Multiple Film Based Daylight Control System

Vishal Garg, Dipti Shiralkar, K. Prabhakara Rao

Center for IT in Building Science, IIIT-Hyderabad, Hyderabad, India

Corresponding email: vishal@iiit.ac.in

SUMMARY

A multiple film based daylight control system for window has been developed to maintain the illuminance level at task plane. The developed system consists of three films with a visual transmittivity (Tvis) range of 0.159 - 0.015 and a 2x55W dimmable compact fluorescent lamp (CFL) fixture. The system works on the principle of feedback control, which records the changes in light intensity with the help of photosensor placed on the ceiling and facing the task plane and accordingly adjusts the film-position as well as the control voltage of dimmable CFL to maintain the task plane illuminance within a tolerance of -10%, +20% of setpoint. Optimized use of solar illuminance saves energy used for the task lighting for the period from 8:00 to 19:00, which was found to be about 70%. The paper describes the design, implementation of the proposed system and the preliminary results for task light illuminance and energy savings achieved in laboratory setup.

INTRODUCTION

Window in a building provides daylight, ventilation and the outside view. A well designed fenestration system usually provides sufficient daylight during the day but it suffers with the problems of glare and heat. Usual glare control strategies deploy blinds or curtains which are not automated and require frequent manual intervention, hence most of the time these systems are kept closed [1]. Moreover, these systems block the outside view and cause lighting energy consumption when they are controlling the excess daylight [2]. Every household and firm spends about 20% of its annual energy budget for lighting purpose [3], [4]. Thus a need arises to develop smart light-controllers [5] for windows which not only maintain a constant light intensity in the room within the comfort levels of the occupants but also decrease glare and maintain outside view for the room. Field studies for such control systems have been done as discussed in [6], [7]. Emerging technologies such as electrochromic windows [8] satisfy the purpose of glare protection and clarity of outside view but they are expensive. The proposed system is not only cost-effective compared to electrochromic windows, but also provides the constant task lighting with the tolerance of -10% to +25% of setpoint with minimized glare.

The controller system was built and installed at the Center for IT in Building Science at International Institute of Information Technology, Hyderabad. The setup consists of a single room with a door, three windows and three twin lamp fluorescent fixtures along with a 2x55W dimmable CFL fixture. The system consists of three films of varying visual transmittivity, joined with each other at ends forming a long sheet and rolled over two rollers. By rolling both the rollers, the system can cover the window with different type of films and thus controlling the
amount of daylight entering into the room. If required illumination at task plane is not being satisfied by sun light even after placing the most transparent film then the system can top up the task plane illuminance by operating dimmable CFLs. A graphical user interface has been provided on mobile phone, using which user can set the comfort value of task plane illuminance.

This paper describes the design and implementation of proposed system and the preliminary results of energy saving as well as the clarity of outside view achieved in laboratory setup.

METHODS

Laboratory setup

A room of the dimensions 5m x 10m with ceiling height of 4m was instrumented and configured to test the multiple film based daylight control system. The room consists of three windows W1, W2 and W3; and three fluorescent fixtures T1, T2 and T3 and a 2x55W dimmable CFL fixture with a control voltage range of 0-10V shown in figure 1. The CFL fixture has been placed at a distance 1.3m from ceiling and 1.7m from task table above W2 at a distance of 0.305m from the vertical wall containing W2.

![Experiment room layout](image)

Figure1: Experiment room layout

Hardware setup

A National Instrument’s data acquisition card (DAQ) PCI-6229 [9] was used for the setup, which has 32 analog input, 4 analog output channels and 4 digital ports.

The sheet of three films was rolled on two rollers. These rollers were connected to gears whose direction and duration of rotation was controlled by stepper motors. The sheet consisted of three tinted films each of varying transmittivity. The darker film was attached below the lighter one to provide less sun light at level of eyes [10].

A lux meter was placed at the centre of the task table which was used to monitor the actual illuminance on the table. A photosensor was installed in between two dimmable CFLs. The
downward-facing, shielded photosensor sends out a proportional signal in response to the illuminance level within its field of view. The sheet used for daylighting control consisted of three different films each of different Tvis. Transmittivity of the three films comprising the controller are 0.159 (Film A), 0.055 (Film B), 0.015 (Film C).

Figure 2: Photograph of installed system

**Control Algorithm**

System is designed to maintain the total illuminance from the artificial lights and daylight within the setpoint illuminance range and to block direct sun by adjusting the sheet position and control voltage of dimmable CFL.

Four correlations were required to determine the daylight and electric lighting contributions to the task plane illuminance in the space, where the average of illuminance at four points on task plane at a distance of 0.30m, 0.60m, 0.90m, 1.20 from window W2, Iavg, was used as the benchmark as suggested in [11]:

1. Correlation between lighting power consumption (W) and Iavg, electric lighting only.
2. Correlation between photosensor signals (V) to Iavg, electric lighting only.
3. Correlation between photosensor signals (V) to Iavg, daylight only.
4. The ratio of measured task plane illuminance to measured illuminance by photosensor as M factor [12] for any given instant in time for all three films.
Figure 3: The correlation between electrical power consumption (W) and I avg, electric lighting only. This shows the average task plane illuminance measured at night by varying control voltage of dimmable CFL.

Formula (1) calculated from night calibration is used to calculate the illuminance caused by artificial lighting during the experiment by using the control voltage given to the dimmer

\[
y = 0.1711x^4 - 4.2481x^3 + 34.541x^2 - 39.846x + 78.923 \quad R^2 = 0.9999,
\]

\( y = \text{Task plane illuminance}, \ x = \text{Control voltage to dimmer of CFL} \) \hfill (1)

Figure 4: Correlation between photosensor (V) to I avg, electric lighting only, with photosensor on top and lux meter on table.

Figure 5: Correlation between photosensor (V) to I avg, electric lighting only, with both the sensors on top. The correlation shown in Fig. 4 has photosensor output in the range from 0V to 0.35V and gives a non-linear relationship with task plane illuminance. But it was observed that during the experiment photosensor output remains in the range of 0V – 0.1V. To get more accurate readings in this range both photosensor and sensor of lux meter were kept on the top, downward facing. This correlation gives the formula (2), which is used to convert photosensor output to Lux within this range.

\[
\text{Lux} = 481.79 \times \text{voltage} - 4.0574 \quad (2)
\]
Figure 6: Correlation between photosensor signals (V) to Iavg, daylight only. This shows that the light distribution is uneven as lower film is darker than upper film, hence average light distribution has been considered.

Figure 7: The ratio of measured task plane illuminance to measured illuminance by photosensor considered as M factor for any given time instance for all three films. This shows how M factor changes for different films at different times of the day. During the experiment the task plane illuminance was calculated by multiplying the lux output calculated from formula (2) with this M factor for Film A, which changes every hour.

The algorithm which has been implemented using in LabVIEW is as follows:
1. Output of photosensor in voltage is converted to Lux using formula (2).
2. Multiply photosensor reading of illuminance by M factor for that time of the day to get task plane illuminance.
3. Calculated task plane illuminance is compared with user setpoint. If it is not in the tolerance range of -10%, +20% of setpoint then appropriate signals are sent to rotate motor and to change the signal voltage of dimmable CFLs.

The main objective of the controller is to attain the setpoint as quickly as possible. The illuminance output of dimmable CFL can be maneuvered quickly and with much ease as compared to the tinted film positioning. Thus by varying the signal voltage by 0.2V, the CFL
output is set as the primary light source till the task plane illuminance comes in the tolerance range of setpoint and till this point of time, the film is the secondary light source. The signal voltage is changed with a small value so as to avoid the fluctuations. Once the tolerance range has been attained, the film is made the primary light source by slowly changing dimmer voltage and repositioning the film until end of sheet comes. The end of sheet has been detected by the amount of time for which film is rotating in a direction. If end of sheet is reached on either side of the film and the instantaneous light intensity is not within the tolerance range, then the dimmer voltage is adjusted to provide the light intensity within the range of setpoint.

**Graphical user interface on mobile phone**

A graphical user interface has been provided on the mobile phone using which user can change the setpoint of task plane illuminance as shown below in Fig. 8. The GUI has been developed for phones supporting Symbian[13] series by using symbian C++. User can enter the value of setpoint either using key pad or value can be incremented or decremented with help of joystick. After entering the setpoint when user presses the “Done” key, the value of setpoint gets transferred to computer via bluetooth.

![Graphical user interface on Mobile Phone to change the setpoint](image)

**RESULTS**

**Reference Case**

In the Reference case, the control voltage of dimmable CFL was at its maximum to achieve the setpoint of 500 lux, which consumes 124W power. The other three fluorescent tubes were also in their ON state and the W1, W2 and W3 were kept covered with opaque blinds to avoid the glare caused by the daylight and to determine the power consumption by the artificial light sources.

**Monitored Data**

The objective of the controller was to maintain the light intensity of the room within the tolerance range. The test value of the illuminance was set at 500 lux which maintained task light in the range 450-600 lux. During the test three fluorescent fixtures T1, T2 and T3 were kept ON and windows W1 and W3 were kept covered with opaque vertical blind. It was found that the controller was able to maintain the task plane illuminance within the designated range for over 99% of the test time.
Figure 9: (Plotted with reading at every 10 seconds)
(a) Task plane illuminance for different timings during the experiment on a typical day
(b) Difference between calibrated and measured task plane illuminance
(c) Power consumption during the experiment by dimmable CFL. The average power consumption was 36.7W and reference case power consumption was 124W. Hence about 70% task light saving was achieved.

DISCUSSION

Controller Performance

The controller was tested on three aspects. First, how effectively can it maintain the room intensity within the tolerance range of setpoint, second, how much task lighting energy was saved and finally, the controller was evaluated by the user feedback as to whether it caused any type of discomfort. It was observed that the system was able to maintain task plane illuminance within the tolerance range for over 99% of the test duration irrespective of the local and global solar radiation intensity. Secondly, as explained in Fig. 9(c), about 70% task light saving was achieved with the base case of CFL being lit at the maximum intensity. Finally, user feedback was taken on comfort aspect achieved by the controller. It was found that the initial algorithm maneuvered the dimmer voltage in the large steps and this caused user some amount of discomfort. The algorithm was then refined to employ a ramp function for the dimmer voltage. The second point of discomfort was caused by the noise of the rollers maneuvering the sheet.
This noise was minimized by keeping the sheet and rollers in between the two pans of the double glazed window.

**Conclusion**

Multiple film based automated day lighting control system is a cost-effective solution for smart fenestration systems which not only provides dynamic sunlight control with glare reduction but also saves energy. As the sheet is in between the two pans of the double glazed window by using reflective films, the amount of heat entering the room can be reduced. The corresponding tests have to be performed to give the savings of air-conditioning in the room. The technology has potential to be used commercially. Pilot studies will help refine the technology.

**ACKNOWLEDMENT**

We wish to acknowledge research students in the Center for IT in Building Science, Murari Hari Babu and K. Niranjan Reddy for their assistance during the hardware setup and preparing figures.

**REFERENCES**

3. [http://www.epa.gov/greeningepa/content/energy/doepart2.htm#piechart](http://www.epa.gov/greeningepa/content/energy/doepart2.htm#piechart)