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# EFFECT OF SELECTED SHADING DEVICES ON OFFICE ROOM TEMPERATURE

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**ABSTRACT**

This study investigated the effects of selected shading devices on office room temperature. The experimental results were presented to show the thermal effects of coating systems used. Initial work for a duration of two months showed that high temperatures occurred during 10:00, 12:00 and 14:00 hours. The coating materials used, were plain glass pane with the thickness of 5 mm (control), tinted film, silver film, and blinds. Results showed that the differences in temperatures between the inside and outside of the office were 4.4$^oC$, 3.8$^oC$, 3.5$^oC$ and 2.9$^oC$ for silver film, blinds, tinted film and clear glass (5 mm), respectively. In terms of cost, the blinds proved to be low in cost with every temperature drop for temperature difference between internal and external temperatures. For every degree difference, silver coating would cost RM 6.80/$^oC$, tinted laminating RM4.57/$^oC$, blind RM 1.97/$^oC$, and clean glass (5mm) RM 1.90/ $^oC$ . RM is Malaysian Ringgit and 1Euro= 4.50 RM. In addition the blinds could be easily fixed comparatively.

**Keywords:** Window, laminating shading devices, Passive design

## 1. INTRODUCTION

Windows have long been used in buildings for the provision of day lighting as well as for supply of fresh air. Transparent or clear glass has been the primary material available for windowpanes. Traditionally glass has long-term durability, almost perfect surface finish and excellent transmission of daylight. Since Malaysia is located in the tropical zone near the Equator that extends from latitudes of 10$^o$ N to 23° N, where the weather is hot and humid throughout the year, resulting in huge heat loads for air-conditioning systems in modern large offices and commercial buildings. This means seasonal temperature difference is small. Daily temperature ranges from 23$^oC$ in the early morning to 32$^oC$ in the afternoon. Al-Homoud (1997) carried out an optimization study on building design variables to minimize annual energy consumption. Minimum glass area of 15% floor was the optimum in his research except in cold climate where larger glass area was required to utilize solar gain for heating. Lam and Li (1999) studied cooling dominated office buildings in Hong Kong. It was shown that the peak cooling load and the annual electricity consumption were reduced by 11% and by 13%, respectively, due to the use of day-lighting. Ismail and Henriquez (2001) presented a two-dimensional complete thermal mode for a ventilated glass panel with conduction, convection and radiation included in the analysis. Etzion and Erell (2000) described an experimental investigation of a novel glazing system, designed to overcome glare and radiation damage to interior furnishings. In summer, it may improve visual comfort even in spaces with large glazed areas facing East or West, while reducing undesired energy gains to a minimum. Bojic et al. (2002) discussed energy performance of different glazing types (clear, tinted and reflective) of windows with single pane types and different flat orientations. Ismail and Henriquez (2003) discussed a mathematical model with numerical simulations of the heat transfer across a simple glass window. Nielsen et al. (2001) presented a simple method to determine the net energy gain. Using the method, diagrams have been produced which give the net energy gain based on the orientation, the tilt, the U-value and the g-value of the glazing or windows. The results were compared to calculations with a detailed building simulation program. The comparison showed good resemblance between the energy savings found by the two methods. Mehlika et al. (2000) established optimum building aspect ratios and South window sizes of residential buildings for thermal performance in the cities in Turkey. Zahedi (2005) studied twenty-year weather data for Kuala Lumpur obtained from NASA to produce typical meteorological year (TMY) and he further confirmed that daily temperature is more pronounced than seasonal temperature difference. Weather data from Sivasankar (2006) has similar statement on daily temperature changes being larger than seasonal changes.

There is limited literature on laminating materials for glass window as a passive method to reduce heat loads of a building. Therefore the methodology adopted for this work is based on this research for using coating materials on windows as a passive method of reducing energy demand in an office room.

## 2. EXPERIMENTAL SET-UP

In this study, a lecturer's office was chosen where majority of the experiment was conducted. Which is located on the fifth floor of Administration Building, Faculty of Engineering, Universiti Putra Malaysia.

### 2.1. Investigated Building

The building selected for the present study was built in 2005 facing N 22 E. It is a seven storey fully air-conditioned building, which consists mainly of offices and study rooms. This building has demonstrated the use of large glass areas as shown in Figures 1.


Figure 1 Test window of office and location of test office

The interior dimensions of the test office are 4.03 m x 3.82 m x 2.61m. This office has been used to demonstrate the use of vertical glass area for the building façade and its dimensions are 2.18 m x 2.12 m x 5 mm. This vertical glass area is equivalent to 30% of the office floor, and it shows deviation from Uniform Building By-Law:1984 which states that window area must be 10% of the floor area. The test rig was made of aluminium angles and the rectangular rig has the dimensions of 2 m x 2.9 m x 2 m.

### 2.2 Installation of Thermocouple Wires

Thermocouples were located at 16 points in the rig for a set of measurements. Six points were put on the interior surface of the window, where three points of those were set at an equal distance of 2 meters above the floor, and three points at 1.2 meters at an equal distance above the floor as shown in Figure 3. Other ten points were located at vertical plane parallel to and 0.4 meters away from the window as shown in Figure 4. This was for the testing done at 10.00 am. With the six points fixed at the window, the second and the third sets of the 10 points were located at 1.2 and 2.0 meters away from the window for the case of testing performed at 2.00 pm and 4.00 respectively. The logic behind the placement of 10 points at three different distances away from the glass was ensued after carrying out some optimization. The reference junction was shielded to reduce radiation effects. Direct readings of temperature were obtained by the use of thermocouple meter, which had sixteen channels per set as shown in Figures 2 and 3.

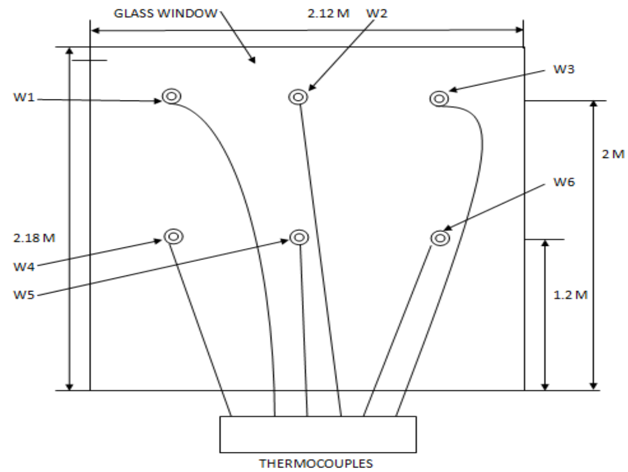


Figure 2 Thermocouple placement on the window surface

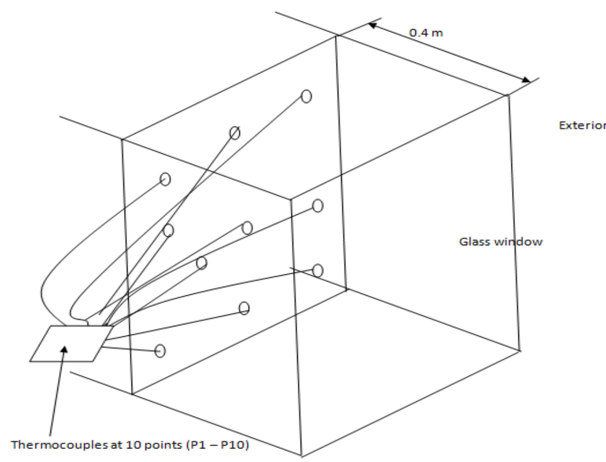


Figure 3 Thermocouples at 10 locations in the office 0.4 m away from the window at vertical plane (the procedure is repeated at distances 1.2 and 2.0 meters away from the window)

### 2.3. Measuring Equipment

The materials and equipments required for performing the experimental work are shown in Table 1.

### 2.4. Data Condition

The field measurement was taken from 12$^{th}$ July to 25$^{th}$ August 2006 which was the hottest period of the year in Malaysia from 9 am to 5 pm. The temperatures measured, were the air temperatures in the test office and also temperatures on surfaces of the window with different glazing materials, ambient temperature, air velocity, and relative humidity were measured in the test office as shown in Tables 2 - 12. Temperature difference presented in Table 10 is the difference between ambient temperature and average interior temperature.

Table 1 Materials and equipments used

| Materials/equipment | Details |
|---|---|
| Aluminium angles | To make test rig |
| Thermocouple wires | To measure air temperature in office |
| Air velocity meter | To measure air velocity (accuracy of 1.5% of maximum reading) |
| Switch meter box | To count flow/points measured |
| Psychrometer | To measure humidity inside the office |
| Thermometer | To measure air temperature (type ST-300-K) |
| Coating materials | Tinted coating, silver coating and blinds |

Table 2 Average interior temperature in test office of clear window (All temperatures in $^oC$)

| Time (h) | Distance (cm) | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ | $P_9$ | $P_{10}$ | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10:00 | 40 | 28.4 | 28.6 | 28.8 | 29.1 | 29.3 | 29.5 | 29.6 | 29.8 | 30.1 | 30.3 | 29.7 |
| 12:00 | 120 | 30.6 | 30.9 | 31.1 | 31.3 | 31.4 | 31.7 | 31.9 | 32 | 32.3 | 32.5 | 31 |
| 14:00 | 200 | 32.1 | 32.3 | 32.4 | 32.7 | 32.9 | 33.1 | 33.3 | 33.4 | 33.5 | 33.6 | 31.8 |

Table 3 Average interior temperature in test office of window with tinted film (All temperatures in $^oC$)

| Time (h) | Distance (cm) | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ | $P_9$ | $P_{10}$ | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10:00 | 40 | 29.5 | 29.7 | 29.8 | 29.9 | 30.1 | 30.3 | 30.5 | 30.8 | 31 | 31.3 | 30.5 |
| 12:00 | 120 | 30.6 | 30.8 | 30.9 | 31.1 | 31.3 | 31.6 | 31.8 | 32 | 32.3 | 32.5 | 31.5 |
| 14:00 | 200 | 31.6 | 31.8 | 31.9 | 32.2 | 32.4 | 32.6 | 32.7 | 32.8 | 33 | 33.2 | 32.5 |

Table 4 Average interior temperature in test office of blinds (All temperatures in $^oC$)

| Time (h ) | Distance (cm) | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10:00 | 40 | 29.2 | 29.5 | 29.7 | 30 | 30.3 | 30.6 | 30.9 | 31.1 | 31.4 | 31.5 | 30.5 |
| 12:00 | 120 | 30.5 | 30.7 | 30.9 | 31.2 | 31.5 | 31.7 | 31.9 | 32.2 | 32.5 | 32.7 | 31.3 |
| 14:00 | 200 | 31.7 | 31.9 | 32.1 | 32.4 | 32.6 | 32.9 | 33.1 | 33.3 | 33.5 | 33.6 | 32..3 |

Table 5 Average interior temperature in test office of window with silver film (All temperatures in $^oC$)

| Time (h) | Distance (cm) | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ | $P_9$ | $P_{10}$ | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10:00 | 40 | 28.2 | 28.5 | 28.8 | 29.3 | 29.9 | 30.2 | 30.4 | 30.6 | 30.8 | 30.9 | 29.8 |
| 12:00 | 120 | 29.9 | 30.2 | 30.5 | 30.7 | 31.3 | 31.2 | 31.4 | 31.7 | 32 | 32.2 | 30.8 |
| 14:00 | 200 | 30.7 | 30.9 | 31.1 | 31.4 | 31.6 | 31.8 | 32 | 32.3 | 32.4 | 32.6 | 31.5 |

Table 6 Comparison between internal surface temperatures, ambient air temperature and average interior air temperature for clear glass

| Time (h) | Glass temperature ($^oC$) | Average interior temperature ($^oC$) | Ambient temperature ($^oC$) |
|---|---|---|---|
| 10:00 | 32.5 | 30.5 | 31.9 |
| 12:00 | 34.8 | 31.5 | 33.9 |
| 14:00 | 35.7 | 32.5 | 35.4 |
| 17:00 | 33.5 | 29.5 | 31.5 |

Table 7 Comparison between internal surface temperatures, ambient air temperature, and average interior air temperature for tinted coating

| Time (h) | Glass temperature ($^oC$) | Average interior temperature ($^oC$) | Ambient temperature ($^oC$) |
|---|---|---|---|
| 10:00 | 33.5 | 29.8 | 32.4 |
| 1200 | 36.6 | 30.8 | 34.1 |
| 14:00 | 37.6 | 31.5 | 35.9 |
| 17:00 | 33.3 | 2.4 | 32.1 |

Table 8 Comparison between internal surface temperatures, average interior air temperature and ambient air temperature for blinds

| Time (h) | Glass temperature ($^oC$) | Average interior temperature ($^oC$) | Ambient temperature ($^oC$) |
|---|---|---|---|
| 10:00 | 33.5 | 30.5 | 32.8 |
| 12:00 | 35.3 | 31.3 | 34.2 |
| 14:00 | 36.5 | 32.3 | 36.1 |
| 17:00 | 32.6 | 28.6 | 30.9 |

Table 9 Comparison between internal surface temperatures, ambient air temperature and average interior air temperature for silver coating

| Time (h) | Glass temperature ($^oC$) | Average interior temperature ($^oC$) | Ambient temperature ($^oC$) |
|---|---|---|---|
| 10:00 | 33.5 | 29.7 | 31.7 |
| 12:00 | 37.2 | 30.8 | 33.5 |
| 14:00 | 37.5 | 31.8 | 35.3 |
| 17:00 | 33.6 | 30.1 | 32.3 |

Table 10 Comparison between the difference temperatures for all materials

| Time (h) | Temperature difference of clear glass ($^oC$) | Temperature difference of tinted glass ($^oC$) | Temperature difference of blinds ($^oC$) | Temperature difference of silver coat ($^oC$) |
|---|---|---|---|---|
| 9:00 | 0.7 | 1.5 | 1.8 | 2.4 |
| 10:00 | 1.4 | 2 | 2.3 | 2.6 |
| 11:00 | 1.8 | 2.4 | 2.6 | 2.9 |
| 12:00 | 2.4 | 2.7 | 2.9 | 3.3 |
| 14:00 | 2.9 | 3.5 | 3.8 | 4.4 |
| 16:00 | 2.3 | 2.5 | 2.7 | 3.2 |
| 17:00 | 2 | 2.2 | 2.3 | 2.7 |

Table 11 Parameters measured outside the room

| Time (h) | Velocity (m/s) | Humidity (%) | Time(h) | Velocity (m/s) | Humidity (%) |
|---|---|---|---|---|---|
| 9:00 | 0.02 | 66.4 | 13:30 | 0.03 | 57.4 |
| 9:30 | 0.05 | 66.4 | 14:00 | 0.02 | 57.5 |
| 10:00 | 0.02 | 66.4 | 14:30 | 0.02 | 57.2 |
| 11:00 | 0.02 | 57.6 | 15:00 | 0.03 | 57.2 |
| 11:30 | 0.04 | 57.6 | 15:30 | 0.03 | 57.5 |
| 12:00 | 0.04 | 57.5 | 16:00 | 0.02 | 57.4 |
| 12:30 | 0.04 | 57.1 | 16:30 | 0.03 | 57.4 |
| 13:00 | 0.02 | 57.4 | 17:00 | 0.02 | 57.4 |

Table 12 Parameters measured inside the room

| Time (h) | Air temperature (°C ) | Humidity (%) | Wind speed ( m/s) | Time (h) | Air temperature (°C ) | Humidity (%) | Wind speed ( m/s) |
|---|---|---|---|---|---|---|---|
| 9:00 | 30.1 | 77.7 | 0.58 | 13:30 | 35.8 | 68.8 | 0.42 |
| 9:30 | 30.9 | 74.4 | 0.47 | 14:00 | 36.1 | 50.6 | 0.86 |
| 10:00 | 32.8 | 65.2 | 0.56 | 14:30 | 35.8 | 59.7 | 0.18 |
| 10:30 | 33.1 | 56.5 | 0.27 | 15:00 | 34.7 | 53.9 | 0.22 |
| 11:00 | 33.5 | 62.2 | 0.27 | 15:30 | 33.9 | 62.7 | 0.35 |
| 11:30 | 33.7 | 61.9 | 0.58 | 16:00 | 32.6 | 56.6 | 0.21 |
| 12:00 | 34.2 | 64.9 | 0.55 | 16:30 | 31.5 | 64.9 | 0.56 |
| 12:30 | 34.7 | 23.7 | 0.15 | 17:00 | 30.9 | 68.8 | 0.42 |
| 13:00 | 35.5 | 68 | 0.3 | | | | |

## 3. RESULTS AND DISCUSSION

### 3.1 Distribution temperature of room and window surface using different laminating materials

Figure 4 presents the influx of air temperature through the clear glass with different laminating materials at 10 points (p1 to p10) in the test office. The temperature in the test office increased from 9 am till midday and decreased at about 5 pm. At noon, on a typical day, the average interior air temperatures were about 32.5°C for clear glass, 31.5°C for tinted glass, 32.3°C for blinds, and 31.8°C for silver coating (taken from Tables 6-9 and verified by Figure 4). The convective and radiative heat transfer rates from the front surface are high, since this surface gains a high amount of heat by radiation and conduction from the glass wall. Figure 5 shows the transient thermal performance of the surface glass temperature for six points in the center glass (W1 to W6) for clear glass, tinted, blind and (W1 to W4) for silver. The flow rate through glass in steady state was the highest at point (W4) in the center of clear glass, tinted, blinds and also at point (W2) for silver due to its very high absorptance and very low reflectance. At the noon time interior radiation level was reduced by absorptive glazing material to approximately 5% of the exterior level as mentioned by Etzion and Erell (2000).

In Figure 6, it could be seen that the average interior air temperatures of laminating materials (clear glass, tinted coating, blind, and silver coating), in the test room simulated at 10 am were 30.5, 29.7, 30.5 and 29.8 °C respectively. The temperatures increased at 12 pm to 31.5, 30.8, 31.3 and 30.8 °C respectively. The temperature peaks occurred at 2 pm and were recorded as 32.5°C, 31.6°C, 32.3°C and 31.5°C respectively. After that, the temperatures started to decrease until 4pm, noted as 30.6°C, 31°C, 29.9°C, and 30.6°C respectively.

Figure 7 shows the comparison among the heat transfer rates for internal surface temperatures for laminating materials (clear glass, tinted coating, blind, and silver), the ambient air temperature, and average interior air temperature in the test room. The internal glass surface and the ambient air temperatures were high and increased from 10 am to 2 pm. The maximum temperatures for both variables were observed at 2 pm. This was attributed to low reflectance and absorption of clear glass and high transmittance temperature into the test room. In addition emissivity radiation from the glass wall to the internal test room was very high. However the ambient air temperatures were higher. The blind has reduced the overall heat transfer rate through the window by reducing the thermal radiation from the indoor glazing. The blinds could lead to better designs of window/shading systems. In this study, the average interior air temperature in the test room was 32.5°C.

The temperature peak was at 2 pm. Figure 8 shows temperature difference between external and internal temperatures for four materials: glass, silver, blinds and plastic. It is observed that the temperature differences for silver, blinds, tinted plastic and clear glass (5 mm) increased respectively to 4.4 °C, 3.8 °C, 3.5°C and 2.9°C at 2 pm through windows with different laminating materials. As far design implication is concerned, the higher the temperature difference, the better the performance of the laminating material. Similar observations were obseerved by Etzion and Erell (2000) and Ismail and Henriquez (2003), where they studied transmission of radiant energy and thermal performance.

### 3.2. The Outdoor Environment Parameters

Figure 9 shows the relationship among air temperature (AT), relative humidity (RH) and wind speed (WS) outside the clear glass environment. The AT increased from 29.3 °C at 9:00 to 35.4 at 2:00 after which it declined to 31.5 °C at 17:00. Both RH and WS fluctuated with time with the maximum values of 77.5 % and 0.45 m/s at 11:00 respectively. The respective minimum values for RH and WS were 22.7 % at 15:00 and 0.22 m/s at 16:00.

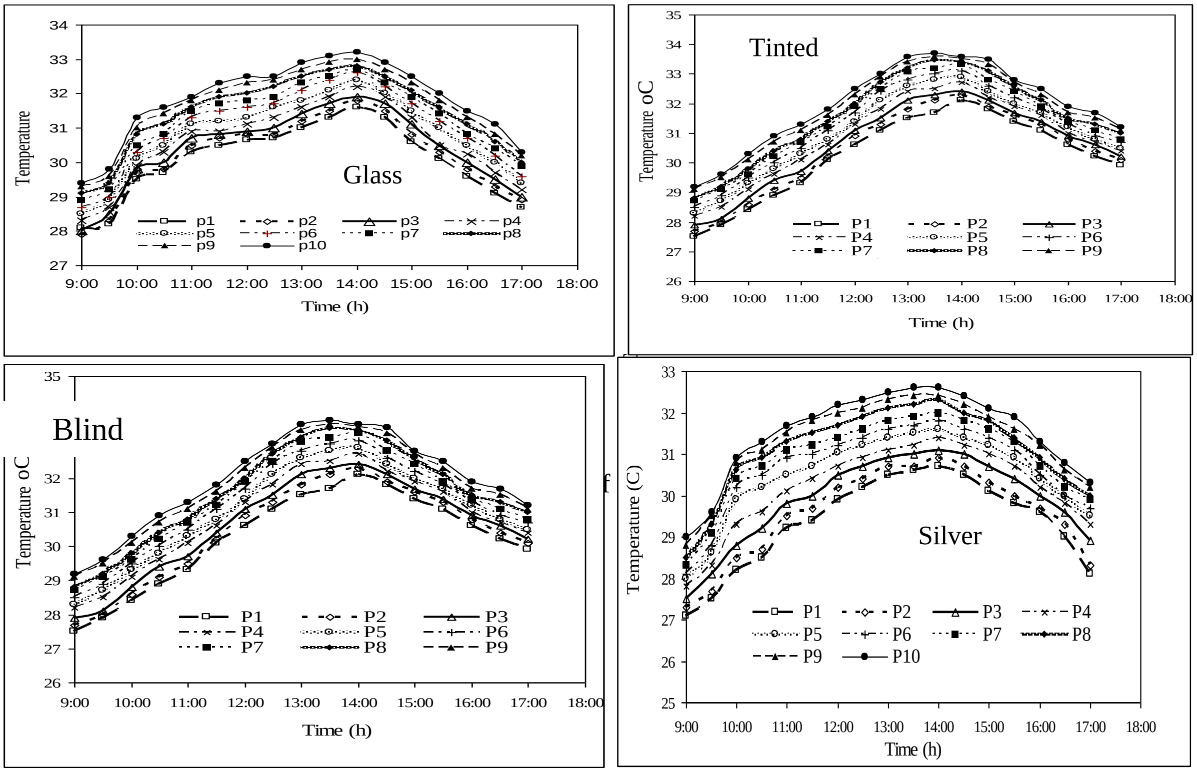


Figure 4 Temperature distribution of room for laminating materials

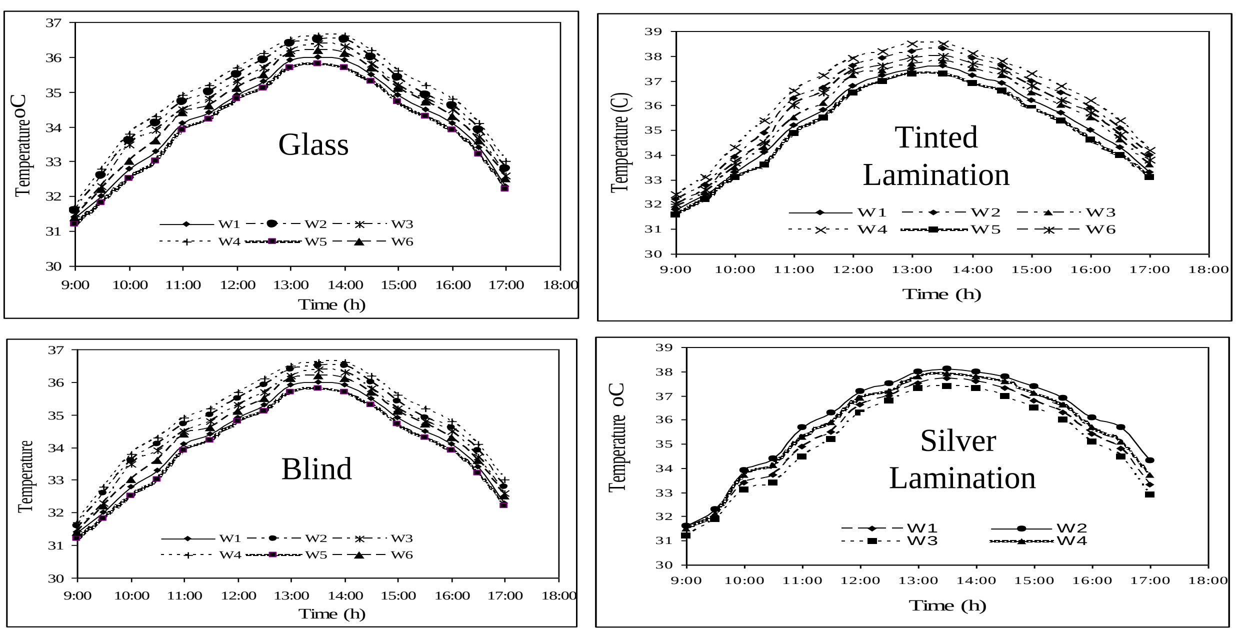


Figure 5: Internal surface temperatures for laminating materials

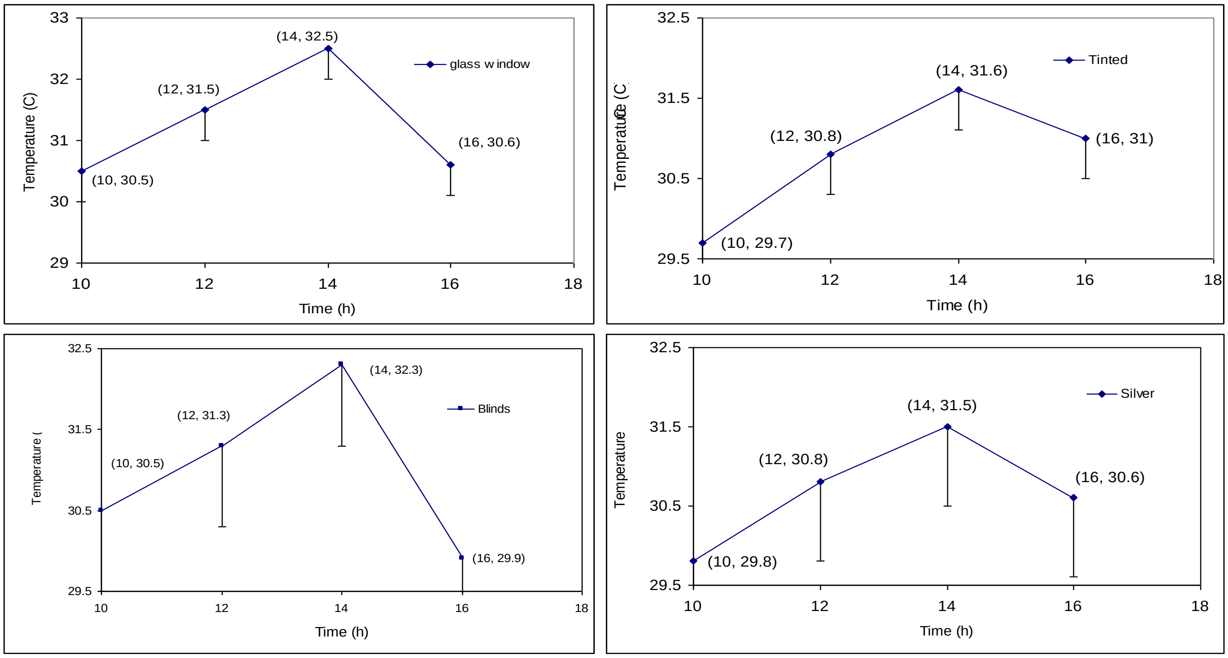


Figure 6 Average interior temperatures in test office (10 am, 12 noons and 4 pm)

**3.3. The Indoor Environment Parameters**

**3.3.1. Airflow/Velocity Rate**

There are various field data readings collected, based on close window condition. Velocity meter has an accuracy of 1.5% of maximum reading. The average indoor air velocity measurement was between 0.025 and 0.0435 $ms^{-1}$, the lowest was at 18:00, and the highest was at 09:00, which was around 0.043 $ms^{-1}$ as shown in Figure 9.

**3.3.2. Relative Humidity**

It could be seen that the average humidity reading in the office was around 57.3% to 66.4%; the lowest being at 12:00, 15:00 and 16:00. The highest was at 09:00 and it could clearly be seen through the graph shown in Figure 9.

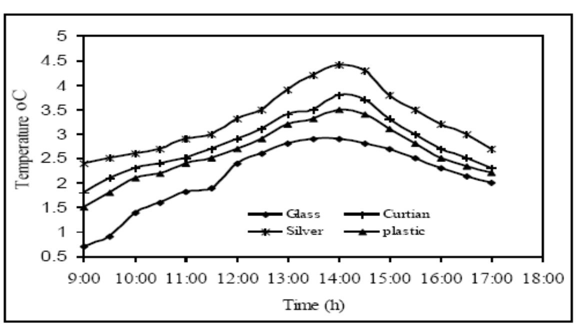


Figure 7 Comparison among the temperature differences for different laminating materials

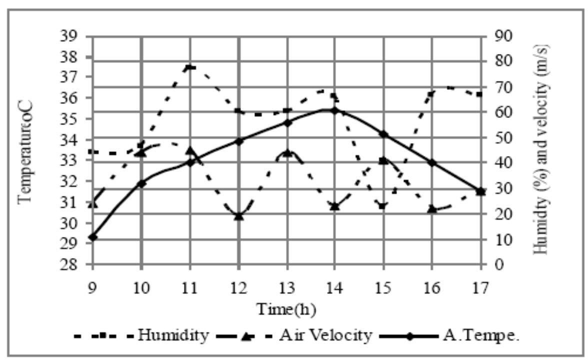


Figure 8 Graph of air temperature, wind speed, and humidity versus time

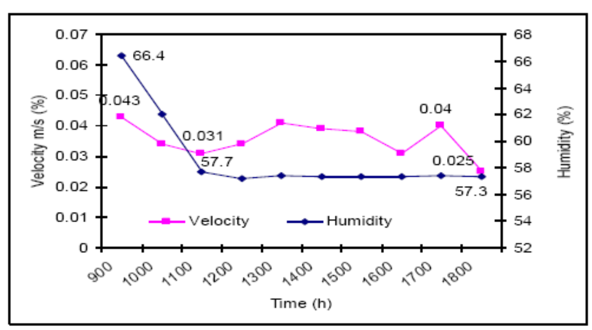


Figure 9: Graph of indoor air velocity, and humidity versus time

## 4. CONCLUSIONS

The results from the experiments along with the measured data were compiled in tables and graphs. Measurements of the interior air temperature, glass window temperature, air velocity, relative humidity and thermal comfort were taken. The field data readings collected were based on various conditions - clear glass, tinted glazing, silver glazing and blinds.

It was observed that the temperature increased in the office and the center glass with the increase in outside air temperature from 09:00 to 17:00 hour. The thermal effects of glass, with different laminating film coatings, are dependent on their optical properties: reflectance, absorption and transmittance.

The differences between average interior air temperatures and external temperatures at noon were respectively 4.4 $^{o}$C, 3.8$^{o}$C, 3.5$^{o}$C and 2.9$^{o}$C for silver coating, blinds, tinted coating, and clear glass (5 mm thick). From the experiment, the lowest interior temperature was found nearest to the glass window (40 cm) while the highest was observed furthest from the glass window (200 cm), while having different outside air temperatures from 09:00 to 14:00 under the four different laminating treatments. The experimental results generally show a lower interior temperature compared to exterior temperature of the test office. Silver has the best optical cooling properties compared to the other materials used in the study.

This work has investigated the effects of selected shading devices on an office room temperature distribution with a glass window. The highest temperature occurred at 14:00. The temperature differences between the inside and outside environment of the office were respectively 4.4$^{o}$C, 3.8$^{o}$C, 3.5$^{o}$C, and 2.9$^{o}$C for silver coating, blinds, tinted coating and clean single glass (5 mm). For every degree difference, silver coating would cost RM 6.80/$^{o}$C, tinted lamination RM 4.57/$^{o}$C, blinds RM 1.97/$^{o}$C and clean glass RM 1.90/$^{o}$C. The data has shown that using blind was the cheapest material.

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