Conference Paper

The Potential of Smart Glazing for Occupant Well-Being and Reduced Energy Load in a Central-Mediterranean Climate

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Abstract

The ever-increasing aesthetically driven demand for fully glazed façades poses a design challenge; not least in controlling the cooling demand and occupant well-being of such buildings, especially in a central Mediterranean climate. This paper outlines the ever-important need to design for occupants and for designers to keep in mind, first and foremost, occupant well-being rather than aim solely to create energy-efficient buildings. The original objective of buildings was to provide shelter. Today however, the need for occupant comfort and its direct effect on productivity cannot be ignored. This need, therefore, ought to feature a central role in any building design. Studies show that occupant well-being is directly related to a range of environmental factors, particularly daylight distribution, glare and indoor air temperature. The use of external shading devices and more commonly, indoor blinds are often the adopted approaches to attempt to achieve indoor occupant comfort, often to the detriment of views. Adaptive facades seek to address the need to somehow strike a balance between occupant comfort and energy efficiency. These facades range from exterior and interior shading devices with varying control strategies, to the different forms of adaptive/switchable glazing technologies intended to control the visual light transmittance and solar radiation transmitted into a building's interior. In the opinion of the authors, electrochromic glazing has a great potential in a cooling-dominated central Mediterranean climate, to achieve a compromise between occupant visual and thermal comfort whilst retaining unobstructed outdoor views at all times. Research shows that the potential benefits of electrochromic glazing have not yet been studied enough in real-life scenarios, and this paper further introduces the objectives for a field study within two identical offices, having a South-South-East orientation, located in a central Mediterranean climate.

Keywords: smart glazing systems, occupant well-being, visual comfort, thermal performance, energy efficiency

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1. Introduction

Energy use has become an ever-growing concern worldwide, especially for buildings, which consume between up to 40 % of the total energy consumption in developed countries, including EU Member States [1]. Following the EU Energy Performance of Buildings Directive (EPBD) of 2002 and its recast in 2010 (2010/31/EU), all new and renovated buildings are to be ``nearly zero energy'' with effect from 01 January 2020 [2].

The concept of today's drive is to have predominantly-glazed buildings [3]. This design approach is very often fuelled by aspects related to the projection of a ``modern'' image to a building and little thought is given to the use of energy required to attain thermal comfort and even less to environmental issues such as thermal and visual comfort of its occupants. The need to align the design requirements with environmental issues is key in establishing a well-balanced approach between aesthetics, occupant well-being and energy use. In hot-humid climatic regions where the cooling season is longer than the heating season, in excess of six months, cooling energy demand for buildings has become a key issue [4]. Many studies have been undertaken and are still ongoing, to provide new performance-enhanced building materials, particularly related to the external building envelope.

The aim of this paper is to highlight the importance of occupant well-being from a thermal and visual perspective, particularly the need to maintain the availability of outlook from a building. Views come at a premium but are often traded off by building occupants in favour of visual and thermal comfort. The need to incorporate adaptivity into facades is increasingly gaining momentum and the inclusion of dynamic glazing is likely to be a promising approach that can employ façade adaptivity to achieve thermal and visual comfort, while retaining the view.

Finally, the paper introduces a forthcoming field-test study to investigate the potential of electrochromic glazing in a real-life operational office building in a central Mediterranean climate to understand better, the benefits of occupant well-being in spaces fitted with this type of glazing.

2. Key Performance Indicators

Employers, building owners, developers and designers are nowadays recognizing that the indoor environment of buildings in general affects the health and well-being of occupants in various ways. In an office environment, staff are the most likely to be the most valuable resource, to which business operating costs can be directly attributed. A marginal increase in staff productivity, therefore, can have a substantial positive effect on the overall performance of any organisation [5].

The 2016, the World Green Building Council set out an Office Metrics Framework that the outlines key performance indicators, subdivided into three categories for a concise approach to building design by respective stakeholders in the built-environment.

Figure 1

The environmental aspect of the building relates to how the varying physical properties of an indoor environment affect the building's occupants, but perhaps more importantly, the occupant experience ought to be the designer's prime objective. Data related to experiential factors would need to be collected via surveys and questions linked to environmental parameters and overall workplace satisfaction. Both so-called `pillars' of this framework affect performance and hence, the economics of a workplace [5].

Field studies carried out by the California Energy Commission [6] have shown that in an office environment, daylight illumination levels are significant and influenced better performance in tests related to mental function and attention. Daylight illumination levels, however, seem to have a lesser effect on visual acuity tests or long-term memory tests. In addition, an ample and pleasant view is likely to be related to better office worker performance, whereas glare from windows often reduces this performance. Following the general shift from working with paper on a horizontal plane to looking at computer screens in the vertical plane, glare on computer screens was always an important concern and largely motivated the change to flat panel screens. This shift in technology may have reduced reflections from glossy CRT computer monitors but the problems with glare remain a primary concern for workers especially in offices with a high glazing ratio (window-to-wall ratios). These studies further demonstrate that ample and pleasant views have been directly linked with improved worker performance, with

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increased fatigue mostly associated with lack of views. Moreover, increased indoor air temperature appears to have a deleterious effect on worker productivity whereas physical comfort conditions directly linked with performance [6].

3. Window Characteristics and the Importance of View

Windows are considered as the least energy-efficient building component with a larger maintenance requirement. Windows are complex components in any building, especially in an office environment. Besides having a direct influence on ventilation and indoor air quality in the case of openable windows, they allow for the ingress of daylight, provide for views and allow for the occupant connection to the outside world; this reinforces the human circadian rhythm. Besides issues related to energy losses and gains through the building fabric, windows can however be the sources of substantial thermal discomfort, glare, noise and distractions. The effect of window characteristics on building occupants is related to factors such as illumination on a work plane, distance of occupants from the window itself, orientation, solar penetration, glare potential, the size and content of the view, as well as the window control strategy. In most buildings, and not less in office buildings, it has often been the case that the higher echelons of an establishment would get the best views. In real estate, the presence of views from an indoor space would automatically translate into a higher monetary value in rental or resale terms [6].

Studies show that sitting close to view windows can be beneficial and visual contact with nature reduces occupants' stress and promotes the quality of life [6]. Moreover, the presence of a view contributes positively to eye health and reduces the effect of computer vision syndrome (CVS) or Digital Eye Strain. Ophthalmologists recommend frequent rest breaks from looking at a digital screen and to complement long distance focus into distant objects. External views provide an attractive alternative focus for eyes [7]. Figueiro & Rea report that computer workers with view offices spent 15% more time on their primary task of programming computers, while equivalent workers without views spent 15% more time talking on the phone or to each other [8].

4. Adaptive Facades and Smart Glazing

Adaptive facades are building envelopes that can adapt to changing climatic conditions on a daily, seasonally or yearly basis. ``Adaptivity'' means the ability to respond or benefit from external climatic conditions to meet efficiently and more important effectively occupant comfort and well-being requirements [9]. Adaptive facades are multi-parameter high performance envelopes that, contrary to fixed facades, react mechanically or chemically to the external climate dynamically, to meet internal loads and occupant needs [10]. Active/dynamic shading systems are often designed to respond to one or multiple environmental situations including the control of daylighting, solar thermal, ventilation control. The application of active shading systems is an important step towards improving both the energy efficiency in a building and its occupant comfort in view of the building's adaptation to varying external conditions. These systems can allow or block solar radiation access into the interior space by adjusting a device installed either inside or on the building skin. Dakheel & Aoul classify active shading systems into three main categories as shown in **Figure 2** [11].

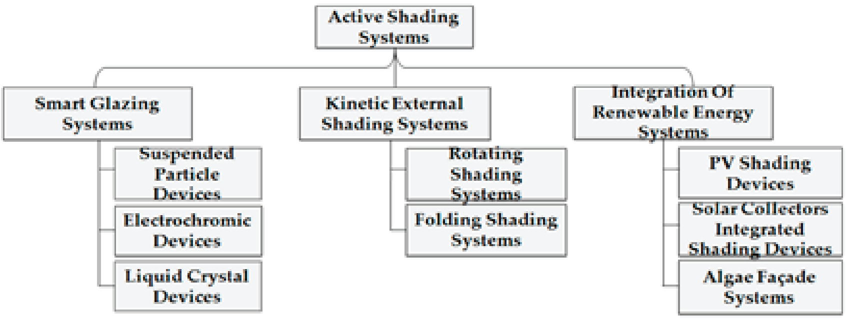

Figure 2: Classification of active shading systems. [11]

Loonen et al, highlight the potential of a ``selective approach'', in that energy-efficient envelopes can be designed by adopting form and skin, the latter being the 'selective filter' between the outdoor and the indoor environment. Incorporating in the building envelope functions such as of managing and modulating energy and mass flow, can achieve a balance between lowering energy demands and increasing occupant comfort. Such an improvement can be achieved by means of adaptive or Responsive Building Elements (RBEs) and systems, which feature a dynamic behaviour, by passively or actively adjusting their thermo-optical properties in a reversible way [12]. Bulow-Hube, 2000 further confirms that although it may be difficult to predict the use or need for shading devices by common measurable factors such as interior illuminance and sky illuminance, shading devices are still necessary to control glare in the working environment.

The use of kinetic external shading systems is still limited primarily because of the need of expensive smart actuators and sensors. In addition, the presence of moving parts within the façade attracts higher maintenance costs and susceptibility to failure of its moving parts. In a world where the adoption of solid-state devices is increasing, together with the minimisation of moving parts, the use of smart glazing systems as an adaptive static skin to reduce energy load and increase occupant comfort would therefore seem to be more sensible.

5. The Potential of Electrochromic Glazing

Electrochromic glazing allows active dynamic control of light and heat transmission, reflection and absorption thanks to a thin-film coating composed of several extremely miniaturized conductive layers. Variation of the properties of these elements is attributable to the addition or extraction of mobile ions from the EC layer: when the electric field is activated, the introduced ions react, generating compounds which alter the colouring of the material. (Fig.3)

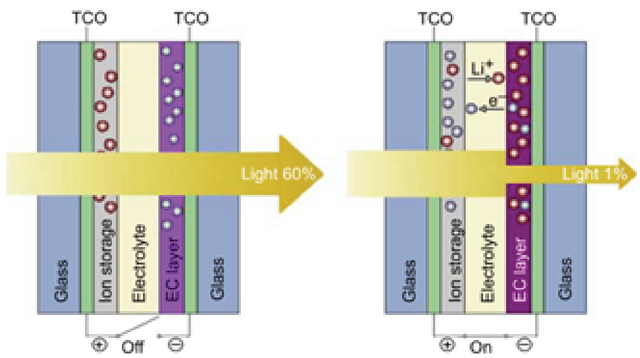

Figure 3: Electrochromic (EC) glazing operating scheme. [14]

Electrochromic glazing seems to be highly promising for dynamic daylight and solar energy applications in buildings. Transmittance ranges in the solar spectrum, UV stability and the number of cycles are all key performance indicators of this type of technology. Compared to liquid crystal windows, electrochromic windows appear to benefit from better maximum transmittance as well as the modulation range in the visible spectrum. Liquid crystal and suspended-particle windows both require an electric field to be maintained in the transparent mode, resulting in a higher energy consumption compared with electrochromic windows which only require an electric field during switching. Baetens et. al. state that the reliability of current commercially available windows has been proven and their properties are within expectations, whereas the adoption of this technology has been found to be allow for the reduction of up to 26% of lighting energy compared with well-tuned daylighting control by blinds, and around 20% of the peak cooling loads in hot climates as California (USA) [15].

Solar-control solutions with automated dynamic shading devices coupled with building automation systems may offer excellent energy performance, but have high installation, maintenance, and management costs, and hinder the view from the inside to the outside. In contrast, dynamic glazing such as electrochromic glass permits the adjustment of the amount of incoming light and heat, thus creating a building envelope capable to adapt fully to the weather conditions and improving the building's overall performance in every kind of climate, especially in hot and Mediterranean countries. [15]. In addition, the integration of EC glazing into a building management system (Fig.4) offers endless possibilities when it comes to building component integration, automation, connectivity and IoT.

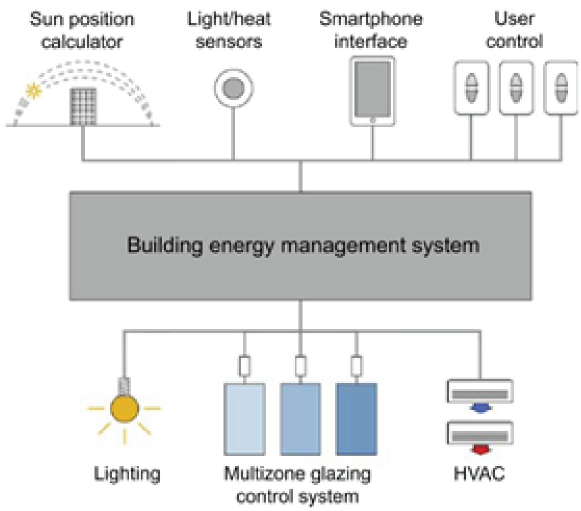

Figure 4: Electrochromic (EC) glazing integration of EC glazing into a building management system. [15]

6. Field Test Study

Research conducted to date has adopted building simulations and virtual modelling environments. While these studies can clearly demonstrate the ways in which dynamic glazing may be controlled, it is necessary to conduct physical field trials and record the results of dynamic glazing being controlled in a variety of climates and with a variety of control methodologies [16].

An ongoing research project aims to focus on this research gap and investigate the performance of EC glazing in a real-life environment, primarily the behaviour of workers in an office, and secondly the energetic performance of an office space situated in a central Mediterranean climate. Two identical office spaces within an occupied, recently-constructed building have been identified and will offer a real-life testing ground for this study **(Fig.5)**.

The existing offices comprise two south-south-east-facing façade spaces, having a window-to-wall ratio of 65% and fitted with insulated double-glazed units. At the design stage, no solar control measures have been employed within this façade, except for a horizontal overhang along the top mullion of the window and a static, solar control coating within the glass. The employers of the company leasing the premises have been facing continuous complaints by their employees due to lack of solar control measures leading to overheating and glare issues and the overall lack of indoor environmental quality within their office environment. The installation of perforated indoor blinds has had very little effect on solar control and the subsequent installation of translucent glazing film and blinds in black-out fabric have obliterated all the views. The above scenario is unfortunately a common occurrence in predominantly glazed buildings in a cooling-dominated climate. Tenants often pay high rental rates for the sake of views not only obliterated by indoor blinds but faced with complaints about overheating and glare, on both their computer screens and in the space in general.

The study will be carried out throughout a period of 12 calendar months and will investigate occupant behaviour under different climatic conditions, throughout an entire calendar year. A comparison is expected to be drawn between the performance of one space fitted with existing, manually controlled indoor blinds and another equipped with an automatically adaptive EC glazing, programmed with a set control strategy. Environmental data is to be collected through sensors strategically located within both offices and will record indoor air and surface temperatures, relative humidity, lighting and glare levels. The study will attempt to correlate indoor environmental conditions with the perception of indoor occupant well-being in both spaces under investigation under different climatic conditions. The quality of the indoor environment as perceived by the occupants of the offices is to be collected through surveys, interviews and observations of occupant behaviour. The use of real-time polling stations for each occupant are planned to be adopted to attain a more systematic data collection and to increase accuracy. In addition, readings of the energy consumption of both spaces through the existing BMS are expected to provide additional data for the analysis of energy consumption patterns of the two spaces across an entire calendar year.

The field test study is projected to span across the years 2020-2021 with the outcome of the initial results expected to be published towards the end of 2021.

Figure 5: Aerial photo of site and office plan to be studied (*SOURCE : Google Earth Pro, SmartCity Malta*).

7. Specific Objectives

This study will aim to shed further insight into the following key questions, some of which may not have not yet been investigated in the context of real-life building.

- How effective is the latest switchable glazing technology at reducing energy loads in buildings within a central Mediterranean climate?
- To what extent can the latest switchable glazing technology increase occupant well-being in buildings with high window-to-wall ratios?
- What would be the effect on energy demand and occupant comfort if one where to combine switchable glazing with external shading strategies?
- Which would be the optimal smart glazing/shading configuration for a fully-glazed façade that performs best in a central Mediterranean climate in terms of energy demand and occupant comfort?

8. Conclusions

Occupant well-being in an office environment has a direct effect on the productivity of the employee, the most valuable resource to which business operating costs can be directly attributed. Moreover, ample and pleasant views have been directly linked with improved worker performance with increased fatigue mostly associated with lack of outlook. Adaptive building façades are considered as a significant step towards improving both occupant well-being and energy efficiency of buildings, with electrochromic windows appearing to be a very promising technology for daylight and solar energy purposes, while retaining views.

Considering that the reliability of current commercially-available glazing products has been demonstrated through scientific research, their true effect on occupant well-being still needs to be investigated further, as only sparse precedent studies exist to date. The proposed field-study aims at providing further insight into this gap and without ignoring the potential of EC glazing in reducing the energy load within an office building in cooling-dominated climate.

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Conflict of Interest

The authors are research-based academics and hereby declare that they have no conflict of interest.

References

[1] European Commission -- Energy (online) https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings (accessed 2nd April 2019).

[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[3] Schittich C., Staib G., Balkow D., Schuler M., and Sobek W. (1999), *Glass Construction Manual*. Birkhäuser Publishers for Architecture, ISBN 3-7643-6077-1.

[4] Fsadni M., (2011), *Thermal Loading of Building Elements in Malta*, Institute for Sustainable Energy, University of Malta.

[5] World Green Building Council, (2016), *Building the Business Case: Health, Wellbeing and Productivity in Green Offices.*

[6] California Energy Commission, (2003), *Technical Report: Windows and Offices: A Study of Office Worker Performance and the Indoor Environment*.

[7] Retrieved from https://www.aoa.org/patients-and-public/caring-for-your-vision/protecting-your-vision/computer-vision-syndrome on 28^{th} April 2019.

[8] Figueiro, M., Rea, M., Rea, A., & Stevens R, (2002), *Daylight and Productivity: A Field Study. in proceeding of 2002 Summer Study on Energy Efficiency in Buildings*. American Council for an Energy Efficient Economy.)

[9] Loonen, R., Tr̆cka, M., Cóstola, D., & Hensen, J. L. M. (2013). *Climate adaptive building shells: State-of-the-art and future challenges*. Renewable and Sustainable Energy Reviews, 25, 483--493.

[10] Luible, A. (2014, May 15). *Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TU1403: Adaptive Facades Network*. COST Action TU1403.

[11] Dakheel, J.A & Aoul, K.T. (2017), Building Applications, Opportunities and Challenges of Active Shading Systems: A State-of-the-Art Review. Energies, 10, 1672.

[12] Loonen R.C.G.M., Trčka M., Cóstola D., Hensen J.L.M., (2013). Climate adaptive building shells: State-of-the-art and future challenges. Renewable and Sustainable Energy Reviews 25, 483-493.

[13] Bülow-Hube, H. (2000), Office worker preferences of exterior shading devices: a pilot study. EuroSun2000. June 19-22, Copenhagen, Denmark.

[14] Casini, M., (2016), Smart Buildings. Advanced Materials and Nanotechnology to Improve Energy-Efficiency and Environmental Performance. Woodhead Publishing / Elsevier, ISBN: 978-0-08-100640-5 (online).

[15] Baetens, R., Jelle, B.P., & Gustavsen, A. (2010), Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review. Solar Energy Materials & Solar Cells 94, 87--105.

[16] McLean, E., Norton, B., Kearney, D. & Lemarchand, P. (2017), A review of control methodologies for dynamic glazing. Advanced Building Skins 2017 Berne, Switzerland, 2 -3 October.