Electrochromic “Smart” Windows To Conserve Energy

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EXECUTIVE SUMMARY

Solar rays emit both light and heat. Once transferred into a building, they provide natural light and as well as heat up a room. Heaters and air conditioners are systems developed to change or maintain the temperature of a building. Once the heat emitted from solar rays enters a room, the air conditioner supplies more cold air to compensate for the addition of heat. When outside temperature is cooler than the interior temperature, thermal energy (heat) escapes to the outside. Heaters will then supply hot air to compensate for the loss of heat. The supplementary work of the heater and air conditioner consumes additional electricity that can be avoided by using electrochromic windows. **Electrochromic** technology is designed to use a small quantity of energy to transition the window between a bleached (**transparent**) state and a colourized (**opaque**) state. When colourized, the windows block solar rays from entering a building to prevent the transfer of thermal energy. Since these windows can be transitioned at any time, they act as an "active solar control device" (Papaefthimiou et al, 2006, para 16-17). The purpose of electrochromic windows is to reduce the overall energy consumption of buildings and to provide a more comfortable environment.

TABLE OF CONTENTS

GLOSSARY

Building Envelope: The components that make up the exterior of a building.

Conduct: To act as a medium for conveying or transmitting an electric current.

Electrochromic: Of or relating to a substance that changes color when placed in an electric field.

Microscopic: So small as to be invisible or indistinct without the use of a microscope.

Opaque: Blocking the passage of radiant energy and especially light.

Polymer: A chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating structural units.

Transparent: The object is clear so that bodies situated beyond of behind can be distinctly seen.

(All definitions taken from *dictionary.com* and *merriam-webster.com*)

1.0 INTRODUCTION

The purpose of this report is to understand how windows affect a building's electricity consumption and to examine how electrochromic technology in windows will increase a building's energy efficiency.

1.1 Heating and Air Conditioning

People spend most of their lives indoors, therefore, maintaining a comfortable interior temperature of a building is essential. The temperature inside a building is regulated by using a heater to increase the temperature or an air conditioner to decrease the temperature. Both systems consume a significant amount of electricity. Electrochromic windows will reduce the need for heating and air conditioning, and thus, are able to decrease the amount of electricity a building consumes.

1.2 Structure of the Report

The sources used in this report are scholarly journal articles published in building and science journals from Humber Libraries online. The main body of this report has 2 sections. The first section examines how heat loss & gain through windows increases the amount of electricity needed to maintain a comfortable building temperature. The second section will examine the parts and process of electrochromic windows, as well as explore the benefits of the technology. For referencing, a glossary of terms is provided on page iv.

2.0 CONSUMPTION OF ELECTRICITY

Thermal energy is easily transferred through windows due to the transparency of glass. This causes a structure to gain or lose heat. Heaters and air conditioners are used to regulate the indoor temperature of a building, however, they require a large quantity of electricity. Jung et al. (2019) claims that "The building sector accounts for 36% of the total global energy consumption and 39% of the CO2 emissions associated with energy consumption." (para 1). Therefore, the need to decrease the energy consumption of buildings is vital to decreasing the global energy usage overall.

2.1 Heat Loss/Gain Through Windows

Windows are made of glass to allow solar rays to enter a room and to provide a view to the outside of the building. When solar rays are transmitted through windows, they provide natural light for occupants to see within the building. In addition to light, they emit thermal energy (heat), which can change the interior temperature of the room. However, a window's ability to transfer thermal energy between the interior and exterior of the building will result in heat gain and/or loss. Grynning et al. (2013) have discovered that "heat loss related to windows contributes over 40% of the total heat loss through the **building envelope** for a typical Norwegian office building" (para 6). Figure 1 shows a pie graph that represents the heat loss from different parts of a typical Norwegian office building.

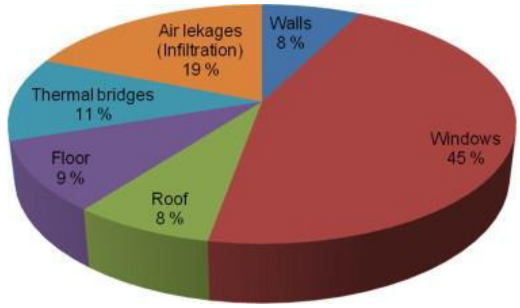

Figure 1: Percentage of heat loss through different parts of the building envelope of a typical Norwegian office building (Grynning et al, 2013, para 6)

Both the numeric statistic of 40% and figure 1 illustrate that the percentage of heat loss through windows is significantly greater than the heat loss through other parts of the building envelope. Therefore, decreasing the exchange of thermal energy through windows, will considerably reduce a buildings overall heat loss.

2.2 Energy Consumption from Heaters & Air-Conditioners

The goal of a building is to be both functional and comfortable for its occupants. The interior temperature of a building is the primary factor that will affect the occupant's feeling of comfortability. As seasons change in Canada, the weather can vary from extreme heat to extreme cold. Therefore, heaters and air conditioners have been invented to regulate a desired room temperature regardless of the temperature outside. When excessive heat is emitted from solar rays, air conditioners produce cold air to cool down the building. Likewise, when windows are losing heat, heaters produce hot air to warm up the building. Overall, for these systems to operate, they consume a large amount of electricity and release additional heat into the atmosphere.

3.0 ELECTROCHROMIC "SMART" WINDOWS

Electrochromic windows, also known as "smart windows", use electrochromic technology to change the tint of the glass. When desired, an electric voltage can be applied to the window which produces a chemical reaction and causes the transparency of the glass to change. The purpose of this technology is to decrease the amount of electricity that heaters and air conditioners consume in order to heat or cool a building.

To understand the purpose of electrochromic windows, imagine standing in the shade of a tree on a hot summer day. The temperature under the tree is cooler than standing in an open field. This occurs because the leaves of the tree act as a barrier against direct sunlight. The solar rays are still emitting light and heat around the tree and through gaps in the leaves, however the diversion leaves the space feeling cooler. When "smart" windows are transparent, direct sunlight is transmitted through the glass. Thermal energy is then transmitted into the space and adds heat to the room. Once the glass turns opaque, the window acts a barrier and solar rays get diverted back to the outside. This will omit the thermal energy from entering the room and leave it feeling cooler.

3.1 Components of an Electrochromic Window

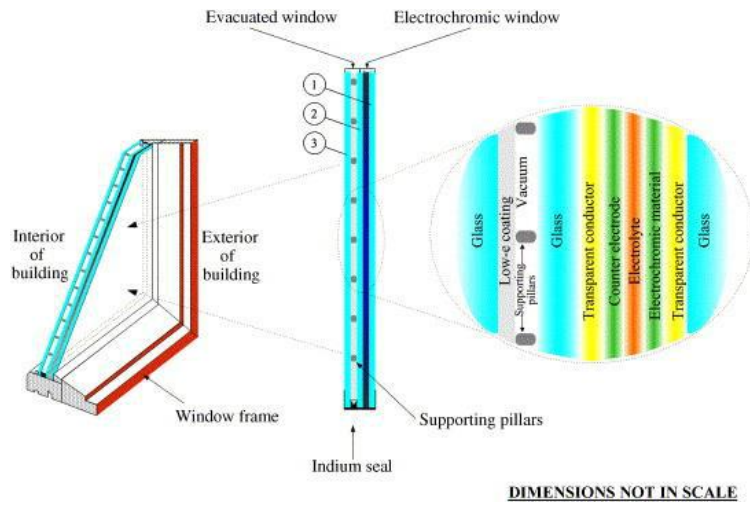

Figure 2: Layers of an electrochromic window (Papaefthimiou et al, 2006)

Electrochromic windows consist of five layers as shown in figure 2 between two glass window panes. Cheng et al (2018) lists the 5 layers from the exterior to the interior as the transparent conducting layer, electrochromic layer, electrolyte layer, counter-electrode layer and another transparent conducting layer (para 3).

The two transparent conducting layers comprised of Fluorine doped Tin-Dioxide (SnO_2:F) coated glass called K-Glass™. The purpose of these layers is to transmit electricity to the electrochromic window system (Papaefthimiou et al, 2006, para 16-17).

The purpose of the electrochromic layer is to colourize (add colour) when mixed with metal (often Lithium) ions and bleach (lose colour) when separated from Lithium ions (Li^+). The purpose of the counter-electrode layer, also known as the ion storage layer, is to colourize when separated from lithium ions and bleach when mixed with lithium ions. There are different chemicals that make up the electrochromic and counter-electrode layers. This is due to new discoveries and experiments to determine which chemicals have the best **conductive** properties such as transition speeds and lifespan (Papaefthimiou et al, 2006, para 18). Currently, in a bleached state the electrochromic layer is comprised of Tungsten Oxide (WO_3) and the counter-electrode layer is currently composed of Lithiated Nitrogen Oxide (Li_yNiO_x). Tungsten Oxide is often used due to its superior ionic and electronic conducting properties (Solovyev et al, 2016, p 3867), while Lithiated Nitrogen Oxide is often used due to its ion storage capabilities (Cheng et al, 2018, para 1).

The middle electrolyte layer is also known as the ion conducting layer. The purpose of this layer is to be a transitional space between the counter-electrode and the electrochromic layers. It helps send the lithium ions from one layer to the other. Solovyev et al. (2016) explains that the two main types of electrolytes are thin solid films or **polymers**. Some of the advantages of gel polymer electrolytes (GPE) are “very good optical transparency, high ionic conductivity, design flexibility and long-term durability.” (p 3867).

3.2 Transition Process of the Glass

The two states of electrochromic windows are a colourized state and a bleached state. Cheng et al. (2018) explains that in the bleached state (window is transparent), the electrochromic layer is composed of WO_3 and the counter-electrode layer is composed of Li_yNiO_x. Once a voltage is applied to the window, Lithium ions (Li_+) in the counter-electrode layer (Li_yNiO_x) transfer to the electrochromic (WO_3) layer. Now the window is in a colourized state (window is opaque) with Lithium Tungsten Bronze (Li_xWO_3) in the electrochromic layer and Nitrogen Oxide (NiO_x) in the counter-electrode layer (para 4). The new chemicals Li_zWO_3 and $Li_{y-z}NiO_x$ both have a greater optical density which means that it is more difficult to see through them (Solovyev et al, 2016, p 3868). To change the glass back to a bleached state, the electric voltage is applied again to cause the Lithium ions to transfer back to the counter-electrode layer from the electrochromic layer. The electric voltage is only needed for the during the chemical change, so once the transition has occurred, the voltage is no longer needed until the next transition. Figure 3 below illustrates both the parts and chemical changes that the electrochromic window undergoes to transition and return the glass back to its transparent state.

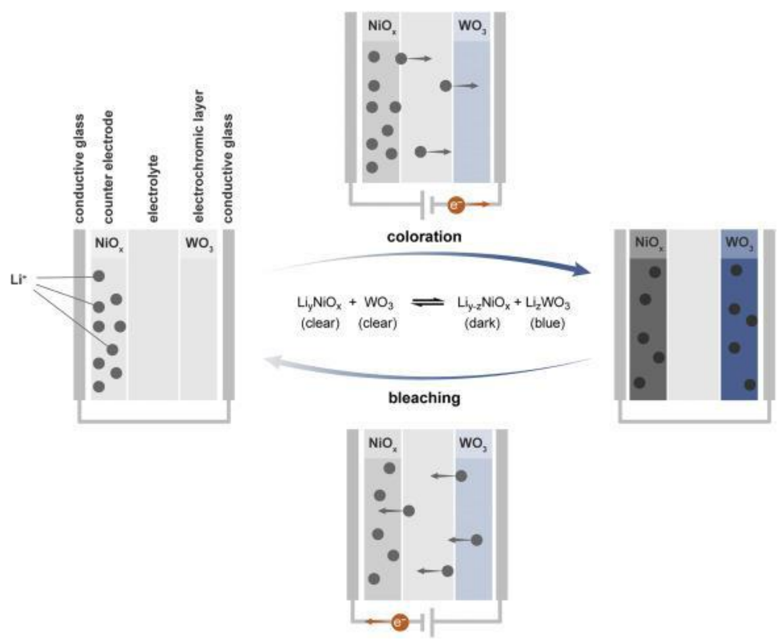

Figure 3: Transition process of colourizing and bleaching the glass (Cheng et al, 2018, para 3)

3.3 Benefits of "Smart" Windows

Electrochromic windows provide numerous benefits for both occupants and the environment. Some of these benefits include glare reduction and lower window maintenance. (Papaefthimiou et al, 2006, para 18). "Smart" windows also eliminate the need for blinds and curtains while maintaining the same level of privacy. Blinds and curtains can emit volatile organic compounds which are chemicals that are harmful to human health. However, the primary benefit of "smart" windows is the ability to control the amount of thermal energy entering a building. Unlike photochromic and thermochromic "smart" windows, electrochromic windows can be transitioned anytime. Photochromic and thermochromic windows need to reach a specific amount of light or temperature respectfully in order to transition. The secondary benefit of “smart” windows is that they limit the need for artificial light during the times of day when excessive amounts of thermal energy are transmitted into a room. This is because when in a coloured state, natural light can continue to illuminate a room while blocking out thermal energy. Overall, there are no immediate risks to leaving this problem untreated, however, everyone will benefit from using electrochromic windows. For example, researcher and manufactures will profit, less non-renewable energy will be consumed and building owners will have lower electricity bills.

3.4 Drawbacks of “Smart” Windows

While the goal of “smart” windows is to decrease the amount of electricity consumed and a building, electrochromic windows require a small quantity of electricity to power the transitioning of the glass. However, Papaefthimiou et al. (2006) states that electrochromic windows have “a low energy consumption (typically 8 W m−2), which is nearly zero when the glazing is kept at constant conditions.” (para 8). Thus, these windows conserve more electricity than they consume. In addition, photovoltaic cells (**microscopic** solar panels) can be attached to “smart” windows to use solar energy to power the windows. Jung et al. (2019) have developed an electrochromic window prototype that has photovoltaic blinds and a ventilation system attached to it (para 1).

4.0 CONCLUSION

Buildings contribute a significant amount to the total energy consumption around the world. This contribution is a result from the large amount of electricity needed to heat or cool a building. The importance of developing electrochromic windows is to achieve optimal use of their bleached and colourized states. This will reduce the amount of energy heaters and air conditioners consume to compensate for the loss or gain of excess heat. Electrochromic windows will continue to be researched and developed as they are an emerging technology. Examining the limitations of these systems and discovering ways to exceed the limits will be the future of electrochromic windows.

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