva et al. (2015) [9] experimentally found that employing PCM in aluminum hollow blade internal window shutter reduces the heat flux from 18 W/m2 to 8 W/m2 in the measurement compartment in Mediterranean climate conditions in summer.

Alternatively, a new material such as Vacuum Insulation Panel with enhanced thermal performance can be employed to improve the thermal resistance of thermal window shutters with minimum thickness. Vacuum insulation panel is a high thermal resistance and energy efficient alternative thermal insulation to conventional thermal insulation materials. VIP consists of an evacuated rigid porous covered with a barrier envelope. VIPs have thermal resistance potentially 5-8 times higher compared to that of conventional insulation and offer thinner sections with the space saving potential [10,11,12]. The benefit of vacuum insulation panel over conventional thermal insulation materials is that it can enhance the thermal performance of the building element without any increasing in thickness. VIPs have been used in many building applications including external and internal surfaces of walls, roof, ground floor, doors, window frames. Vacuum insulation panels are suitable for window shutter applications due to the following reasons:

- Lower thermal conductivity values (0.005 - 0.008 W/mK)
- Slim section
- protection inside the wooden, metallic or plastic cover of thermal shutter

Vacuum insulation has been suggested for window shutter applications [13]. However, the challenges of thermal bridging and its effects on the thermal window shutter insulated with VIPs applications has not been investigated in the literature. Further, higher thermal resistance VIP insulation need to be compared with conventional insulation material in thermal window shutter application to ascertain the energy saving benefits. Within this context, this paper describes the comparative performance of employing VIP and conventional insulation in internal thermal window shutter applications. In this paper, different window scenarios with internal thermal shutters and different types of insulation materials including VIP has been investigated. The objectives of the research are to compare the thermal performance of windows with and without thermal shutter and also asses the performance of thermal shutter when insulated with conventional and VIP thermal insulation.

2. Methodology

Static thermal simulations were carries out in Voltra to assess the performance of different thermal insulations for internal window thermal shutters. VOLTRA is a thermal analysis software used for simulating three-dimensional transient heat transfer in rectangular objects [14]. Voltra is commonly used for:

- “Transient analysis of thermal bridges
- Dynamic thermal analysis of floor heating
- Analysis of building elements exposed to fire
- Ground heat losses (EN ISO 13370)
- Heat exchange problems
- Advanced façade engineering
- Passive solar building design”

Simulations were carried out in VOLTRA for different scenarios for a 1000x1000mm window with 50mm aluminium frame as follows:

- Bare window (without thermal shutter)
- Window and internal shutter with normal/conventional insulation (thermal conductivity: 0.35 W/mK)
- Window and internal shutter with VIP insulation (thermal conductivity: 0.006 W/mK)

Two glazing types with different *U*-Values (good performance: 1.4 W/mK and average performance: 2.0 $W/m^{2}\cdot K$) were also considered to evaluate the performance of shutters for high and average performing windows. Six combinations scenarios were therefore simulated to evaluate the performance of shutters for normal/conventional insulation and VIP panels. A constant internal and external temperatures of 20 °C and 0 °C were considered for the purpose of the simulations. Table 1 shows the material properties and outside/inside temperature used for the simulations.

Table 1. Input for simulations.

Material	Thermal conductivity (W/mK)	Thickness (mm)	Temperature (°C)
Outside	-	-	0
Inside	-	-	20
Brick	0.90	100	-
Cavity insulation	0.035	80	-
Concrete	0.85	140	-
Gypsum board	0.50	15	-
Double glazing type 1*	0.028	20	-
Double glazing type 2*	0.040	20	-
Shutter (Conventional insulation)	0.035	50	-
Shutter (VIP)	0.006	50	-
Air cavity between shutter and window	-	120	-

* Additional inside (0.13 m2K/W) and outside (0.04 m2K/W) surface resistance (BS EN ISO 10077-1) [15] should be considered for U-Value calculations.

3. Results

According to the results, heat loss through the high and average performance windows were 31.65 W and 41.8 W respectively. The results indicate considerable reduction in heat-loss through the windows when internal shutters were deployed. Heat-losses through high performance window reduced by 50% and 55% for the normal/conventional insulations and VIP, respectively. This heat-loss reduction for the average performing window was 55% and 59% for normal/conventional insulation and VIP panels. Table 2 shows the heat-loss values through the window with and without the shutter for two different window types.

Table 2. Heat-loss values through the window with and without the shutter for two different window types

Window	U-Value 1.4 (W/m²K)	U- Value 2.0 (W/m²K)
Shutter	**Heat loss through the window (W)***	
No shutter	31.65	41.80
Normal Insulation	15.67	18.85
Vacuum insulation panel	14.27	16.97

* Values include losses through glazing and window frame.

Figure 1 and Figure 2 show the temperature and heat-loss ranges through the window and shutters. The figures indicate a higher temperature around the perimeter of the shutters which is the indication of thermal bridging through these areas. The dark green colour at the centre of the shutters also indicate considerably lower losses through the VIP panel compared to the normal insulation; however, the losses through the surrounding walls and shutter frames are comparable.

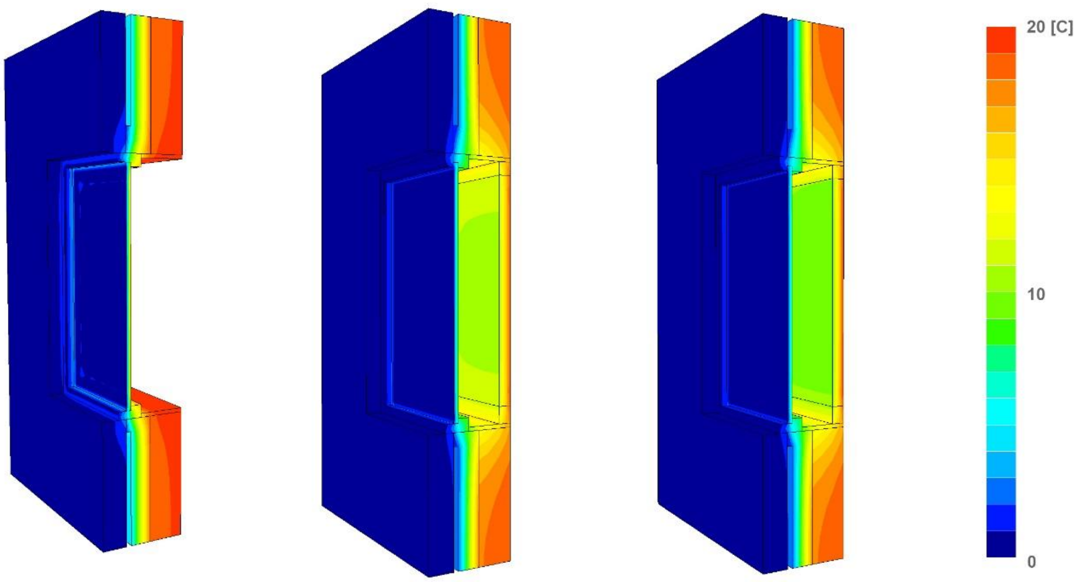

Fig. 1. Tempreture range (°C) for the bare window (left), Normal insulated shutter (middle), and Shutter with VIP panles.

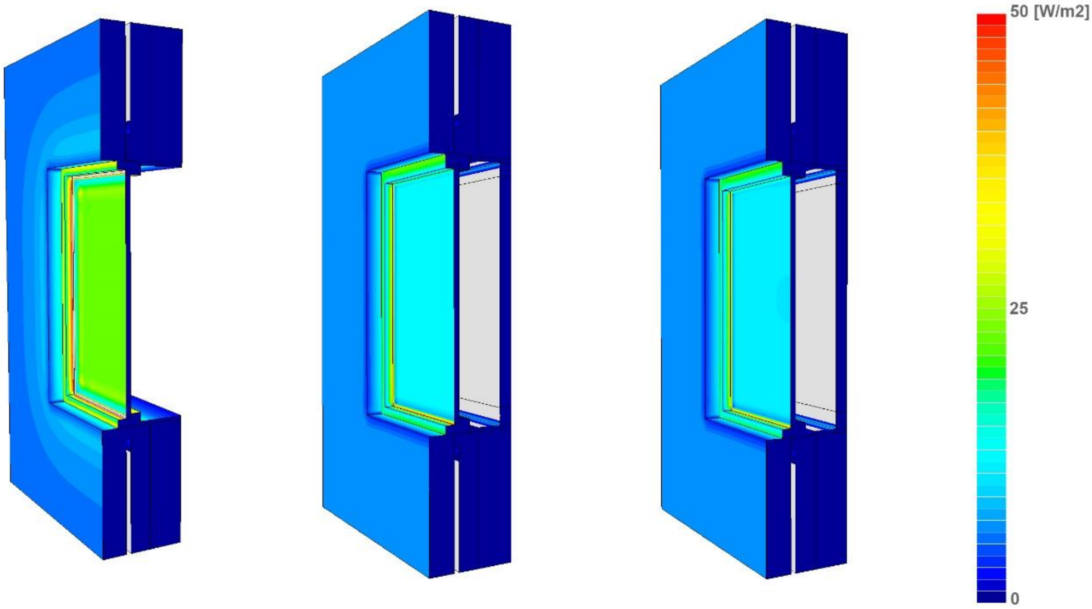

Fig. 2. Heat-loss range (W/m^2) for the bare window (left), Normal insulated shutter (middle), and Shutter with VIP panles.

4. Discussion

The results of simulations revealed that normal/conventional insulation had similar performance to VIP despite VIP thermal conductivity was 5.8 times smaller than the normal insulation. The difference in heat loss for VIP was only 5% less than the normal insulation. A possible explanation for this is the significant heat losses through the shutter frame and surrounding walls. According to Hashemi and Gage (2014) [4], thermal bridging could significantly affect the performance of thermal shutters. Additional simulations were therefore carried out to evaluate effects of thermal bridging in more detail. For the purpose of new simulations, the thermal conductivity of surrounding walls were changed to nearly zero to eliminate heat losses from surrounding walls. To create a uniform panel window shutter, the shutter frame was also changed into the same material as the shutter (Normal/conventional insulation or VIP). Eliminating the thermal bridging through the walls would reveal the pure losses through the window and shutters. Table 3 shows the heat loss values through the window when surrounding walls changed into adiabatic.

According to the results, the heat loss through the high and average performance windows for normal insulation were 6.53 W (79% reduction) and 9.35 W (77% reduction) respectively. The heat-loss reduction for the VIP shutter for the high and average performing windows were, in order, 1.53 W (95% improvement) and 1.67 W (96% improvement).

Table 3. Heat-loss values through the window with adiabatic surrounding walls

Window	**U-Value 1.4 (W/m^{2}K)**	**U- Value 2.0 (W/m^{2}K)**
Shutter	**Heat loss through the window (W)***	
No shutter	30.91	41.02
Normal Insulation	6.53	9.35
Vacuum insulation panel	1.53	1.67

* Figures include losses through glazing and window frame.

The amount of heat losses through the surrounding walls (thermal bridging) was also calculated by deducting the figures shown in Table 2 from the ones shown in Table 3 as follows:

- Heat-loss through the walls and frame for shutter with normal insulation: 15.67-6.53= 8.08W
- Heat-loss through the walls and frame for shutter with VIP: 14.27-1.53= 11.51W

The above figures reveal the effect of thermal bridging is significantly higher for the VIP panels. Indeed, thermal bridging has deteriorated the performance of the normal insulation by 2.4 times while the VIP performance has deteriorated by approximately 9.3 times. In other words, reducing heat loss through the frame and surrounding walls could significantly improve the shutter performance.

Considering the significant effect of thermal bridging on the performance of the shutter, it is recommended to insulate the window reveal to reduce thermal bridging. This is particularly important for uninsulated, externally insulated and cavity insulated walls. Reducing the cavity/gap between the shutter and the window may also improve the performance of the shutter as this would reduce the overall thermal bridging area; however, this would also reduce the air gap between the window and the shutter which acts as additional insulation. There is an implicit recognition of air gap R-Value in BS EN ISO 10077-1:2006 [15]. For a tightly fitted shutter an additional R-Value of 0.17 $m2.K.W^{-1}$ should be considered to recognise the insulating effect of the air gap between the window and the shutter. Further investigation is required to evaluate the effects of the air gap on the overall performance of the thermal shutter.

5. Conclusion

Buildings require façade with higher thermal insulation performance for reducing building energy consumption. Presently, improving thermal resistance of windows is the biggest challenge especially in historic buildings due to the nature of protected façade. Thermal shutter is one of the option to realise high energy performance of windows without any significant impact on the façade. This paper reports the findings of windows thermal performance with and without thermal shutter. Further, thermal performance of windows with internal shutters insulated with vacuum insulation panel (a higher thermal resistance insulation material) was compared with those insulated with conventional insulation material. Simulations were performed using 3-D heat transfer simulation software VOLTRA for different scenarios. Heat loss through the high and average performance windows was found to be 31.65 W and 41.80 W respectively. By insulating the shutter with conventional insulation heat loss values decreased by 50% and 55% respectively.

The small improvement in heat loss when VIP was employed is due to the significant thermal bridging effect. By eliminating the thermal bridging, the heat loss through the windows was reduced to 79% for the normal/conventional insulation. The heat-loss reduction for VIP shutter for the high and average performing windows were 95% and 96%, respectively. This improvement in heat loss was attained without any change in the thickness of the insulation. It was found that, in case of VIP insulated thermal shutter, thermal bridging led to deterioration in performance by approximately nine times. This study shows that eliminating the thermal bridging in the design of thermal window shutter is key to fully exploit the higher thermal insulating properties of vacuum insulation panel. Moreover, this research recognises the importance of air gap/cavity between the window and the shutter as additional thermal insulation. Further investigation is required to evaluate the effects of the air cavity as well as the airtightness on the performance of the thermal shutter.

References

[1] United Nations Framework Convention on Climate Change UNFCCC (2016). Adoption of the Paris Agreement- Proposal by the President (Draft decision -/CP.21), Conference of the Parties, Twenty-first session Paris, 30 November to 11 December 2015. Available from https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf [Accessed on 02 May 2018]

[2] European commission (2018). https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings [accessed 03 May 2018]

[3] HM Government. 2010. Conservation of fuel and power: Approved Document L. Available at: https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l

[4] Hashemi A., Gage S. (2014). Technical issues that affect the use of retrofit panel thermal shutters in commercial buildings. Building Services Engineering Research and Technology, 35 (1): 6-22.

[5] H. Sinnesbichler, H. Erhorn, A. Nimtsch, E. Lindauer, G. Haag, Further development and evaluation of technologies and of evaluation methods for improving the overall energy efficiency of buildings (EnEff06), IBP Report WTB-02-2007 , Available at: https://www.ibp.fraunhofer.de/content/dam/ibp/en/documents/oeVB_eng_2_tcm1021-30994.pdf [Accessed on 02 May 2018]

[6] Pickles D., McCaig I., Wood C., Molyneux N. and Makri E. (2017). Traditional Windows. Their Care, Repair and Upgrading. Historic England. Available at: https://content.historicengland.org.uk/images-books/publications/traditional-windows-care-repair-upgrading/heag039-traditional-windows-revfeb17.pdf/ [Accessed on 15 June 2018]

[7] Historic Environment Scotland (2013). Fabric Improvements for Energy Efficiency. Short Technical guide. Available at https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=179c1909-3679-4486-9583-a59100fa98c1 [Accessed on 02 May 2018]

[8] Alawadhi E. M. (2012). Using phase change materials in window shutter to reduce the solar heat gain Energy and Buildings 47:421– 429.

[9] Tiago Silva T., Vicente R., Rodrigues F., Samagaio A., Cardoso C. (2015). Performance of a window shutter with phase change material under summer Mediterranean climate conditions. Applied Thermal Engineering, 84, 246-245.

[10] Brunner S. and Simmler H. (2008). In situ performance assessment of vacuum insulation panels in a flat roof construction. Vacuum, 82, 700-707.

[11] Alam M., Singh H. and Limbachiya M.C. (2011). Vacuum Insulation Panels (VIPs) for building construction industry - A review of the contemporary developments and future directions, Applied Energy, 88, 3592 - 3602.

[12] Alotaibi, Sultan Sanat and Riffat, Saffa (2014) Vacuum insulated panels for sustainable buildings: a review of research and applications. International Journal of Energy Research, 38 (1). 1-19.

[13] TURVAC, (2018). http://www.turvac.eu/0/ApplicationfieldsandIndustries.aspx
[Accessed on 10 June 2018].

[14] VOLTRA Physibel. Available at: http://www.physibel.be/v0n2vo.htm [Accessed on 6th July 2018].

[15] BSI (2006). BS EN ISO 10077-1:2006, Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. British Standards Institution.