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SUSTAINABLE BUILT ENVIRONMENT

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THE DEVELOPMENT OF PHOTOELECTROCHROMIC GLAZING PANEL IN BUILDING ELEMENT

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ABSTRACT

Human activity has increased sea levels and air temperatures, disrupted weather patterns, and made the oceans more acidic by releasing carbon dioxide and other greenhousegases (GHGs) into the atmosphere. Buildings are important and account for 30% to 40% of the global primary energy consumption. The use of transparent glazing or roller blinds is a hindrance because it can cause discomfort towards the building users. Although this is the case, poorly performing glazed buildings harm and increases the solar heat and daylight penetration, particularly for large office building facades. Therefore, the objective of the research is to propose a PEC Glazing Panel that allows the amount of daylight to be minimized into buildings in Malaysia. Extensive literature reviews conducted via various databases (i.e., Web of Science, Science Direct, and Scopus) were explored. Later, the simulation model using SketchUp 2023 was used to visualize the concepts and ideas of the PEC Glazing Panel. The findings reveal that the proposed PEC Glazing Panel has the potential to be marketed (i.e., locally or internationally) due to its great benefits (i.e., minimal daylight penetration, and glare into the building). Thus, it is hoped that the proposed PEC Glazing Panel would improve the performance of existing glazing and provide comfort, health, and well-being to the building users.

Keywords: *"Photoelectrochromic Glazing Panel, Simulation model, Daylight, Glare, Comfort"*

INTRODUCTION

Recently, human activity has released carbon dioxide and other greenhouse gases into the atmosphere raising sea levels and the temperature of the planet's surface air, disrupting weather patterns, and making the ocean more acidic. Decarbonizing energy production and improving energy efficiency are two ways to resolve the energy-environment conundrum while maintaining economic growth and providing for a population that is expanding and becoming more concentrated in urban areas. Building contributes to 30-40% of the global primary energy consumption (Granqvist et al., 2018).

The use of transparent glass was unable to block the sun glare which caused the users' eyes discomfort, skin infections, heat exhaustion, and heat stroke (Abdel-Moneim & AbdelKader, 2022). According to Casini (2015), when the levels of outside light are relatively high, direct solar radiation can still interfere with visual activity inside the buildings. This happens to the building facades that face east and west, which are exposed to low-angle sun rays that can go deep into the buildings. Furthermore, utilizing traditional blinds is an ineffective way instead of automatically controlling with the concern of the weather condition on the outside of the building. With a high level of durability and compressive resistance, glass is a delicate substance used in buildings (Pariafsai, 2016). The glazed building exterior components' thermal, solar transmittance thermal and solar transmittance of glazed building exterior components frequently results in subpar performance. This is because the glazing experiences stress when it is applied over the material's capacity, which causes cracks to emerge (Wang et al., 2013). Large office building façades have an impact on the amount of daylight and solar heat gain.

The photoelectrochromic (PEC) glazing of the building is automatically controlled based on the condition of the outdoors to minimize the daylight and heat in the room (Casini, 2015). The third (3) SDG can be achieved as its goals are to ensure healthy lives and promote well-being for all ages. The application of the PEC glazing to the building will reduce glare and prevent overheating in the room in thus providing comfort, health, and well-being, that means the occupants are safe in the building from physical diseases such as skin cancer and cataract. Hence, this research aims to propose the PEC glazing panels that allow the amount of daylight be minimized into buildings in Malaysia.

LITERATURE REVIEW

This section explores the existence of innovative smart windows. The selection of this energy, heat absorbent, and glare which provides significant problems for building users (Baetens et al., 2010). The introduction of smart windows can reduce energy consumption depending on their thermal transmittance value (U-value) (Pereira et al., 2022).

Aguilar-Santana et al., (2019) has proven that in extreme weather it is quite difficult to maintain thermal comfort as it is a challenging task especially given the amount of electricity used by the appliances to do so in a building that consumes too much energy. According to Ke et al., (2019), smart windows save about 10% of the overall energy used by the building when compared to conventional static windows, such as low emissivity windows. In the past 10 years, usage of smart windows have grown significantly, and a variety of windows depending on various stimuli have been developed, thus, windows based on electro-, and thermo-, have been heavily pursued.

According to Malekafzali Ardakan et al., (2017), the Electrochromic (EC) smart window function uses electricity which causes the glazing to darken when lithium ions and associated electrons move from the counter electrode to the EC electrode layer, and vice versa. A low-voltage of direct current (DC) power source controls the EC reaction. EC glazing can modify its optical and thermal qualities by applying an electric field. It can change from a clear condition with a maximum of 60% visible light transmittance (VLT) to a fully darkened state with 1% VLT, or it can stay in a few selected intermediate-colored states (Malekafzali Ardakan et al., 2017). EC glazing never loses its transparency, protecting the outside view while reducing solar heat gain and transmitted light. They consist of a sandwich structure with a functional material layer sandwiched between two (2) transparent electrodes that, when a potential is applied, can reversibly alter optical properties (Ke et al., 2019).

While, Thermochromic (TH) window uses materials that are thermally responsive and can either be appropriately encapsulated between two glasses or coated on the glass surface as solid glazing (Ke et al., 2019). TH windows act by allowing all of the sun's energy to enter the room at low temperatures while reflecting the infrared portion of the sun's energy at temperatures above the critical, the reflectance and transmittance properties change at a specific critical temperature, where the materials go through a semiconductor-to-metal transition (Kalogirou, 2009; Obieglo et al., 2009). According to Wu et al.,(2023), the thermochromism phenomenon has been seen in a variety of materials, including inorganic oxides, liquid crystals, and conjugated oligomers, and the phenomenon is characterized by a function that reversibly changes color with temperature. They also mentioned that Vanadium dioxide (VO2) is one of the most promising thermochromic inorganic oxides due to its ability to undergo a reversible transition at a phase transition temperature, such as when the material's temperature is lower than transition temperature, it is monoclinic, semiconducting, and mostly transparent in the infrared, and when it is higher than the transition temperature, it is tetragonal, metallic, and reflecting in the near-infrared.

Photochromic (PC) is a type of glass that contains materials that will change color when it is exposed to specific wavelengths of light. The glazing is manufactured by embedding active chemicals into transparent hosts and then coating them on a clear substrate (Ke et al., 2019). PC glazing works by a reversible process, where some physical characteristics of photochromic compounds, for example, the absorption spectra, fluorescence emission, conjugation, electron conductivity, electrochemical properties, magnetic properties, coordination properties, dipole interaction, refractive index, dielectric constant, and geometrical structure are tuned by light (Zhang et al., 2013).

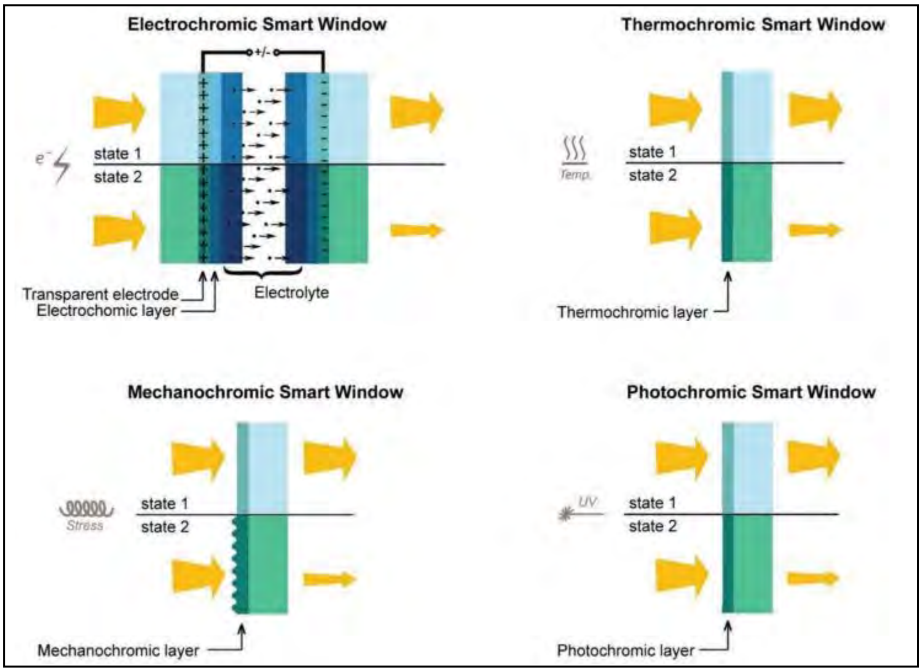

Figure 1: Smart windows illustration (Ke et al., 2019)

Figure 1 shows the illustration of the smart windows. Referring to the illustration it shows how the heat transfer goes through these windows as their properties are different. The EC glass will need electricity to activate the glass, while the thermochromic glass only reacts to the sun's heat. Among these smart windows, ECwindows are the most appealing category which has been commercialized and has undergone a long period of steady evolution (Ke et al., 2019). For TC and PC windows, both of the types are unable to block the sun glare even though they can minimize the amount of daylight entering through the building, compared to the EC which is more effective in blocking the sun glare. Furthermore, TC itself is an expensive and less cost-effective technique to control the dispersion of the nanoparticles in polymeric hosts (Aburas et al., 2019; Garshasbi & Santamouris, 2019). Hence, this resulted in the idea of designing an innovative product, which is the PEC glazing panel that can allow the amount of daylight to be minimized into buildings in Malaysia.

METHODOLOGY

The methodology of this research focuses on a literature review from past research. The journal databases (i.e., Web of Science, Science Direct, and Scopus) have been used and reviewed as literature sources for this research. These journal articles and proceedings were drawn from Malaysia and international publications towards obtaining updated information regarding the PEC Glazing Panel. Content analysis isused to analyze the data obtained from these databases. After the literature is conducted, a simulation model is carried out to visualize the concepts and ideas of the PEC Glazing Panels. The research can only be done through simulation as the material to conduct the experiment and producing a prototype is beyond the student's capability (due to time constraints and limited cost expenditure).

RESULT AND DISCUSSION

- **Development of innovative ideas**

The idea is taken based on the smart glazing panel performance bycombining two of the smart glazing panels (i.e., PC and EC glazing panels). Figure 2 below shows the illustration of the innovativeproduct.

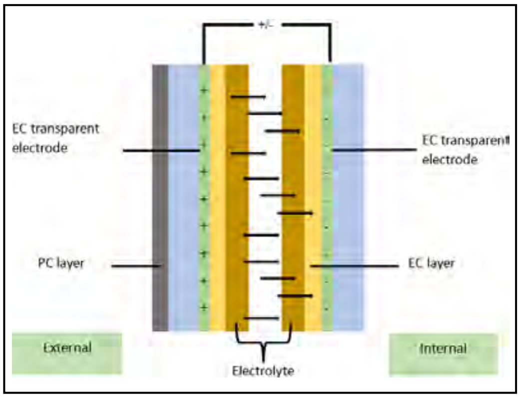

Figure 2: The idea concept of the PEC Glazing Panel

The combination of PC and EC glazing panels increases the performance of the glazing during daylight. Since both are from the smart glazed window category, both functions can work together during daylight based on the users' comfort in the building (Rashidzadeh & Heidari Matin, 2023). As such, the PC layer becomes darker as time passes as it works to minimize the sun glarethat passes on its own, rather than EC glazing that needs electricityto be switched on to block the glare. If the weather during the day iscloudy, hence the amount of daylight is less, the occupants can depend on the EC glazing panel by switching on the electricity to turnthe transparent glazing into an opaque state. With both glazing combinations, the thermal and visual comfort, heat gain, and solar gain can be minimized even more and the rate of energy efficiency can be enhanced because both provide excellent performance towards the environment, occupants, and the buildings (Gorantla etal., 2018).

- **Components of the PEC Glazing Panels**

The sandwich panel combines the PC and EC materials with durable and low-maintenance aluminium frame. The tempered glass panel is designed to be one-glazed with a sandwiched layer that has eight layers, where it contains a PC layerand two EC layers, two EC electrodes, and an electrolyte layer in between two glasses EC materials will need an amount of electricity to charge the ions to turn the layer of the glazing into either an opaque or transparent state. By implementing the EC properties onto the glazing panel, theamount of daylight can be decreased, as well as the heat transmittance. From this function, it is suitable to be implemented asit will not fully block the daylight entering the building but minimize the daylight amount. As a result, the occupants will still obtain light during the day but at a suitable amount, with a sufficient heat gain from the sun, making the temperature of the building low, as well asreducing the amount of electricity utility (Masdar Institute of Scienceand Technology, 2018: Cannavale et al., 2020). PC materials are typically obtained by adding a photochromic component to a transparent material (Bahlol, 2010). PC materials will change their colors depending on the amount of sunlight absorption, for example, when the sun is above the head, which is during noon time, the PC layer will turn dark to minimize the amount of sunlight entering the room of the building, and while the weather is cloudy and the amount of sunlight is less, the PC layer will become less dark as the absorption of the sunlight is less. This is beneficial to the occupants in the building, reduces exposure to skin infections, eczema, skin cancer, and eye diseases as well as preventing furniture damage.

- **Assembly of the PEC glazing panel**

The PEC glazing panel is a single-glazed unit of a window with a sandwiched layer of glasses that have PC material on one glass and EC materials between glasses, as shown in Figure 3. The design of the panel is on a large scale with a dimension of 1000 mm length × 2500 mm height. It is designed to be used as a fixed window acting as a glass wall panel for commercial buildings in order to improve the appearance of the building.

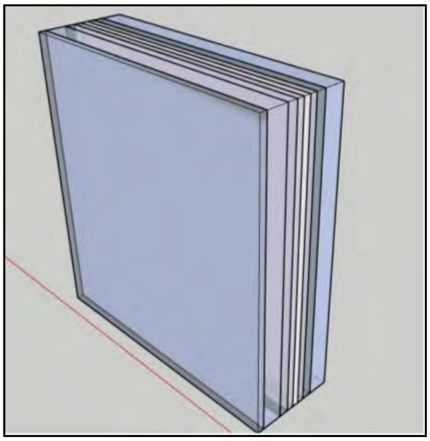

Figure 3: The cross-section of the PEC Glazing Panel

The following figure 4 shows the position of the innovation product in a Starbucks building.

Figure 4: The position of the PEC Glazing Panel at a Starbucks building

- **Operational Procedure of the PEC Glazing Panels**

The purpose of this research is to develop the PEC glazing panel which allows a minimized amount of direct daylight to enter into the buildings in Malaysia. The operational procedures of the PEC Glazing Panels are illustrated in Figure 5-8 below;

Figure 5: Glazing Panel inTransparent State.

Figure 6: The Glazing Panel isgetting Slightly Darker.

Figure 7: The Glazing Panel is in aComplete Darkened State.

Figure 8: One of the Glazing Panels in Opaque State.

Figures 5-7 show the surface of the glazing that slowly changes over time from a transparent state to a dark state where the PC material reacts to daylight. It can be deduced that the higher amount of daylight it receives, the darker it will become. This is to ensure the interior of the building receives a suitable amount of lighting and achieves a comfortable condition for the occupants. In addition, the EC mode will operate when the electricity is turned on, turning the appearance of the glazing panel from a transparent state to an opaque state, to block the sun glare. In Figure 8, the glazing panel will remain darkened with an opaque state when the electricity is being turned on.

- **Performance of the PEC Glazing Panel**

The following Table 1 presents the comparison of the PEC Glazing Panel performance compared to the existing smart windows (i.e., Electrochromic (EC), Thermochromic (TC), and Photochromic (PC smart windows. The table shows that the PEC Glazing Panel is effective to be used as it is sun dependent, energy efficient, comfortable, has less heat gain, provides minimal glare, and low thermal transmittance, but is higher on the cost side. The performance of PEC Glazing Panel is the ability to minimize the amount of daylight in the building as well as blocking the sun glare. As a result, the interior of the building can achieve comfort conditions as the heat from the daylight is minimized, and eye glare will be prevented. Furthermore, when the PEC Glazing Panel affects minimal daylight and glare into the building, the use of air conditioners can be minimized thus reducing utility bills, which means a cooler and greener environment can also be achieved.

Table 1: Performance of the PEC Glazing Panel

Types of Glazing Panel / Glass Performance	TC	PC	EC	PEC
Sun dependents	✓	✓	✗	✓
Energy efficiency	✓	✓	✓	✓
Comfort	✓	✓	✓	✓
Heat gain	Low	Low	Low	Low
Glare	Low over time	Low over time	Low	Low
Thermal transmittance	Low over time	Low over time	Low	Low
Cost	High	Low	High	High

Remarks: TC (Thermochromic), PC (Photochromic), EC (Electrochromic), PEC (Photoelectrochromic Glazing Panel)

Therefore, to ensure the PEC glazing panel is accessible to individuals, organizations such as contractors, suppliers, or developers; various strategies should be taken by the construction industry in Malaysia. As such, this can be obtained with help from e- commerce marketing via official websites to promote

PEC Glazing Panel in the local and international markets. In addition, the alternative use of the PEC Glazing panel among construction players in the Malaysian Construction Industry can also be spread using social media platforms (i.e., Instagram, Facebook, and Blog). These strategies will enhance the development of the PEC Glazing Panel in Malaysia, minimizing the amount of daylight in the building, increasing comfortability in the building by reducing the usage of air-conditioning as well as contributing to a greener environment.

CONCLUSION

The paper identifies the issues, problems, and ideas for the development of the PEC Glazing Panel. From the research, the following conclusion can be made that the conventional glass faces problems related to material selection which causes discomfort (i.e., glare, skin infections, and heat stroke) to the building users. The application of the PEC Glazing Panel used in the building becomes one alternative to mitigate building overheating. PEC Glazing Panel is viable to be used in buildings due to its great potential impact. These include being sun-dependent, energy efficient, comfortable, offers less heat gain, providing minimal glare, and low thermal transmittance. Despite the initial investment cost being higher, the long-term benefits of the PEC Glazing Panel are vital. Further research should be emphasized on the application and effectiveness of the PEC Glazing Panel for selected buildings in Malaysia. Due to this, the evaluation of other aspects such as cost, and maintenance also require further research. In addition, another suggested recommendation for further research is to obtain the Malaysian Construction Industry Stakeholders' perception regarding the development of the PEC Glazing Panel via surveys or interviews.

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