Environmental Performance of External Roller Blinds Retrofit for Offices in the United Kingdom

Kenneth Ip[1], Hanna Ylitalo[2] , David Marshall[3]

Abstract

Fixed external shading devices, such as louvers, are widely used to combat solar gains that can lead to excessive overheating. External roller blinds, although commonly used in mainland Europe, are rarities in the UK.

External roller blinds are retractable shading devices formed of horizontal slats that roll up into a casing above a window opening. They are a well-developed technology with distinct advantages over fixed external shading devices. When fully extended the blinds block solar radiation externally reducing heat gain in summer, in the winter they add thermal resistance and reduce heat loss through windows. Appropriate design and applications of external roller blinds have the potential to improve the sustainability of buildings.

This paper reports on an on-going applied research project that investigates the effect of external roller blinds on the internal thermal environment and potential advantages to the sustainability of retrofitting office buildings in the UK. The first part of the paper describes a proof of concept study in which an in-situ external roller blind was installed in a 'test' room and its summertime thermal performance was compared with that of a 'control' room under the same external climatic conditions.

Dynamic thermal analysis was carried out to establish the annual thermal performance of the blind, including impact on cooling and heating energy requirements. Associated annual carbon dioxide emissions were established and the blind was discovered to reduce the greenhouse gas emissions (CO_{2e}) by 15% annually, majority of which is reduction in requirement for heating.

The life cycle impact of the blind was investigated. Individual process contributing to the production, manufacture, decommissioning and transport of the blind were assessed in terms of their greenhouse gas emissions. Under the conditions of the concept study scenario and taking into account the recycle of the components, the external roller blind in operation is estimated to take approximately six months to save enough to compensate the embodied greenhouse gas emissions mainly due to the manufacturing process. The results

[1] Principal Lecturer: School of Environment and Technology, University of Brighton, Cockcroft Building, Lewes Road, Brighton BN2 4GJ, United Kingdom, E-mail: k.ip@brighton.ac.uk
[2] Sustainability Technologist: Alonso Marshall Associates, No. 5 Level 5 South, New England House, New England Street, Brighton BN1 4HG, United Kingdom, E-mail: hanna@amaconsult.co.uk
[3] Director: Alonso Marshall Associates, No. 5 Level 5 South, New England House, New England Street, Brighton BN1 4HG, United Kingdom, E-mail: davidj@amaconsult.co.uk

have demonstrated there is significant potential of using external roller blinds to reduce the operational and life cycle greenhouse gas emissions of buildings in the United Kingdom.

Keywords: External roller blinds, shading devices, solar control, environmental impact, heat loss reduction.

1. Introduction

There is a growing demand for strategies to combat excessive solar gains in buildings. Inclusion of effective shading has the potential to improve the indoor thermal environment: it can reduce summertime overheating, regulate swings in temperature and reduce cooling load. Windows are usually the weakest thermal element in the building envelope, and one of the most common causes of overheating is excessive solar gain through windows. Therefore reducing solar gain though windows is a key consideration in maintaining comfortable indoor temperature and implementing low energy building design. In comparison to mechanical cooling, shading is a more energy efficient and cost effective way to control overheating (CIBSE, 2006; Littlefair, 2002; 2006). Effective shading as an integral part of a building should be considered from early design stages of new buildings and for retrofit of existing buildings.

To evaluate the true environmental benefits, the greenhouse gas emissions throughout the life cycle of the shading device including its production, installation, operation, maintenance, decommissioning, recycling and transportation should be taken into account. A methodology commonly used, and adopted in this study, is the Life Cycle Assessment (LCA), which identifies and quantifies the inputs and outputs for a whole life cycle or individual life cycle stages of a product. Review indicated that previous study to establish the life cycle impact of external roller blinds has not been carried out. One relevant study carried out by Huang et al (2012) demonstrated that retrofitting a fixed overhang for shading had a negative environmental impact over its lifetime due to the geographical and meteorological factors.

This paper reports on an on-going applied research on the feasibility of integrating external roller blinds as a sustainable technology for retrofitting office buildings in the UK. It summaries the initial findings and conclusions of the first three stages of the research programme: an in-situ experimental concept study, computer modelling and simulation of the annual operation and performance, and the life cycle assessment of its environmental impact.

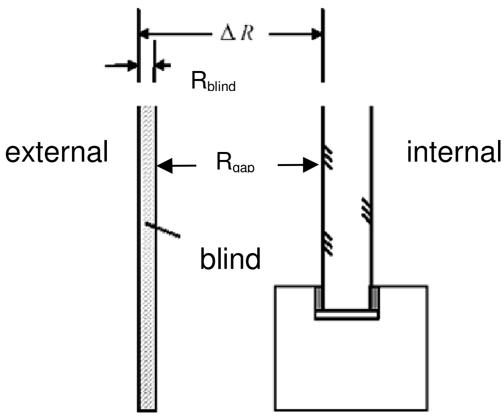
1.1 Background

The solar radiation transmitted by and absorbed within the glazing system establishes the level of solar gain in a space (CIBSE, 2006). External shading is more effective than internal shading in reducing overheating, as most of the heat in solar radiation is prevented form reaching a building surface. According to Wulfinghoff (1999) external shading can reduce solar heat input by 80% to 90%. Detailed design, in particular of fixed systems, is required to ensure heating and lighting demand is not increased as incoming daylight is blocked and useful winter solar gain can be reduced (Littlefair 2002; 2006). The need for shading is not the same throughout the year; variation comes from seasonal requirements, daily weather and occupant requirements. Therefore, moveable devices that can respond to the climate and user needs are preferred.

1.2 Quantifying shading

On a clear summer day, an unshaded window in the UK can admit 3 $kWh/m^2/day$ (Littlefair, 1999). To reduce overheating, a shading device should have a low total *solar transmittance,* or *g-value* - the fraction of incoming solar radiation that passes through a window and shading system. It includes radiation that is transmitted directly through the window and radiation that is absorbed; and the re-radiated, convected or conducted heat into the room. If possible, the g-value should be low in the summer to reduce solar heat gain and high in the winter to take advantage of passive heat gain. The *effective solar transmittance*, or effective g-value g_{eff}, allows for the effects of radiation coming in from different angles, throughout a sunny day, accounting the extra radiation blocked by a shading device (CIBSE, 2006). Current definition of g-value for static shading devices is not applicable to moveable roller blinds. Dynamic g-values governed by the blind's shading position and external climatic condition at a particular time and day of the year are needed to be developed to represent the dynamic shading performance.

External blinds provide additional insulation due to the air enclosed between the window and the blind. The degree of insulation depends on the level of enclosure, the effective entrapment by top and bottom seals and side channels (CIBSE, 2006). EN ISO 10077-1:2006 gives the thermal transmittance of a window with closed external blind, U_{WS}, as:



$$U_{WS} = \frac{1}{1/U_W + \Delta R}$$

U_W	thermal transmittance of window;
ΔR	additional thermal resistance due to the air layer (R_{gap}) enclosed between the blind and the window, and the closed blind (R_{blind}) itself.

Figure 1: Thermal transmittance of a window with closed external blind (BSI, 2006)

1.3 Quantifying greenhouse gas emissions

Greenhouse gases emissions can be calculated by measuring the energy consumption of the processes and applying published conversion factors. Conversion factors used are based on Defra (2011) guidelines as indicated in Table 1.

Table 1: Carbon emissions conversion factors (Defra 2011)

Spain electricity	UK electricity	Natural gas	Transport road	Transport shipping
0.32588 kg CO_2e / kWh	0.48462 kg CO_2e / kWh	0.224 kg CO_2e / kWh	0.25897 kg CO_2e / tonne.km	0.00411 kg CO_2e / tonne.km

2. Performance and functionality of external roller blinds

External roller blinds are retractable shading devices that are widely used in continental Europe. They provide solar control and reduce heat gains by blocking solar radiation externally. In a down position the blind increases thermal resistance, resulting from both the blind itself and the additional air layer enclosed between the window and the blind. External roller blinds have a range of different insulating properties; thermal and acoustic insulation and resistance to wind and water. In wintertime, due to the supplementary thermal resistance in a closed position they can reduce heat loss through windows at night. When fully extended the access to natural light and ventilation can be restricted. The blinds are commonly used with windows that open inwards or that have a sliding opening mechanism.

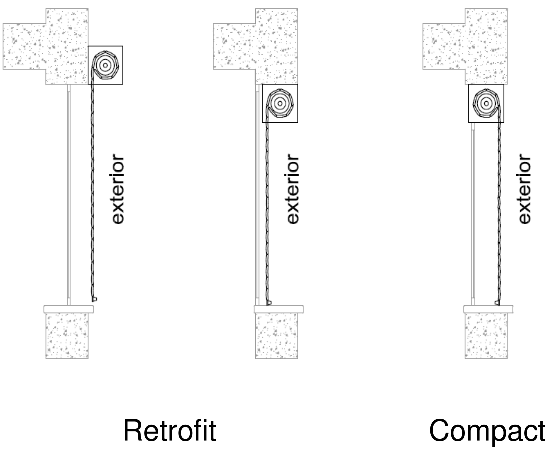
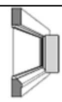
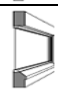


Figure 2. External roller blind systems

Table 2: Functionality of generic shading devices (Littlefair 2006, Stack et al 2000)

Shading device	Description	Performance g_{eff} *	Recommended orientation (UK)	Illustration
Fins	Vertical projections fixed at the sides of window openings	0.35	North	
Louvres vertical	Framed assemblies of vertical slats, fixed or adjustable angle	0.31	Northeast, northwest	
Overhangs	Horizontal devices fixed above window openings	0.27	South, southeast southwest	
Reveals	The sides to window openings, window heads and sills	0.35 (0.2 x width) 0.16 (0.5 x width)	South, north	
Louvres horizontal	Framed assemblies of horizontal slats, fixed or adjustable angle	0.21 (no tilt) 0.15 (45° tilt)	South, southeast, southwest	
Awnings	Retractable fabric-on-frame projections above window openings	0.13	Any	

*South facing low emissivity double-glazed window with *g* value of 0.68

The thermal impact of various fixed external shading devices has been studied (Littlefair 2006, Stack et al 2000); focus often being on reducing summer overheating without blocking out useful daylight. Performance indicators are established for generic shading devices as shown in Table 2. However, these performance indicators, in terms of *effective solar transmittances* (g_{eff}), are not appropriate for external roller blinds. Dynamics shading coefficients that relate blind position and time of the year are currently being developed. The market place for external roller blinds in the UK is currently mainly for security applications. Anecdotal evidence indicates that the public perception of the system is as a security product and their thermal impact is not realised. The importance of establishing the thermal performance of the system is a key consideration for wider applications in the UK.

There are two main types of roller blind systems: retrofit and compact, as shown in Figure 2. The retrofit system has the blind mechanism fixed to the exterior of the building with access to all components externally. The compact system has the blind as part of the window system, housed in a lintel box, with internal access to all components. Operating system is either manual belt driven or motorised. Motorised blinds can be automated via a building management system, or by local control using wireless handheld device or wall mounted switch. The slats that form the shutter are aluminium with polyurethane insulation. The thermal capacity of the blind is determined by the thickness of the slat and density of the polyurethane foam.

3. Demonstration of concept study

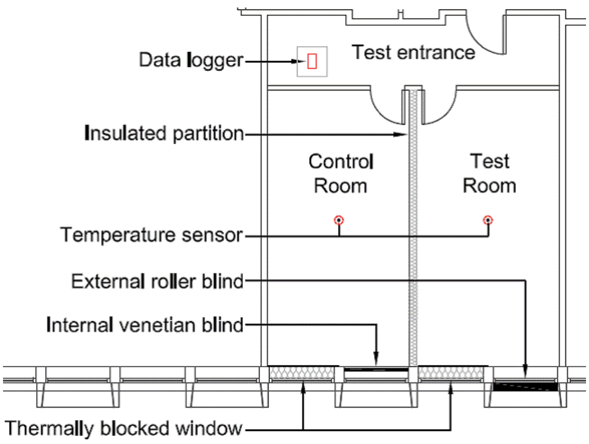


Figure 3. Floor plan of the concept study

A study was conducted with the aim to determine the shading effect of an external roller blind. The concept study was carried out in August 2011 at the University of Brighton, England. A southwest facing room was partitioned into three compartments: entrance area, control room and test room, as shown in Figure 3. Control room and test room had the total floor area of 16.5 m^2 each, 3.5 m high. Each room had two windows with boxed type projection fins, one of which was blocked and thermally insulated. The remaining window was installed with either an internal venetian blind or an external roller blind. Blind positions were set manually at midday to an internal daylight level of 300 lux in order to achieve visual comfort in offices (CIBSE, 2006). This set the external roller blind 650 mm open from the base. Rooms were unoccupied, windows remained closed, the lights were switched off and no equipment was present. The mean radiant temperature was recorded at five-minute intervals. Local meteorological data (Weather Underground, 2011) of external air temperature was collated.

3.1 Concept study results

Temperature data was simplified to hourly mean values and organised to daytime; 8 am to 6 pm, and night time 6 pm to 8 am, representing office occupation hours. The results (Ylitalo et al 2012) summarised in Table 3, show that the mean daytime temperature difference between the rooms was 1.8℃, maximum difference 3.5℃ and minimum difference 0.4 ℃. The analysis of temperature frequency in rooms revealed that the temperature range in test room is more uniform and levels out at a lower temperature with peaks closer to the trend indicating that the external roller blind is regulating the level of solar gain.

Table 3: A summary of the experimental study daytime temperature data

	Mean radiant temperature ℃			External air ℃
	Test room	Control room	Difference	
Mean	20.4	22.2	1.8	17.3
Max	22.5	24.7	3.5	23.0
Min	18.6	20.0	0.4	12.0

4. Computer thermal modelling and simulation

Dynamic thermal simulation was carried out using IES Virtual Environment software to predict the impact of an external roller blind on cooling and heating loads. The simulation parameters are based on the concept study setup as summarised in Table 4.

Table 4: Simulation parameters

Item	**Parameter**
External wall	300mm concrete, cavity, concrete block, U-value 1.06W/m^{2}K
Internal partitions	120mm plasterboard, glass fibre quilt, plasterboard, U-value 0.34W/m^{2}K
Internal ceiling/ floor	Carpet, screed, concrete, cavity, ceiling tiles, U-value 1.0687W/m^{2}K
Glazing	1.3m x 2.3m, 6mm single glazing, metal frame, U-value 5.56W/m^{2}K
External shading device	Left and right fin projection 500mm, offset 0mm
External roller blind	Summer profile: extended at 300W/m^2 incident radiation, retracted at 100W/m^2, extended when building unoccupied, U-value 2.5 W/m^{2}K Winter profile: extended at night and when building unoccupied, U-value 2.5 W/m^{2}K
Internal venetian blind	Shading coefficient 0.61, short-wave radiant fraction 0.4
Weather data	Heathrow
Heating	1st Oct – 31st May, temperature set at 21℃, follows occupancy profile
Cooling	1st Jun – 31st Aug, temperature set at 23℃, follows occupancy profile
Occupancy profile	8am – 6pm, Mon to Fri, unoccupied at weekends and holidays

4.1 Simulation results

The results in Table 4 show different temperature profiles for test room and control room,. Majority of annual energy consumption is for heating energy, the room with external roller blind has 13% lower requirement. The summertime results show a lower requirement for cooling energy in the test room with the external roller blind. Test room cooling requirement is not significant enough to justify the installation of an active cooling system. The simulation results show that with the use of external roller blinds annual emissions can be reduced by 68 $kgCO_{2e}$, or 15%.

Table 4: A summary of the simulation annual energy consumption results

	Heating energy		Cooling energy		Annual total	
	(kWh)	($kgCO_2e$)	(kWh)	($kgCO_2e$)	(kWh)	($kgCO_2e$)
Control room	2018	452.32	23	11.15	2041	463.47
Test room	1761	394.46	1.5	0.72	1762.5	395.18
Difference	257 (13%)	57.86 (13%)	21.5 (94%)	10.43 (94%)	278.5 (16%)	68.29 (15%)

5. Environmental impact of external roller blind

The environmental impact of the external roller blind is established by life cycle assessment (LCA), consisting of four phases; goal and scope defining; life cycle inventory; life cycle impact assessment and interpretation (ISO 2012).

5.1 Goal and scope definition

The goal of the LCA is to establish the life cycle greenhouse gas emissions of one functional unit of an external roller blind. The scope includes establishing a functional unit of the same dimensions and specifications as used in the concept study. The production of aluminium is included but a benchmark figure is used for embodied energy content. The assessment includes the mechanical processes of aluminium roll forming, coating, blind manufacturing and associated transport, including transport to site and end of life recycling of steel and aluminium. The end of life management process beyond recycling is excluded.

5.2 Inventory of processes and emissions

5.2.1 Inventory of processes

i. **Aluminium production –** The main material of external roller blinds is aluminium. Aluminium is widely used in the construction industry; it is lightweight, strong and long lasting. Aluminium can be recycled without loss of quality; the re-melting of aluminium requires 5% of energy in comparison to production of primary aluminium. The production process starts by surface mining of Bauxite, an ore containing alumina, or aluminium oxide. In 2011, the largest producers were China, Russia and Canada (USGS 2012). The alumina refinery process involves four steps; digestion; clarification; precipitation and calcination. To burn bauxite into alumina, the ore is ground and mixed with lime and caustic soda, the mix is pumped into high-pressure containers and heated. The alumina is dissolved by caustic soda and precipitated out of the solution. It is then washed and heated to drive off water. What is left is the alumina, a white granular material that becomes aluminium metal in the smelting process. The smelting takes place in the electrolytic cell, where current passes through molten aluminium oxide dissolved in a 920 - 980℃ cryolite bath. The process separates aluminium metal for casting as primary aluminium. Primary aluminium is transported around the world to further processing (IAI 2012).

ii. **Coil manufacturing -** In the coil manufacturing process the primary aluminium ingot is combined with recycled aluminium and manganese to form an alloy. External roller blinds in the concept study are made of aluminium alloy. The aluminium alloy is processed by continuous casting to form 19 mm thick strip. The strip is reduced by hot rolling mill to 2mm strip, cold mill process further reduces the thickness to as thin as 0.25 mm. Tension levelling line is used to improve the precision flatness of the aluminium strip. The slitting line cuts the master coil down to required width. The end plates for the roller casing box are die cast. The extruded aluminium side guides are formed from sheets. Raw aluminium components are transported to coating factory.

iii. **Coil coating -** For the coating process the raw aluminium coils are linked to form a continuous band to allow coating. To clean and surface treat the aluminium, in order to improve adhesion and resistance to corrosion, a pre-treatment layer is applied. Prime coating is then brushed over as a first step of the lacquering process. Following this, the upper face receives a primer or paint coat, depending on the product, and the back face receives a protective layer, which is then dried and cured in a furnace. Final coating is applied, then dried and cured. End plates and side guides are coated. Coated aluminium is transported to blind manufacturer.

iv. **Roller blind production -** The coated coil is roll formed by sheet roll forming machine that produces the slat. Polyurethane foam insulation is injected during the forming process. Slats are cut to size at the end of the line. The casing is roll formed in sections. Other components are sourced, including the manual operating mechanism, seals and brackets. The blind is assembled and the final product is packaged ready to be transported to site. The blind used in this study is transported from Valencia in Spain to Brighton in England.

v. **Installation, operation and maintenance -** The blind is manually operated with no associated operational energy. Annual cleaning and maintenance is required. Replacement of some components is required, namely the belt. The blind has 25-year lifespan.

vi. **End of life management -** End of life management is taken to include recycling of majority of the components. Of the aluminium content 95% is recycled, 80% of steel is recycled (Hammond and Jones 2011). Remaining components will go to landfill.

5.2.2 Inventory of emissions

This assessment includes the manufacturing of the blind from aluminium ingot, with assumed recycled content of 33% (Hammond and Jones 2011), the transport of ingot to manufacturer is not included in the assessment. One functional unit is taken as external roller blind sized to fit experimental study window, sized 1.3m wide and 2.3m high (surface 2.99m^2). Total weight of aluminium is 21.8 kg. Assessment is based on *Aluplex A-40 Curved* high performance insulated slat (Aluplex 2012). Any part of the blind that contributes less than 2% to the total quantity of the blind, such as coatings and operating mechanism components, are not included in this assessment. Blind lifespan is 25 years. The transport energy is based on weight of one functional unit and packaging, taken as 30kg. Return journeys and maintenance of vehicles are not considered. Table 6 details the greenhouse gas emissions contribution in the life cycle of the external roller blind.

5.3 Impact assessment

Annual saving of 68.29 $kgCO_{2e}$ can be expected from the results of the computer simulation in the concept study and the life cycle impact of the blind from the LCA is 37.54 $kgCO_{2e}$. Therefore, within the boundary of the assumptions and limitations, the saving of greenhouse gases while the blind is in operation will compensate its life cycle emissions in less than six months, which are mainly due to production of aluminium and transport. If end of life management is not taken into consideration and the blind is not recycled, the life cycle emission becomes 215.19 $kgCO_{2e}$, approximately three years operational saving would be required to cover the life cycle emissions.

6. Analysis of results and discussion

This study consists of three parts. Firstly, the proof of concept in-situ experimental investigation, secondly the assessment of annual energy consumption and associated carbon emissions analysis and thirdly the life cycle assessment.

The concept study set out to demonstrate the thermal impact of external roller blinds. Results of temperature profiles show improvement of thermal comfort in the test room when compared with the control room. Daytime data analysis shows that maximum temperature difference between the rooms was 3.5ºC; mean temperature was reduced by 1.7ºC and temperature swing reduced by 3.2ºC. Therefore, it can be concluded that under the concept study conditions external roller blind has demonstrated potential to improve thermal comfort and reduce overheating.

The dynamic thermal analysis of annual energy consumption is a comprehensive study of both summer and winter performances taking into account the daily operation profiles of occupants and the operations of the roller blind. The results indicated a 15% carbon reduction could be achieved. Proportion of heating energy was significantly higher than cooling energy and the results suggested the possibility of avoiding the requirement of comfort cooling with the use of external roller blind.

Table 6: Life Cycle Assessment summary

Process	Input	Item	Quantity	Data source	Output ($kgCO_2e$)
Aluminium production	N/A	Bauxite mining Alumina refinery Aluminium smelting Recycled secondary aluminium (33%) Ingot casting	22 kg x 155MJ = **181.28 $kgCO_2e$**	Hammond & Jones (2011)	181.28
Transport energy		Transport to factory	Excluded		
Coil manufacturing	Natural gas	Aluminium strip continuous casting	5.86 kWh = **1.31 $kgCO_2e$**	Process energy estimated	3.967
	Electricity	Strip milling Tension levelling Coil slitting	1 kWh = **0.32588 $kgCO_2e$**		
Transport energy		Transport between factories	300km by road = **2.33073 $kgCO_2e$**	Defra (2012)	
Coil coating	Coatings Electricity	Prime coating Paint coating Curing	0.5kWh = **0.16294 $kgCO_2e$**	Process energy estimated	2.555
Transport energy		Transport between factories	250 km by road **= 1.942275 $kgCO_2e$**	Defra (2012)	
External roller blind production	Polyurethane Electricity Natural gas	Polyurethane insulation injection	1.8 kg **= 6.264 $kgCO_2e$**	Hammond & Jones (2011) Process energy estimated	13.06
		Slat roll forming Casing roll forming	1kWh = **0.32588 $kgCO_2e$**		
		End plate die casting Side guide extrusion	1.95kWh **= 0.4375 $kgCO_2e$**		
	Steel	Steel axle	4.5 kg **= 6.03 $kgCO_2e$**	Hammond & Jones (2011)	
	Metals Plastics	Other minor components	Out of scope	Hammond & Jones (2011)	
	Electricity Packaging	Product assembly Packaging	Out of scope	Hammond & Jones (2011)	
Transport energy		Transport to site	1900km by road **= 14.76129 $kgCO_2e$** 120km by ferry **= 0.014796 $kgCO_2e$**	Defra (2012)	14.77
Site	Out of scope	Installation Maintenance	n/a	Hammond & Jones (2011)	
End of life management		Aluminium recycled Steel recycled Others landfill	95% -ve 172.22 80% -ve 5.43	Hammond & Jones (2011)	-ve 177.65
				Net	**37.54**

The life cycle analysis cannot be considered as comprehensive, but adequate to establish preliminary results in terms of the carbon payback. Minor items excluded in the study are likely to cause a slight increase in the embodied carbon, nevertheless within its 25 year lifespan the external roller blind will clearly result in significant greenhouse gas savings.

7. Limitations and future work

The concept study was limited in time and provided a snapshot of the blind operation only. Further monitoring of blind installation to collect real time summer and winter operation data is planned. The simulation is based on fixed operation profile for the roller blind, the integration of dynamic shading coefficients being developed will enable closer to real-life simulation of the shading performance of the roller blind in response to the external climate. The LCA study is hampered by the lack of existing manufacturing data. The assumptions made have to be validated in the future studies when the data become available.

8. Conclusion

External roller blinds are movable external shading devices with potential to improve the thermal performance and sustainability of buildings in the UK climate. An experimental trial concluded that summertime internal temperatures, temperature peaks and temperature swing could be reduced with use of external roller blind. Computer simulation predictions corroborate the results of the experiment that external roller blind can be used to reduce, or in some cases, avoid the requirement for active cooling.

Life cycle analysis of greenhouse gas emissions of a functional unit representing the roller blind used in the concept study, taking into account the key materials and processes throughout its life cycle, show that a six months payback time for the life cycle greenhouse gas emissions or three years if the metallic components were not recycled. The findings so far indicated there is significant potential of using external roller blinds to reduce the operational and life cycle carbon emissions of buildings in the United Kingdom. The on-going research continues to develop the dynamic performance of the roller blinds that can work in conjunction with interior lighting and thermal systems of the building as well as responding to the external climatic conditions and other functional requirements of the building facade.

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