# A Literature Review Outlining the Importance of Blinds and Shutters as a Sustainable Asset that has the Potential to enhance the Productivity of Occupants in the UK.

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**Abstract**

Blinds and Shutters in the UK are still thought of as an optional window dressing rather than a low cost sustainable building asset that can enhance a window/glazing system's performance and in return, save energy through passive thermal measures and measurable solar performance. Although the array of benefits is validated for blinds and shutters there are historic barriers to realising the potential for saving energy. Simple behavioural change related to the use of existing products would be a no cost productivity and energy benefit.

Use of blinds and shutters is based on the need of a variety of factors in both commercial and domestic markets. These factors can be categorized into three broad areas namely energy savings, comfort (inclusive of visual, thermal and acoustic preferences) and occupant satisfaction which contribute to improving the health, well-being and productivity of occupants.

In recent publications it has been demonstrated how thermal, visual, acoustic and controllability of occupants' working environments impacts productivity. The business case for linking productivity to 'green' working environments has been made by the World Green Building Council (WGBC) highlighting how productivity of staff is a greater incentive for commercial buildings to become more sustainable.

This study incorporates a literature review of the sustainable benefits of shading and illustrates how they are an asset to the building façade in creating dynamic, comfortable and potentially productive environments for the commercial sector. However, we highlight the difficulties of this research and outline a potential future study.

**Keywords**

acoustic comfort, behaviour change, blinds and shutters, energy saving, health and well-being, low cost, productivity, sustainability, thermal comfort, visual comfort.

## Introduction

In the EU (28 member states) the existing building stock currently accounts for 40% of the total energy consumed (Publications Office, 2010). Globally space heating and cooling is reported to account for over one third of all energy consumed by buildings, rising to as much 50 -60 % in cold climates (IEA, 2013a). Energy demand in buildings is expected to increase globally by 50% by 2050 if no action is taken to improve the energy efficiency in the building sector. This is due to the increase in the number of households, residential and services buildings required, higher ownership rates of electronic devices and increasing demand for new products (IEA, 2013b). Part of this increase in energy consumption is attributed to a substantial requirement for cooling within buildings, which is expected to inflate by 150% globally by 2050 (IEA, 2013a). Within the EU (28 member states) there has been an estimated increase of 63% in sub-sector services between 2000 and 2010 (IEA, 2013b).

The building envelope is highlighted as an area where substantial improvements resulting in energy savings and lower $CO_2$ emissions can be made. The 2010 recast of the Energy Performance Buildings Directive (EPBD) emphasised the potential of passive cooling techniques such as shading to enhance the thermal performance of buildings during summer and reduce issues regarding overheating in favour of the use of air-conditioning systems (Publications Office, 2010). The challenge for Europe is that whilst new buildings can be built to higher performance levels in OECD member countries, 75 – 90% of the current building stock will still be standing in 2050 and currently renovations are being carried out at only 1% per year across Europe (IEA, 2013a).

Abroad shading is common place in warm and colder countries and is incentivised through government. In Austria and Belgium VAT reductions are applied to the purchase of blinds and shutters, in Italy there are allowances for corporation tax and income tax that allow companies and individuals to offset the capital costs against their tax liabilities. Furthermore, in Norway shading is favoured in Building Regulation models and in Denmark a multiplier is applied to the mechanical cooling energy consumption (Seguro and Palmer, 2016).

Energy consumption is a well-established contributor to Green House Gas (GHG) emissions, which is a direct contribution to climate change. It has been reported by the Committee on Climate Change (2015) that commercial buildings and public sector buildings in the UK were responsible for 26% of these emissions in 2014. Although $CO_2$ emissions fluctuate due to annual weather conditions, it has been noted that there has been little change in the commercial sector's emissions since 2007 in comparison to residential emission rates.

Further triggers to drive change within the commercial sector are needed. Particularly because recent research shows that improving productivity can incentivise improvements to be made to the building envelope (WGBC, 2014). This paper reveals how improvements in productivity and energy savings can be met through the installation and correct usage of blinds and shutters. Although the research considered primarily focuses on office environments it can be assumed that the implications will be similar for other work environments.

## Blinds and Shutters and Energy Saving

Blinds and shutters have been shown to be an important method in reducing heat loss through the building envelope whilst also preventing heat gain via the window system in summer and simultaneously offering dynamic daylighting strategies to reduce electricity consumption (BBSA, 2015). Seguro and Palmer (2016) recently explored this by identifying that when a range of shading methods (comprised of external and internal screen fabrics) were combined with low e double glazing, the U-values can be reduced by 13 – 25% and G - totals 13 – 85 % depending on the type of shading selected.

Previous studies have shown how blinds and shutters can provide heating energy savings of up to 35% in the case of single glazing and by 25% with double glazed windows and could feasibly reduce energy $CO_2$ emissions by 31 million tonnes per year as was the conclusion from a simulation study that incorporated the climates of four European countries, Brussels, Stockholm, Budapest and Rome (ES-SO, 2015).

Blinds and Shutters are a passive cooling method that can reduce window surface temperatures, which in turn help maintain operative temperatures below maximum thresholds. It has been highlighted how external shading needs to be dynamic to improve energy savings throughout the year. A study carried out by Dubois (2011) investigated the differences in energy savings when a fixed awning was positioned year round on a south facing window in Stockholm and when a seasonal awning was only used in summer. The seasonal awning reduced annual cooling energy by 80% where the fixed awning increased heating by 31%. The dynamic ability of blinds and shutters in comparison to fixed shading is important when considering different seasons and should not be overlooked or energy penalties will incur.

Implementing external shading is not always possible although it is most effective at preventing solar radiation from entering the building in summer. Interior shading can also be effective in improving internal temperatures and reducing energy consumption a simulation study carried out by Seguro and Palmer (2016) evidenced that internal venetians could reduce total energy end use by 5% (-£1.40 per $m^2$) and internal rollers by 12% (-£3.2 per $m^2$). These energy savings could be potentially higher if the side of an internal blind that faces the glazing was coated with a reflective layer that returns more of the solar radiation before it is absorbed by the internal environment (BBSA, 2015).

**Energy Consumption in Commercial Buildings**

Within an analysis of $CO_2$ emission savings in Europe a potential of 17% of the 3.2 $GtCO_2$ savings can be met through improving the building envelope (IEA, 2013b). It is approximated that in the UK there are 2 million non-domestic buildings that contribute to producing one fifth of the nation's annual $CO_2$ emissions (Armitage et al. 2015). In the EU (27 members) the largest energy end-use is space heating in terms of final energy consumption. This totalled to 40% of the total energy used in the non-residential sector in 2010, cooling accounted for 6% and lighting contributed to 8% (IEA, 2013b).

The non-residential building sector is complex to understand in terms of end-use energy consumption as there are a variety of uses depending upon the purpose of the building. Hospital and hotels have considerably longer usage patterns compared to schools and offices which are only used within term-time or between regular working hours. Each building category having different requirements for lighting, ventilation, heating, cooling, refrigeration, IT equipment and appliances (Atanasiu et al. 2013).

Energy savings have stagnated in the commercial sector (Committee on Climate Change, 2015). Even though various incentives/policies have been introduced to highlight the importance for energy saving in the commercial market to encourage business owners to make investments.

**Drivers for Commercial Buildings to Save Energy**

The EPBD policy created in 2002 and which was recast in 2010 (Publications Office, 2010) required the UK to make new policies and incentives to encourage energy saving within the built environment these are outlined within Committee on Climate Change (2015). To rectify this most recently the Energy Savings Opportunity Scheme has been introduced which requires organisation of 250 or more employees or those in excess of €50 million annual turnover to participate. They are required to complete energy audits that are repeated every four years, the first report was required in 2015 (EA, 2016). Within the scheme there is no direct requirement to make improvements, despite the audit having to highlight energy saving measures (Fry and Hubbard, 2016). We await to see the impact this will have on the commercial market, yet it is still only likely to influence those larger organisations, leaving little drive for change within small to medium size organisations.

A driver that has been realised and spoken about widely is the link between green building design and productive workplaces. The WGBC (2013) produced a 'business case' for green building design to highlight the financial benefits. Various incentives were revealed such as lower operating costs; increased marketability and asset value; potential equal cost comparison between sustainable and conventional builds; and improved health, well-being and productivity of staff. Productivity yields many benefits for commercial organisations that hold almost immediate financial benefits. When staff costs tend to account for 90% of a business's expenditure and energy costs account for 1% you can understand why CEOs are not swayed by the idea of investing in energy efficient solutions (WGBC, 2014). In addition, the pay-back time of investments in improving the indoor environment quality (IEQ) are generally less than 2 years. It has been quantified that very little increases in work performance, 1%, can off-set the costs of the annual costs of ventilating a building (Wargocki et al. 2007).

**Barriers to Blinds and Shutters**

Part L of the building regulations addresses solar gains by saying that non-domestic buildings must either limit solar and internal heat gains or otherwise show that they will not over heat. This is addressed by providing evidence that total internal gains will not be more than 35 W per m² on peak summer days or they can show that the building will not exceed a threshold (that are dependent on building activities) for more than a number of hours each year, which only supports the use of solar shading by ensuring that naturally ventilated buildings do not over heat in summer. Compliance via SBEM fails to identify the full extent of energy savings that can be made with use of blinds and shutters as the climate datasets are averaged (Seguro and Palmer, 2016). The National Building Specification also under-value blinds and shutters by classifying them as a general fixture/ fitting element (NBS, 2016). Coinciding with this, in the pre-design phase these savings are often neglected in building modelling packages as the vast majority of leading mainstream whole-building simulation packages do not conform to internationally recognised EN/ISO Standards, such as ISO 15099 (Seguro and Palmer, 2016).

Cost saving benefits of implementing shading are hard to predict due to the large variables within each building environment (including the type of blind, type and orientation of building, type of glazing, and location) and therefore has to be assessed on a case by case basis. A simulation study of an air-conditioned 1960's open-plan office in London showed that it required 55kWh/m² a year to operate the air-conditioning which accumulated to a running cost of roughly £15/m² year. An alternative measure could have been reached through the use of a mid-plane or external blinds alongside the management of night time ventilation, a common passive design strategy. The study also showed how in offices where air-conditioning had already been fitted that the shading could pay for itself in under five years (Littlefair, 2002).

### Productivity Benefits and Blinds and Shutters

The impact of shading is not limited to these cost saving and environmental energy saving benefits. An area that is somewhat overlooked is the impact they can have on an individual's performance (Seguro and Palmer, 2016). Blinds and shutters in commercial offices are generally installed to prevent glare issues and control daylighting to conform with BS EN12464-1 (BSI, 2011) and EN14501. Shading can also be used to improve other factors that impact on the productivity of staff.

#### Visual Comfort

Uncomfortable visual environments can have harmful effects on an individual's productivity and more importantly on an individual's health and wellbeing (Seguro and Palmer, 2016). The importance of this issue has become impossible to ignore when people now spend more than 90% of their time indoors (ES-SO, 2015). In recent years it has become a popular topic specifically within offices, schools and hospitals due to the changes in technology we use to perform work activities. Poor visual comfort is created by poor daylighting relating to a lack of contact with the outdoors, discomfort glare, and poor colour rendition (Ticleanu et al. 2015).

Daylight affects an individual's circadian rhythm and triggers positive emotional, cognitive and attitudinal responses. A study performed on office workers showed that workers who worked in close proximity to windows got an average of 46 minutes more sleep per night and overall a better quality of sleep than other workers (Boubekri et al. 2014). Occupant dissatisfaction of individuals' workstations has been associated with the lack of access to a window through a study carried out in 2008 of 779 workstations in 9 different buildings (WGBC, 2014). Work stress and dissatisfaction was quantified as being reduced if nurses were exposed to daylight for at least 3 hours a day (Alimoglu and Donmez, 2005). Several studies have also identified the healing effects of daylight which have been carried out by examining patients in healthcare facilities (Aries et al. 2013). Joarder and Price (2013) investigated 263 coronary artery bypass graft surgery patients and revealed that a patient's length of stay in hospital was reduced by 7.3hrs per 100 lux increase of daylight exposure. Provisions were made to exclude other environmental factors such as outdoor view and room status.

Daylight contributes to an association of access to the outside world although a view out can also have a psychological cost due to a lack of privacy (Boyce, 2014). Evidence has highlighted that individuals with scenic views will be more satisfied with their workplace irrespective of their access to daylight. A study cited by Boyce (2014) by Marwaee and Carter (2006) found that 65% of people working in spaces with windows were satisfied but only 45% of those working in windowless spaces were satisfied even though they had access to daylight delivered through a tubular guidance system. In addition, a study by Ulrich (1984) concludes that patients in a ward with a view of trees will recover quickly in comparison to those with a view of a brick wall. However, it has also been established by Boyce (2014) that the window view is more appreciated when the occupant's environment is small and has little possibility of leaving the space suggesting that worker's dissatisfaction can be associated with the lack of variety within the space. It is suggested that in office spaces where there are little visual stimuli the view out becomes a primary focus for environmental stimulation, where in larger work environments school classrooms (Larson, 1965) and factories the lack of windows has a variable impact.

Glare can cause eyestrain, headaches and postural problems. Each individuals experience differs considerably depending on their own personal sensitivities. Discomfort glare is the most common type of glare and is caused by an uneven distribution of luminance within the visual field (Ticleanu et al. 2015). BS EN12464-2011 (BSI, 2011) requires lighting to be considered at the work plane, walls, ceiling and vertical planes (Boyce,2014). Ticleanu et al. (2015) identifies how discomfort glare can contribute to symptoms of eye irritation, dry or watery eyes, itchiness, tense muscles, blurred or double vision, headaches or fatigue and in turn such symptoms can lead to discomfort and stress.

Similarly, poor colour rendition can have detrimental effects upon stress levels and productivity (Seguro and Palmer, 2016). The colour rendition index is an indicator of the quality of light from electric sources in comparison to natural daylight ranging up to 100, with 100 considered ideal. This quality is defined by the ability of a light source to render an objects' colour accurately (Ticleanu et al. 2015). Within our buildings we place a filter between ourselves and the incoming daylight. Clear single and double glazing are associated with good quality colour rendering. Double glazing can achieve a CRI of 97% which is equal to double glazing with shading, where products such as 2-pane solar control glass are reduced to a CRI of 86% (ES-SO, 2015) which can negatively affect the quality of light. The preference for daylight as opposed to artificial lighting is proven in buildings (Seguro and Palmer, 2016). Due to the variability, intensity and thermal impacts which we will address shortly, excessive daylight can lead to serious health issues. For office buildings a level of 500lux is recommend (BSI, 2011). When daylight starts to cause either thermal or visual discomfort the requirement for daylight diminishes (Boyce, 2014).

Blinds and shutters are able to perform dynamically in relation to daylight exposure throughout the year, allowing for comfortable limits to be maintained (Seguro and Palmer, 2016). The selection of the type of blind is imperative when considering visual comfort and Visible Light Transmittance (Tvis) and Openness Coeffcient (Co) are the most important design parameters to consider when trying to enhance visual comfort with the use of fabric blinds. When lower openness coefficients are chosen, such as in the case of dim-out blinds, there is less visible light transmittance as this is an indicator of the number and size of holes within the fabric. When a higher openness coefficient is chosen more daylight is allowed to pass through but there is an increased risk of glare, this is commonly present in screen blinds (BBSA, 2015). BS EN14501:2005 (BSI,2005) gives guidance on shading product classifications for opacity and glare control, which is of particular importance when computers or visual screens are used. The standard also gives classifications for visual contact to the outdoors, night privacy and daylight utilisation. Fabric colour is also of equal importance as it can be used to control reflected light, by utilising daylight whilst reducing glare (Dalke et al. 2004). Lighter colours can increase the illumination of interiors but can cause increased surface brightness which can be equally problematic for visual comfort. Where darker colours combined with a higher openness coefficient (screen fabric) can provide adequate lighting control and are able to provide a view to the outside whilst the blinds are down (BBSA, 2015).

**Thermal Comfort**

An individual's thermal comfort is driven by the need to maintain a constant internal temperature of 37°C which is essential for our health and well-being. ASHRAE's generally accepted definition of thermal comfort describes this as "That state of mind which expresses satisfaction with the thermal environment" (Nicol et al. 2012) while CIBSE Guide A (2015) recommends that there are physical and personal factors that will lead to thermal comfort. The physical environmental factors are air temperature, relative humidity (RH), mean radiant temperature (MRT) and relative air speed and personal factors include clothing levels and metabolic heat rate.

Air temperature is generally the most important environmental variable affecting thermal comfort. (CIBSE, 2015). Changes in air temperature and MRT affect the way the body reacts and how occupants interpret thermal sensation is highlighted in ASHRAE 55:2010 and is defined as the operative temperature (Wargocki et al. 2007). Air temperature has a direct effect on an individual's performance of office tasks, the best temperature range is between 20°C – 24°C, with an optimum of 22°C (Seppänen et al. 2006). Heschong Mahone Group, Inc (2003) identified that the performance of call centre staff slowed by 2% when temperatures increased from 23°C to 24°C. High indoor temperatures also contribute to an increased risk of symptoms associated with Sick Building Syndrome (SBS) (Wargocki et al. 2007, Seppänen et al. 2006).

A study carried out by Fang et al. (2004) who reviewed the effects air temperature and humidity on the perceived air quality, SBS and performance of office staff found that although performance was not significantly affected several symptoms of SBS were alleviated when occupants worked at the lower air temperature of 20°C and RH of 40%. The study resolved that if the occupants in the study were subjected to longer exposure times there may have been a significant difference in work performance. Humidity is directly linked with air temperature. Within the UK humidity is of little concern; levels within the range of 40 – 70% are considered acceptable. (CIBSE, 2015).

Low air temperatures have an impact on manual tasks due to reduced dexterity of hands and sensitivity to air movements and draughts. Similarly, with high temperatures the perception of draughts is increased (Seguro and Palmer, 2016) alongside the sensation of dryness of the air (Wargocki et al. 2007).

MRT encompasses the average temperature of all surfaces within an environment. It is a simplified method in order to understand the full radiant landscape which varies significantly across a room and would requires surface temperatures to be recorded for each surface within the view of each occupant. Within a furnished open-plan office this is excessive and impractical to consider (Nicol et al. 2012). The MRT can be influenced by a multitude of factors including lighting, glazing exposed to solar radiation, ventilation and electronic equipment dependant on its positioning within the room.

Air temperature adjustments are recommended by CIBSE Guide A in the case of lighting, ventilation and electronic equipment and with the recommendation to install shading for solar radiation exposure to prevent local discomfort and to account for asymmetric radiant temperature differences (CIBSE, 2015). Asymmetric thermal radiation is found at the perimeter of a room which can be caused by local cooling, local heating and intrusion of short-wavelength radiation. This is cause for concern when seating occupants close to glazing as mechanical air-conditioning cannot address the issue of radiant thermal exchange (Seguro and Palmer, 2016).

The glazing area of a workspace can have a great impact on the thermal comfort of a room due to the consistently changing weather conditions we experience in the UK and the thermal properties of the window system (Seguro and Palmer, 2016). The weather affects the external temperature and solar radiation which in turn has an effect on the interior wall/glass surface temperatures and transmitted solar gains (Bessoudo et al., 2010). It is widely predicted that climate change will inflict more frequent and intense heatwaves (ZCH, 2015) with the potential to cause further discomfort to occupants positioned close to windows. This has been a prevalent feature within research from Cambridge University, where it has been reported that 90% of UK hospitals are susceptible to overheating because of how they have been designed (Iddon, 2014). Although temperature can be controlled by installing a blind or shutter, as solar gains can be reduced from the window surface and the inner space, the positive effects of shading systems on the indoor environment are undervalued in colder climates where as they are widely recognised in warmer climates (Curcija et al. 2013, Seguro and Palmer, 2016, Taleb, 2014, Tzempelikos et al. 2007).

Highlighting this a study carried out by Bessoudo et al. (2010) evidenced how blinds and shutters impact asymmetric thermal radiation. On a cold (<15°C) but sunny day the interior surface of low e glazing without shading reached 30°C, radiant temperature asymmetry (RTA) exceeded 15°C and operative temperatures exceeded 25°C to a maximum of 31°C. When internal roller blinds were installed the blind and glazing reached a surface temperature of 41°C, yet the operative temperature during the working day remained within the comfort zone and the RTA stayed below 5°C. The alternative solution, other than installing solar shading is addressed by occupants opening windows or decreasing office air temperatures, which decreases thermal uniformity or costs energy, and sometimes is pre-planned by building managers by positioning desk space and occupants further away from windows. Although this is a costly expense to companies as it reduces the number of employees they can have in a given area.

The cooling effect of air movement is also well established and often welcomed through a variety of methods when occupants experience warm conditions (CIBSE, 2015). Radiation heat loss to a large cold surface, as in the case of glazing, can generate cool air movement that is often unwanted in winter. The cooling affect is often misinterpreted as a draught (Nicol et al., 2012). But an additional thermal barrier could prevent this.

**Acoustic Comfort**

Acoustic comfort of buildings is often forgotten during project planning and design when other aspects such as functionality, aesthetics (Seguro and Palmer, 2016) and utilisation of space come into play. It is a key contributor to work performance and well-being in the workplace GSA Public Building Service (2011). Acoustic comfort has been highlighted of importance to performance particularly within schools in a study carried out in London Primary Schools external noise was found to have a negative impact upon performance and this was greater within older children (Shield and Dockrell, 2008). Within the work environment noise is a leading contributor to employee dissatisfaction a study carried out by GSA Public Building Service (2011) in America found this to be true in a pre and post design evaluation of seven federal buildings. In addition, a study carried out in the UK looked at office layouts and occupant satisfaction and found that when an office had been transformed from a cellular office space to an open-plan office space in order to increase occupancy. Noise levels were highlighted as a leading contributor to occupant dissatisfaction (Bunn and Marjanovic-Halburd, 2016).

Acoustic comfort can be achieved by controlling the external noises commonly produced from traffic, motorways, rail and air traffic, and from high-reverberation times within the office which is due to sound reflecting of surfaces. Glazing units and other light weight building components have low sound insulation factors, which allows for sound propagation due to the material properties of the glass, frame and installation (Seguro and Palmer, 2016). Through selecting appropriate shading fabrics, a reduction in noise can be achieved but further research is needed to identify the full potential different shading mechanisms can have when combined with different glazing systems.

**Occupant Satisfaction**

Psychological factors created by environments are also important to consider. In the WGBC (2014) report individual control over environmental constraints can increase satisfaction. For example, by providing personal control of light levels with an option to use dimmers satisfaction, mood, comfort, motivation and task performance can be improved. In terms of temperature a study carried out by Wyon (1996) showed how control over a 4°C range can increase logical thinking performance by 3% and typing performance by 7%. Acoustic control is still hard to control post design phase. But good acoustic control can be addressed by users and organisations in the planning stages by creating "quiet zones". Within the GSA WorkPlace 20.20 program a survey of 50% of work staff said noise keeps them from being productive, yet 60% said they will often stop and talk to colleagues at work stations. Implementing protocols to make colleagues aware of noise issues are additional control methods that can be put in place (GSA Public Buildings Service, 2011).

The perception of controllability is vital to occupant satisfaction although a wave of new technologies has been produced that reduce their control. With the rise of "smart homes" and the pressure to improve energy savings it is important for designers of future innovations to imbed the user at the centre of the design process. Blinds and shutters have addressed this through the integration of motorised systems. A study carried out by Paule et al (2015) shows that motorised systems encourage users to open and close blinds at the touch of a button. Within automation systems, improved algorithms have been calculated involving sun/shade modelling that communicate with exterior and/or internal lighting and temperature sensors to instigate the opening and closing mechanism. In order to satisfy a large number of users and room types (for example, office spaces and meeting rooms, that have very different requirements) raises new challenges for the industry. Maintenance and tweaking of control systems after installation is now essential to ensure that the systems in place are working to the benefit of users and do not cause interference that could lead to system overrides that could lead to energy saving opportunities being wasted. Examples include users leaving blinds closed and turning electric lighting on, potentially wasting thermal gains and daylighting opportunities. Several methods have been produced to ensure their effectiveness through implementing strategies such as movement of blinds occurring during work breaks, systems where occupants can override the systems for a set period of time (Littlefair, Ortiz, and Das Bhaumik, 2006) and graduation of blind opening and closing.

A simulation study which evaluated the energy saving potential of automatic systems reflected how an air-conditioned building in London could save an additional 3% in $CO_2$

when automatic blind control was implemented. These savings accumulated to 9% with automatic internal blinds and 8% with external blinds. Within the same study a comparison was made with an office located in Scotland where automated external shading caused an energy penalty of between 3% and 9%. Yet internal automated shading still provided a benefit of reducing $CO_2$ emissions by 2% compared to no shading or manual controls. This highlights how situation and longitudinal location is still important to consider when considering control mechanisms (Littlefair, Ortiz, and Das Bhaumik, 2006).

Throughout the industry it is recognised that the utmost has to be done to ensure satisfaction of users with their living and working environment. Predicted Mean Vote (PMV) is a calculation methodology that can be applied during the design phase and is the basis for a majority of thermal comfort measures in the UK and has been introduced through EN ISO 7730:2005 based on (Fanger et al., 1988) as cited by Nicol et al. (2012). It combines the physical and personal factors in relation to a subjective vote, Ashrae's Thermal Sensation Scale, which was carried out in laboratory, steady-state conditions. It is used to identify the Predicted Percentage Dissatisfied (PPD), the percentage of people who likely to feel too hot or too cold among a group of people assuming their activity (metabolic rate) and clothing level is the same (CIBSE, 2015). The criteria for an excellent PPD index is ≤ 6% within EN 15251:2007, IS0 7730:2005 and ASHRAE Standard 55 (Wargocki et al., 2007).

Obtaining complete satisfaction of all users is unrealistic due to the number of variables within the built environment when considering people. The environmental constraints alone are confounded by variables which are hugely influenced by an individual's physiology, how they themselves produce heat or how they interpret light depending on their health, age, or gender. Secondly their psychophysics would need to be considered; how their brain regulates the body to cope with the surrounding environmental factors. Thirdly, the physics between the environment and each occupant, for example air moisture or wind chill amongst many other environmental factors are too broad to measure independently, reliably or accurately. Finally, the behaviours of the occupant which are dependent on what clothes they choose to wear, how they use and feel about available controls and what posture and activity they impose on themselves and the environment. It is also worth mentioning that there are a large number of psychological constraints, in particular what an individual expects from an environment and in turn how they adapt to it (Nicol et al., 2012).

**Testing Productivity**

Productivity is very difficult to test and is often defined in terms of elements that are indicators of productivity. The WGBC (2014) highlights how absenteeism and staff turnover are indicators of productivity however, this can only really represent the productivity lost because someone is not at work. Rather than associating it with a poor work environment (Sullivan et al, 2013).

A meta-analysis of studies that analyse the effect of temperature on task performance conducted by Seppänen et al. (2006) found 24 studies that used a variety of objective indicators of performance (excluding industrial work performance studies). There were two main categories, namely those that are carried out in the field, and those that are conducted in laboratories. It is assumed that field studies have more weighting as they give a reference of performance relating to real work. This is also supported by CIBSE (2015) as field studies have more relevance to normal living conditions. Call centres are ideal scenarios to test the impact of an environmental constraint as organisations often record an objective value of productivity through the number of calls taken, time required to talk with customers and processing time between calls (Seppänen et al. 2006).

Another strategy is to combine laboratory and field study methods. The Heschong Mahone Group, Inc, (2003) utilised the existing work environment but used a performance test battery as the objective measure that was able to gauge aspects of work performance. Which has been used in many laboratory settings (Lan et al., 2011, Wargocki et al., 1999). The tests given have associations with work performance as they rely on cognitive functions (Sullivan, Baird, and Donn, 2013). Cognitive performance test batteries include replication of office tasks; typing, mental arithmetic (Miyake et al., 2000, Wargocki et al., 1999, Lan et al., 2011), short term memory, long term memory (Heschong Mahone Group, Inc, 2003, Lan et al., 2011), problem solving and speed of information processing (Lan et al., 2011, Wargocki et al, 1999). One of the issues with this form of testing is practicality as the testing battery process is time consuming when combined with subjective surveys (Sullivan et al, 2013).

Subjective surveys are a well-known method in assessing psychometric measures which include mood (Lan et al. 2011, Terry et al. 2003), fatigue (Tanabe and Nishihara, 2004), mental workload (Lan et al. 2011), job satisfaction, job engagement and intention to quit (Sullivan et al. 2013). These give another indication into whether well-being and productivity are affected by environmental constraints. These factors are important to identify as there are many other variables that could affect a person's subjective choice that are unrelated to the environment. Subjective questionnaires in relation to the environment are used to ask occupants to assess what they perceive the environmental impacts to be. The areas that are assessed are thermal, visual, acoustic, controllability, indoor air quality and satisfaction of the workplace (WGBC, 2014). This type of survey is used in Post Occupancy Evaluations and are vital to correlating dissatisfaction with the work environment with an objective performance measure and subjective psychometric measures to produce a triangulated dataset of results which is considered to provide corroborative evidence.

## Conclusion

This paper clearly shows the energy saving benefits that blinds and shutters can make in the building environment. In conjunction with this it has been highlighted how the associated effects of blinds and shutters can contribute to improving the Indoor Environment Quality (IEQ). This correlates to a substantial body of evidence that relates improvements with the IEQ to improved health, well-being and productivity of staff. The productivity benefit has been quantified as a cost and energy saving measure in commercial organisations and has been represented as a valued driver to commercial companies to retrofit or design specifically "green" environments.

It is apparent that providing evidence for this is difficult due to the large range of blinds and shutters available, because they have very different characteristics; alongside this the built environment is well known for its complex variables that all need to be recorded and monitored and then compared against the complexity of producing justifiable evidence for productivity. There are a number of barriers to this research including optimising research to include thermal, visual and acoustic characteristics of blind and shutter systems, in depth behavioural studies of the use of blind and shutters with different control systems and further validation of the relationship between productivity and the built environment. However, the authors will endeavour to overcome some of these barriers in order to further assess the impact of blinds and shutters on productivity.

## References


Alimoglu, M.K. and Donmez, L. (2005) 'Daylight exposure and the other predictors of burnout among nurses in a university hospital', International Journal of Nursing Studies, 42(5), pp. 549–555. doi: 10.1016/j.ijnurstu.2004.09.001.

Aries, M., Aarts, M. and van Hoof, J. (2013) 'Daylight and health: A review of the evidence and consequences for the built environment', Lighting Research and Technology, 47(1), pp. 6–27. doi: 10.1177/1477153513509258.

Armitage, P., Godoy-Shimizu, D. and Palmer, J. (2015) The Cambridge non domestic energy model the Cambridge non- domestic energy model domestic energy model. Available at: http://www.carltd.com/sites/carwebsite/files/CNDM%20Report%20260215.pdf (Accessed: 15 May 2016).

ASHRAE (2013) Standard 55-2013 - Thermal Environmental Conditions for Human Occupancy. .

Atanasiu, B., Despret, C., Economidou, M., Maio, J., Nolte, I., Contributions, O.R., Laustsen, J., Ruyssevelt, P., Staniaszek, D., Strong, D. and Zinetti, S. (2013) EUROPE'S BUILDINGS UNDER THE MICROSCOPE A country-by-country review of the energy performance of buildings. Available at: http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf (Accessed: 17 May 2016).

Bessoudo, M., Tzempelikos, A., Athienitis, A.K. and Zmeureanu, R. (2010) 'Indoor thermal environmental conditions near glazed facades with shading devices – part I: Experiments and building thermal model', Building and Environment, 45(11), pp. 2506–2516. doi: 10.1016/j.buildenv.2010.05.013.

Boubekri, M., Cheung, I.N., Reid, K.J., Wang, C.-H. and Zee, P.C. (2014) 'Impact of windows and daylight exposure on overall health and sleep quality of office workers: A case-control pilot study', Journal of Clinical Sleep Medicine, . doi: 10.5664/jcsm.3780.

Boyce, P.R. (2014) Human factors in lighting, Third edition. United States: CRC Press.

British Blinds and Shutters Association (2015) Guide to Low Energy Shading. Issue 2 edn. United Kingdom: BBSA.

BSI (2005) Blinds and shutters - Thermal and visual comfort - Performance characteristics and classification. BS EN12464-1:2005.

BSI (2011) Light and Lighting: Lighting of work places. Indoor work places. BS EN12464-1:2011. London: BSI.

Bunn, R. and Marjanovic-Halburd, L. (2016) 'Occupant satisfaction singatures: Longitudinal studies of changing comfort perceptions in two non-domestic buildings', CIBSE Technical Symposium: CIBSE. Available at: http://www.cibse.org/knowledge/cibse-technical-symposium-2016/occupant-satisfaction-singatures-longitudinal-stud (Accessed: 18 May 2016).

CIBSE (2015) CIBSE Guide A: Environmental design. 8th edn. CIBSE.

Committee on Climate Change (2015) Meeting Carbon Budgets - Progress in Reducing the UK's emissions - 2015 Report to Parliament. Available at: https://documents.theccc.org.uk/wp-content/uploads/2015/06/6.737_CCC-BOOK_WEB_030715_RFS.pdf (Accessed: 30 April 2016).

Curcija, C.D., Yazdanian, M., Kohler, C., Hart, R., Mitchell, R. and Vidanovic, S. (2013) Energy savings from window attachments. Available at: http://energy.gov/sites/prod/files/2013/11/f5/energy_savings_from_windows_attachments.pdf (Accessed: 18 May 2016).

Dalke, H., Littlefair, P., Loe, D. and Camgöz, N. (2004) Lighting and colour for hospital design. Available at: http://www.wales.nhs.uk/sites3/Documents/254/B(01)02%20Lighting%20and%20colour.pdf (Accessed: 18 May 2016).

Dubois, M. - C. (2011) Solar shading for low energy use and daylight quality in offices. Report No TABK--01/1023. Lund University.

EA (2016) LIT 10094 complying with the energy savings opportunity scheme. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/509835/LIT_10094.pdf (Accessed: 18 May 2016).

ES-SO (2015) A NEW VISION ON SOLAR SHADING. Available at: http://www.verozo.be/sites/verozo/files/files/Brochure_SolarShading_screen_LR.pdf (Accessed: 17 May 2016).

Fang, L., Wyon, D.P., Clausen, G. and Fanger, P.O. (2004) 'Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance', Indoor Air, 14(s7), pp. 74–81. doi: 10.1111/j.1600-0668.2004.00276.x.

Fanger, P.O., Melikov, A.K., Hanzawa, H. and Ring, J. (1988) 'Air turbulence and sensation of draught', Energy and Buildings, 12(1), pp. 21–39. doi: 10.1016/0378-7788(88)90053-9.

Fry, P.M. and Hubbard, M. (2016) 'The true test of ESOS', Energy in Building and Industry (April), p. 30.

GSA Public Buildings Service (2011) Sound matters. Available at: http://www.gsa.gov/portal/mediaId/172515/fileName/GSA_Sound_Matters_(Dec_2011)_508 (Accessed: 18 May 2016).
Heschong Mahone Group, Inc (2003) Windows and offices: A study of office worker performance and the indoor environment. Available at: http://h-m-g.com/downloads/Daylighting/A-9_Windows_Offices_2.6.10.pdf (Accessed: 19 April 2016).
Iddon, C. (2014) Climate change, hospitals and patient well-being. Available at: http://www.secontrols.com/news/item/climate-change-hospitals-and-patient-well-being/ (Accessed: 17 May 2016).
IEA (2013a) Technology Roadmap energy efficient building envelopes. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf (Accessed: 17 May 2016).
IEA (2013b) Transition to sustainable buildings - strategies and opportunities to 2050. Available at: http://www.iea.org/publications/freepublications/publication/Building2013_free.pdf (Accessed: 30 April 2016).
Joarder, A. and Price, A. (2012) 'Impact of daylight illumination on reducing patient length of stay in hospital after coronary artery bypass graft surgery', Lighting Research and Technology, 45(4), pp. 435–449. doi: 10.1177/1477153512455940.
Lan, L., Wargocki, P., Wyon, D.P. and Lian, Z. (2011) 'Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance', Indoor Air, 21(5), pp. 376–390. doi: 10.1111/j.1600-0668.2011.00714.x.
Larson, T.C. (1965) The Effect of Windowless Classrooms on Elementary School Children. Available at: http://files.eric.ed.gov/fulltext/ED014847.pdf (Accessed: 19 May 2016).
Littlefair, P. (2002) Retrofitting solar shading. United Kingdom: IHS BRE Press.
Littlefair, P., Ortiz, J. and Das Bhaumik, C. (2006) THE ENERGY EFFECTS OF CONTROLLING SOLAR SHADING. Available at: https://www.somfysystems.com/file.cfm/Controlling-Solar-Shading.pdf?contentID=278064 (Accessed: 18 May 2016).
Marwaee, M.A. and Carter, D.J. (2006) 'A field study of tubular daylight guidance installations', Lighting Research and Technology, 38(3), pp. 241–258. doi: 10.1191/1365782806lrt170oa.
Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A. and Wager, T.D. (2000) 'The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis', Cognitive Psychology, 41(1), pp. 49–100. doi: 10.1006/cogp.1999.0734.
NBS (2016) Fixtures and fittings, or FF & E. Available at: https://www.thenbs.com/knowledge/fixtures-and-fittings-or-ff-e (Accessed: 7 March 2016).
Nicol, F., Nicol, F., Humphreys, M. and Roaf, S. (2012) Adaptive thermal comfort: Principles and practice. New York, NY: Taylor & Francis.
Paule, B., Boutillier, J. and Pantet, samuel (2015) Global Lighting Performance. Available at: http://static.wm3.se/sites/45/media/29281_ESTIA_Study_English_ver_3_0.pdf?1426675541 (Accessed: 18 May 2016).
Publications Office (2009) Establishing a framework for the setting of ecodesign requirements for energy-related products (recast) directive 2005/32/EC of the European parliament and of the council of 6 July 2005 establishing a framework for the setting of ecodesign requirements fo. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:en:PDF (Accessed: 17 May 2016).
Publications Office (2010) Directive 2010/31/EU of the European parliament and of the council of 19 may 2010 on the energy performance of buildings. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF (Accessed: 17 May 2016).
Seguro, F. and Palmer, J. (2016) Solar Shading Impact Report. National Energy Foundation.
Seppänen, O., Fisk, W.J. and Lei, Q. (2006) Effect of temperature on task performance in office environment. Available at: https://indoor.lbl.gov/sites/all/files/lbnl-60946.pdf (Accessed: 7 March 2016).
Shield, B.M. and Dockrell, J.E. (2008) 'The effects of environmental and classroom noise on the academic attainments of primary school children', The Journal of the Acoustical Society of America, 123(1), p. 133. doi: 10.1121/1.2812596.
Sullivan, J., Baird, G. and Donn, M. (2013) Measuring Productivity in the Office Workplace. New Zealand: Centre for Building Performance Research.
Taleb, H.M. (2014) 'Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. Buildings', Frontiers of Architectural Research, 3(2), pp. 154–165. doi: 10.1016/j.foar.2014.01.002.

Tanabe, S. and Nishihara, N. (2004) 'Productivity and fatigue', Indoor Air, 14(s7), pp. 126–133. doi: 10.1111/j.1600-0668.2004.00281.x.
Terry, P.C., Lane, A.M. and Fogarty, G.J. (2003) 'Construct validity of the profile of mood states — adolescents for use with adults', Psychology of Sport and Exercise, 4(2), pp. 125–139. doi: 10.1016/s1469-0292(01)00035-8.
Ticleanu, C., King, S. and Howlett, G. (2015) Lighting and health. United Kingdom: IHS BRE Press.
Tzempelikos, A., Bessoudo, M., Athienitis, A. and Zmeureanu, R. (2007) The impact of shading on thermal comfort conditions in perimeter zones with glass facades. Available at: http://www.inive.org/members_area/medias/pdf/Inive%5CPalencAIVC2007%5CVolume2%5CPalencAIVC2007_V2_096.pdf (Accessed: 18 May 2016).
Ulrich, R.S. (1984) View through a window may influence recovery from surgery. Available at: https://mdc.mo.gov/sites/default/files/resources/2012/10/ulrich.pdf (Accessed: 18 May 2016).
Wargocki, P., Andersson, J., Boerstra, A., Clements-Croome, D. and Olaf Hanssen, S. (2007) Indoor climate and Productivity in Offices How to integrate productivity in life-cycle cost analysis of building services: Guidebook No 6. Edited by Pawel Wargocki and Olli Seppänen. Second edn. Finland: REHVA.
Wargocki, P., Wyon, D.P., Baik, Y.K., Clausen, G. and Fanger, P.O. (1999) 'Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with Two different pollution loads', Indoor Air, 9(3), pp. 165–179. doi: 10.1111/j.1600-0668.1999.t01-1-00003.x.
WGBC (2013) THE BUSINESS CASE FOR GREEN BUILDING A review of the costs and benefits for developers, investors and occupants THE BUSINESS BENEFITS. Available at: http://www.worldgbc.org/files/1513/6608/0674/Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf (Accessed: 18 May 2016).
WGBC (2014) Health, wellbeing & productivity in offices. Available at: http://www.worldgbc.org/files/6314/1152/0821/WorldGBC__Health_Wellbeing__productivity_Full_Report.pdf (Accessed: 17 May 2016).
Wyon, D. (1996) 'Indoor environmental effects on productivity.', Atlanta, Procceeding of IAQ '96 ' Paths to Better Building Performance': ASHRAE. pp. 5–15.
ZCH (2014) ZERO CARBON HOMES AND NEARLY ZERO ENERGY BUILDINGS. Available at: http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCHomes_Nearly_Zero_Energy_Buildings.pdf (Accessed: 17 May 2016).
Zero Carbon Hub (2015) Overheating In Homes - The Big Picture. Available at: http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingInHomes-TheBigPicture-01.1.pdf (Accessed: 17 May 2016).
Zhang, H., Arens, E., Fard, S.A., Huizenga, C., Paliaga, G., Brager, G. and Zagreus, L. (2007) 'Air movement preferences observed in office buildings', International Journal of Biometeorology, 51(5), pp. 349–360. doi: 10.1007/s00484-006-0079-y.