SMART Glass

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Abstract

HALIO Glass created by AGC is an electrochromic glass that changes its light transmittance when a voltage is applied across the components in the glass. However, it is seen that there is still not enough testing made to find out the relationship between light transmittance and heat transmittance of the glass. Hence, this project aims to investigate how light transmittance affects heat transmittance of the glass. This is accomplished by a series of experiments. The team varies the light transmittance of the glass and allowing electromagnetic waves (visible light and infrared rays) produced by a light source to pass through the glass. This allows the light level and temperature to be measured across a period of time. It was observed that there is a strong correlation between the light transmittance and heat transmittance of the glass. However, it is also observed that at 2 points, namely 30% and 70% progress of tinting of the glass, are the heat transmittance the highest and lowest respectively. These results were not expected and it lead to further testing of the glass and the test confirmed the results. In conclusion, by using the above results as a basis for the conclusion, it is found that heat transmittance is highest at 0% and 30% progress of tinting of glass, and the heat transmittance is lowest at 70% and 100% progress of tinting of glass.

Introduction

Electrochromic glass, or “smart” glass, is a device that can change its light transmission properties when a voltage is applied to it, allowing users control over the amount of light and heat passing through. There are two main layers of the glass, the separator and the electrode layer. The basic working principle involves lithium ions that migrate back and forth between the two electrodes through the separator. When a small voltage is applied to the electrodes, the ions migrate through the separator to the outermost electrode. The ions reflect light, making the glass opaque. No voltage is required to maintain the state of the glass, making it energy efficient.

Electrochromic glass can be used in homes, offices and even public transports to allow for comfort of the user. Unlike the conventional blinds and curtains used to block out light, electrochromic glass can be automated to provide the best thermal comfort while at the same time allowing maintaining visibility of the outside. Users can also manually control the amount of light and heat passing through to suit their needs, providing flexibility and convenience for the user. With potential benefits, more research should be put into place to improve the lives of many with this technology.

However, not much testing has been done using electrochromic glass to find out the relationship between light transmittance and heat transmittance of the glass as it is still a new technology. Such results could help to find the best settings for maximum thermal comfort in different situations, allowing users to experience the full benefits of electrochromic glass. Hence, there is an importance to find the relationship between light and heat transmittance.

Currently, there are ways to test for the light and heat transmittance. Light transmittance is tested using a transparency meter that determines light scattering behaviour of glass by measuring, total transmittance, transmission haze and clarity. Light transmittance is calculated using the following formula:

Incident light - (Absorption + Reflection) = Total Transmittance (in percentage)

Heat transmittance is tested using a thermal chamber that determines the U-factor and G-factor of the glass. U-factor refers to how much heat escapes via the window and G-factor refers to how much infrared radiation is allow in through the glass. U-factor is calculated using the following formula:

U-factor = $PA^{-1}|(\theta_o-\theta_i)|^{-1}$

- Where U-factor is specific U-value, in Wm^{-2} $°C^{-1}$
- P is heat flow from the sun, in W,
- A is surface area of glass, in m^2,
- θ_o is temperature outdoors, in °C,
- θ_i is temperature indoors, in °C

G-factor is calculated using the following formula:

G-factor = P_o/P_i

- Where G-factor is specific G-value, as a ratio,
- P_o is total solar heat gain of glass, in W,
- P_i is incident solar radiation, in W

However, these conventional methods of testing require sophisticated and bulky equipment to test glass professionally, and such specific ISO standards that cannot be replicated in the school lab. Therefore, this project aims to determine the relationship between light and heat transmittance of the glass. This is done by conducting a watered-down version of the experiment within our means and measuring increase in temperature as indication of infrared transmittance. Due to constraints in the school lab, a black box was used to house the glass, and the heat sources used were incandescent light bulbs and an infrared lamp. Also, light and heat sensors connected to a data logger were used to collect data. Using the data collected, the optimum settings for maximum thermal comfort can be determined, and can be used to benefit the users of the electrochromic glass.

Solution Design

Aims

The aims of the project are:

- Test how the different degrees of transparency (light transmittance) of HALIO glass affect its heat transmittance (thermal comfort)
- Find out what (optimal) settings of the glass is most suitable is different situations

Variables:

Independent: light transmittance of glass

Dependent: heat transmittance of glass

Constant: brightness of light/heat source, position of light/heat source, position of light/heat sensor, ambient temperature before start of experiment

Equipment and Materials

- 1 wooden box
- 1 HALIO Glass
- 1 sheet of corrugated cardboard
- 1 wooden board
- 1 roll of duct tape
- Blu tack
- 2 40W incandescent bulb
- 2 light bulb holders
- 2 three-pin plugs
- 1 Infrared Lamp
- 1 light sensor
- 1 heat sensor
- 1 datalogger
- 1 electrical fan

Experiment 1: Method

The following steps were taken while constructing all set-up:

1. Sketch of the simple design of Setup 1 on paper (Figure 1a) and an Inventor sketch on computer (Figure 1b)

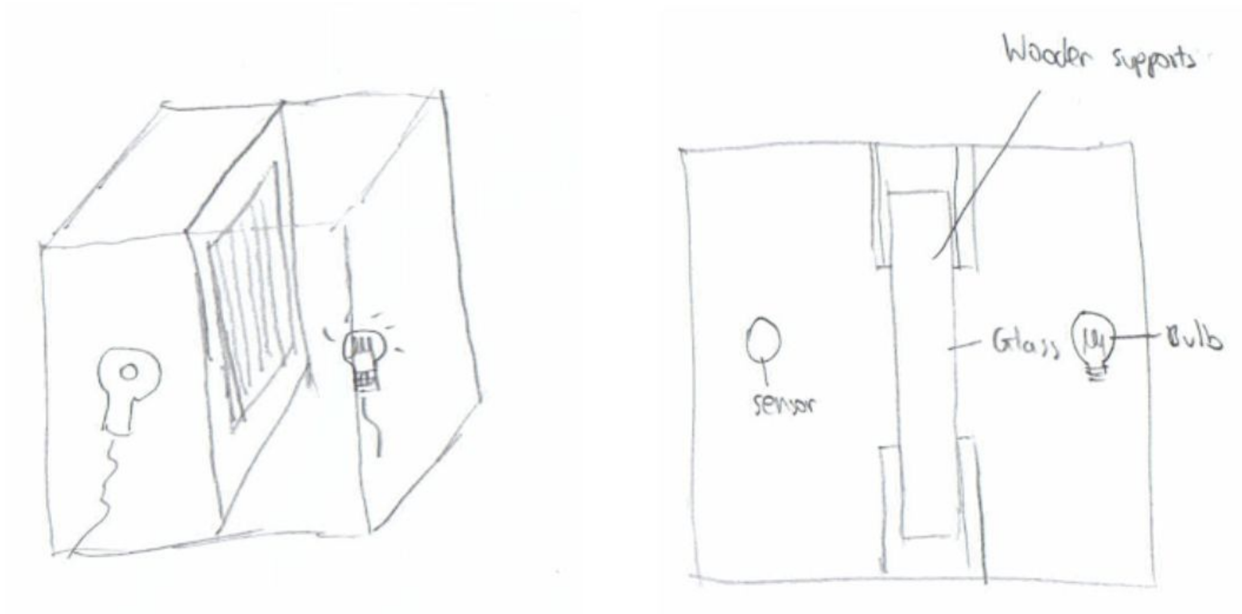

Figure 1a - sketch on paper

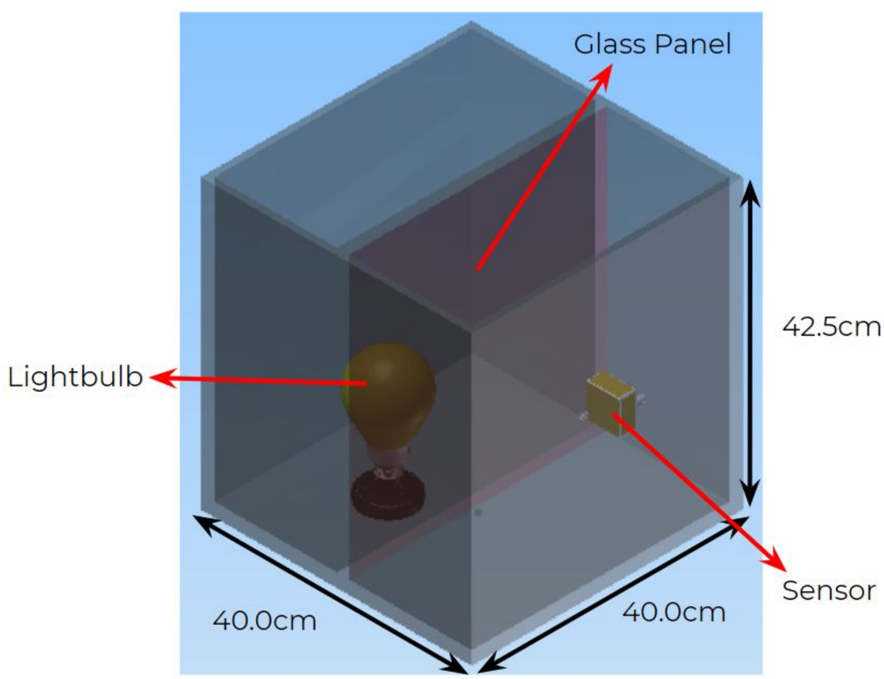

Figure 1b - Inventor sketch

2. Creation and completion of Setup 1 (Figure 2).

Figure 2 - completed Setup 1

Construction method:

a. Construct box of measurement 40.0 cm by 40.0 cm by 42.5 cm.
b. Secure 2 L-brackets to the internal base of the box using screws.
c. Insert 4 folded sheets of black corrugated cardboard.
d. Insert 2 pieces of corrugated cardboard parallel and touching the glass and secure to the glass using blu tack
e. Mount a light bulb holder onto a piece of wood and insert it parallel to the glass, keeping the piece of wood as far away from the glass as possible, securing it to the internal side of the box with duct tape
f. File holes on the top of the box to allow wires for light bulb, light sensor and heat sensor to be draw outside the box.
g. Screw the light bulb into the light bulb holder.
h. Place light and heat sensor on the opposite side of the light bulb, secure with suitable adhesive.
i. Connect both sensors to a datalogger.

Experiment 2: Method

3. Added one more bulb to Setup 1 and made minor improvements to create Setup 2 (Figure 3)

Figure 3 - Setup 2

Experiment 3: Method

4. Replaced bulbs with an infrared lamp to create Setup 3 (Figure 4).

Figure 4 - Setup 3

Preparation Procedure

1. Fully tint the glass.
2. Close the box and turn on the light bulb.
3. Measure light transmittance in lux, L_1.
4. Repeat steps 2 and 3 with a fully clear glass to find L_2.
5. To find lux for y% of tinting, use the formula: $(L_2-L_1)\times(y/100)$.

Experiment Procedure

1. Set the glass to 100% tint setting.
2. Ensure that the initial temperature of the box is constant using the heat sensor.
3. Close the box and turn on the light source (light bulbs for Setup 1 and 2, infrared lamp for Setup 3).
4. After 5 minutes, measure the temperature change in °C using the heat sensor.
5. Repeat steps 2 to 5 using 80%, 60%, 40%, 20% and 0% tint setting.
6. Convert tint setting to light transmittance using the formula: $((L_2-L_1)\times(y/100))/L_2$
7. Plot a graph of temperature change/°C against light transmittance/%.

Results & Discussion

Figures 5a, 5b and 5c shows results for Setup 2.

Progress of clearing	lux
100%	670
80%	539.2
60%	408.4
40%	277.6
20%	146.8
0%	16
30%	212.2
70%	473.8

Figure 5a - Amount of lux obtained from different progress of clearing of the glass

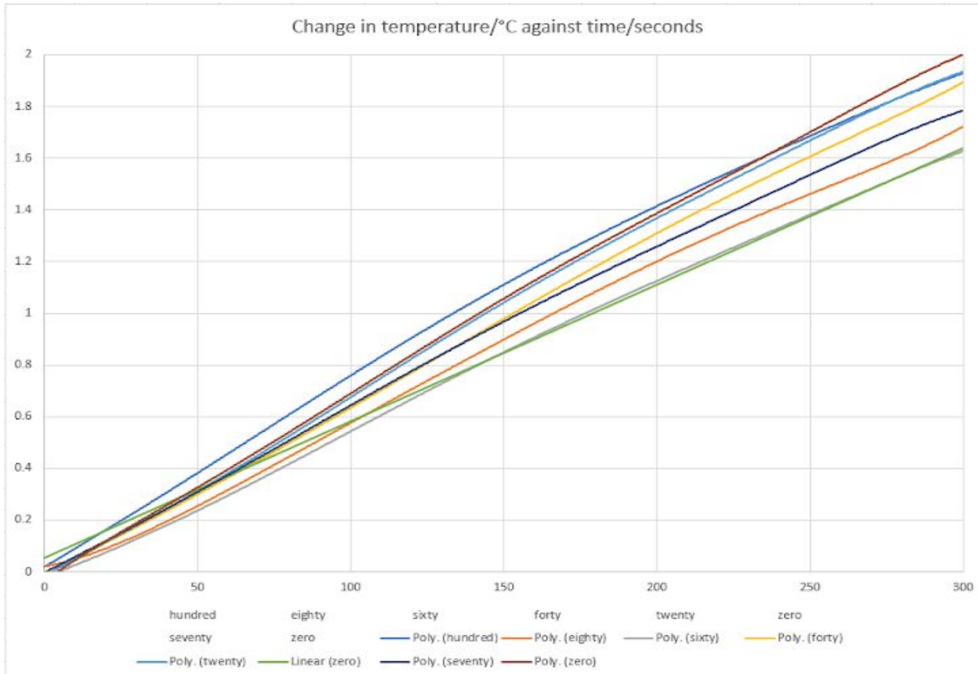

Figure 5b - Graph of change in temperature/°C against percentage of light transmittance

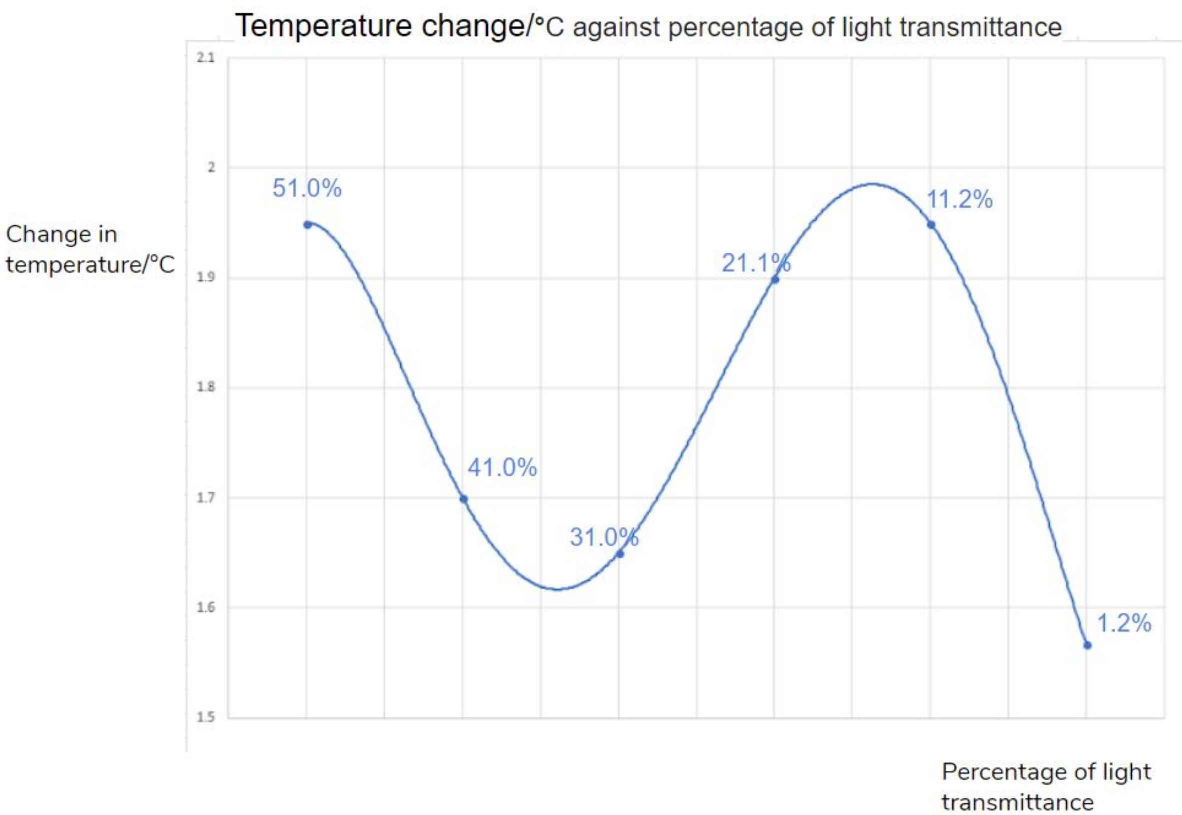

Figure 5c - Graph of change in temperature/°C against percentage of light transmittance

Figure 6 shows results for Setup 3.

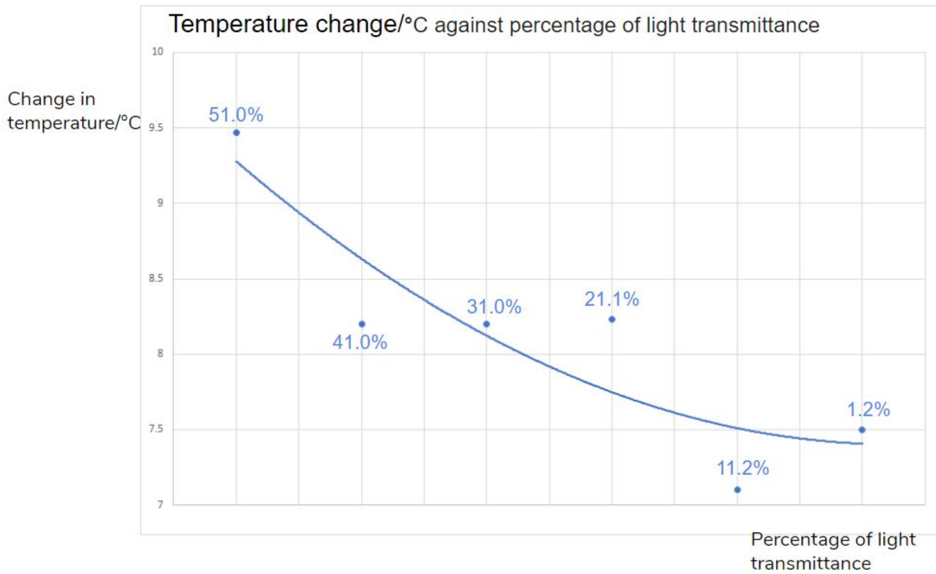

Figure 6 - Graph of change in temperature/°C against percentage of light transmittance

The results of Setup 2 are one where 2 incandescent light bulb were used, whereas the results of Setup 3 is where an infrared lamp was used instead. The team predicted that the heat transmittance to decrease as light transmittance decrease. The results of Setup 3 match the prediction, but contrary to the prediction, the results of Setup 2 tells the team otherwise. Although the results seemed ambiguous, it is repeated and confirmed to be correct.

Setup 3 shows how the electrochromic glass is effective in blocking out certain ranges of waves, and confirms our prediction. However, the team has based their conclusion on the results of Setup 2 as it is more representative of the Sun. The infrared lamp produces a smaller and much difference range of electromagnetic waves as compared to the Sun, which produces a mixture of waves, ranging from infrared to visible light to ultraviolet.
According to Marek Wojciech Gutowski from the Institute of Physics of the Polish Academy of Sciences, 2015 “Our Sun is pretty good imitation of a black body, with nice and smooth spectral content, most easily parametrized by its surface temperature around 6500 K. This fact alone suggests that the ordinary light bulbs, operating with hot tungsten (incandescent light bulbs), might be most appropriate.”

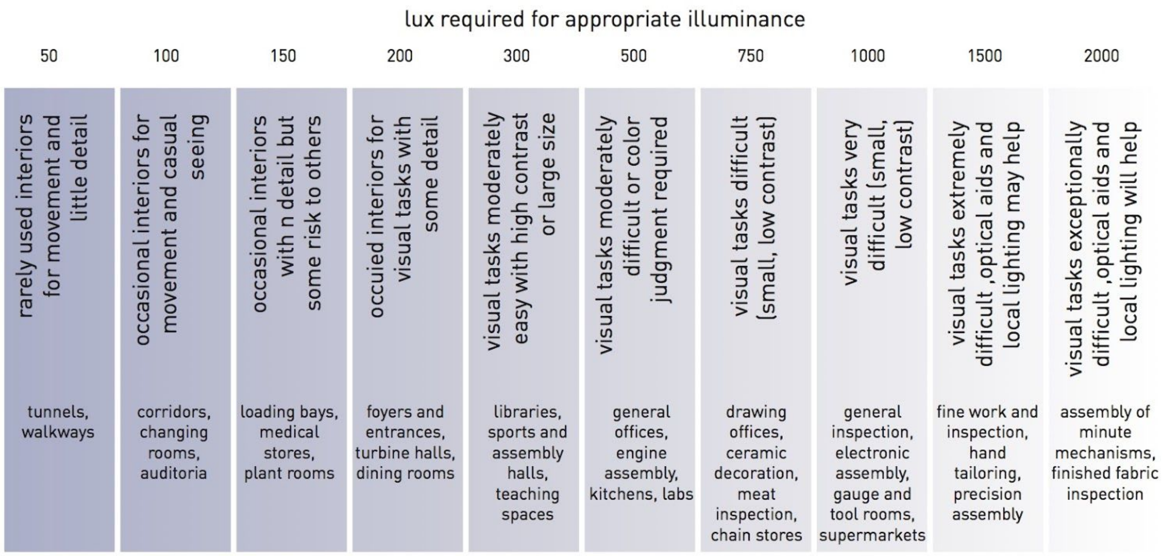

Figure 7a - Lux required for different environments

Outdoor Temperature /°C	Maximum amount of light to enter the building	Moderate amount of light to enter the building	As little light as possible to enter the builiding
<22	**100% clear**	**-**	**30% clear**
22-24	**90% clear**	**55% clear**	**15% clear**
24-26	**85% clear**	**50% clear**	**10% clear**
26-28	**70% clear**	**-**	**0% clear**

Figure 7b - Table of optimum settings for general usage

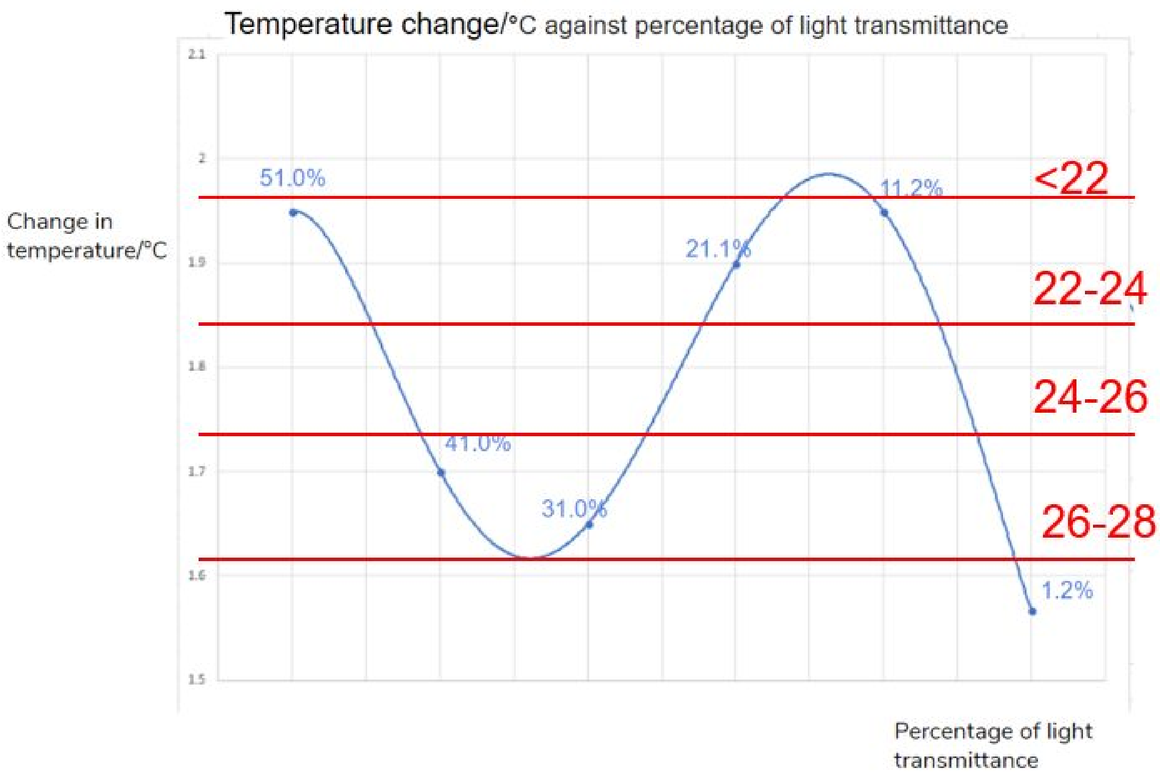

Figure 7c - graph showing optimal settings

The results obtained from the tests were then used to determine optimum settings for the glass to provide the best thermal comfort. With reference to the amount of lux required for different environments (Figure 7a), the team has come up with the optimum settings for the SMART glass for general use at different outdoor temperatures. (Figure 7b). This was achieved by finding the points of intersection on the graph with relation to the general temperature of maximum thermal comfort, which happens to be from 20 to 22 °C. For example, at outdoor temperature of less than 22 °C, the optimal settings would be calibrated for maximum thermal transmittance so as to allow the temperature outdoors to be as close as that of the indoors, providing optimal thermal comfort to the user.

Conclusion

The team has concluded that the relationship between the light transmittance and heat transmittance of electrochromic glass fluctuates in an unexpected manner. While further research to explain such unusual results can be carried out, it is beyond the scope of our project. However, a theory the team has come up with is that the transmittance of different wavelength of infrared can vary by varying transparency of glass, which may be due to the chemical properties of the glass. Using the results obtained from the experiments, the team has managed to come up with optimum settings for the SMART Glass in different environments to allow the SMART Glass to provide maximum thermal comfort for its users.

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