ADAPTIVE LOW-E DOUBLE GLAZING WINDOW

Hussein Abaza[1] and Ihab Sa'ad[2]

ABSTRACT

This paper investigates the thermal performance of a new adaptive window which is seasonally reversible. The new window is similar in construction to the regular double-hung low-e windows, but can reverse its properties. In this window, the low-e coating faces the inside during the heating season, which reflects the infrared radiation to the inside. During the cooling season, the low-e coating faces the outside to reflect the outside heat. This window was tested in two test cells to evaluate its thermal performance. WINDOW5.2a software was used to predict the window thermal properties and BEANS building simulation software was used to predict the energy savings of the new window design. The simulation results showed an increase in the heat gain through the new window of up to 38% over the conventional double-glazing low-e window during the heating period for heavy thermal mass buildings, and 14% for light weight thermal mass buildings. At the same time, the window maintained its low heat gain properties in the cooling season . When used in moderate climates, the new adaptive window will significantly reduce energy consumption in buildings during both the heating and the cooling seasons.

KEYWORDS

low-e, window, glass, adaptive, energy, efficiency, simulation

BACKGROUND

Improving the performance of windows is an attractive pursuit for researchers as well as manufacturers in many disciplines. The goal is to improve the heat reflectancy of the glass, increase heat flow resistance through windows, and improve window constructability. Much research was conducted to produce energy efficient glass types that improve solar reflectancy while maintaining a high level of light transmittance (Bally 2002). The double pane low-e glass window is the leading window design in this effort. It consists of two panes of glass which are separated by a cavity filled with an inert gas. In hot climates, a low-emissivity coating is usually applied on the outside glass pane and on the surface that faces the air cavity (surface 2) as shown in Figure 1, thus reflecting heat to the outside and reducing heat gain through windows. In cold climates, the low-e coating is applied to the cavity side surface of the inward glass pane (surface 3) and thus reflects heat to the inside. In moderate climates, however, standard low-e glass can either serve the cooling or the heating season, but not both seasons at the same time.

The efforts to produce glass windows that change their properties to adapt to the heating and cooling loads have led to the production of several switchable glass systems. The first type of switchable glass is the electrochromic glass (Goldner 1988). This glass runs on very low voltages and changes its thermal and optical performance by the action of an electric field. However, it changes back when the field is reversed. A second type of switchable glass is the liquid crystal glass (Glassonweb 2006). When current is applied, this material changes from translucent to relatively clear. This glass is useful for privacy control, but does not provide any significant change in thermal performance and does not affect energy savings. In addition, to maintain a clear state, the voltage has to be continuously applied. A third type of the switchable glazing is the thermochromic glass, which changes properties in response to changes in ambient temperature (Kato 2003). As this glass gets warmer, it

1. Assistant Prof., Department of Construction Management, College of Technology and Computer Science, East Carolina University, NC 27858, USA, abazah@ecu.edu.
2. Assoc. Prof., Department of Construction Management, College of Technology and Computer Science, East Carolina University, NC 27858, USA, saadi@ecu.edu.

changes from clear to diffused white and becomes reflective. A fourth type is the photochromic glass that darkens in the presence of light (Zyabnev 1995). This is the same technology that has been used for years in optical glasses. At present, this glass is still uneconomical for general applications. This glass is also suitable for glare control, but not so much for solar heat gain as it tends to reduce only the visible portion of the spectrum.

Currently, switchable glazing is not yet a mature product. In addition, these glass types are relatively expensive and require electric power sources (Pacific Gas and Electric Co. 2006). In order to control heat gain through windows, some window designs are integrated into the building mechanical systems. In these designs, shading devices and mechanical control devices are incorporated and connected to a central building control system which controls solar radiation gain in the buildings (Kosny 1998).

Windows usually have lower thermal resistance when compared to the rest of the exterior building walls, which creates two problems. The first problem is condensation on the window surfaces. To solve this problem, designers typically place air registers or heating radiators near the windows, which increase the internal glass surface temperature. It can also increase air circulation in front of windows which helps in removing the condensation from window surfaces.

Applying low-e coating to the outside glass (surface 2) is favorable in the cooling season, but has adverse effects during the heating season because it lowers the internal surface temperature of the glass. For example, ASHRAE Fundamentals Handbook (ASHRAE 1997) shows that a 1/8 low-e 0.2 on surface 2 would have a Solar Heat Gain Coefficient (SHGC) of .65, while the same glass would have a SHGC of .81 if the 1/8 low-e 0.2 is on surface 3. In addition, the room air temperature is usually uniform throughout the space. However, glass tempera-

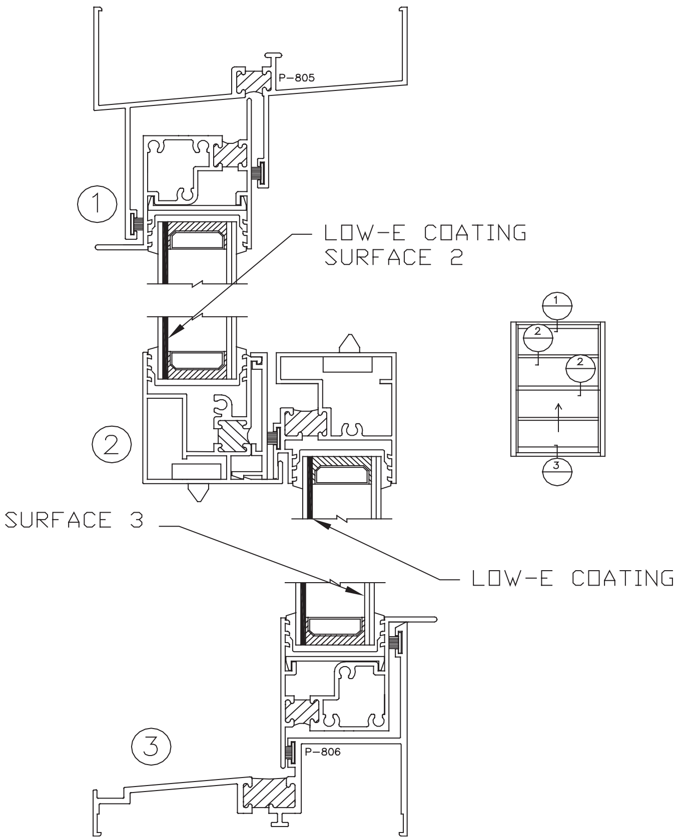


FIGURE 1. Typical window construction which is used in test cell one.

ture is usually lower in winter, which means a lower mean radiant temperature near the window and less thermal comfort. To overcome the feeling of discomfort, users tend to lower the curtains inside buildings. However, lowering window curtains reduces the daylight, which can lead to an increase in energy consumption.

THE NEW WINDOW DESIGN

The suggested window design is based on a simple concept. As with regular low-e windows, the window has two layers of glass. The first is low-e coated glass, and the second is conventional uncoated glass. As with the conventional low-e double-glazing window, the low-e coating faces outward on surface 2, Figure 1. The new window design can be reversed, which makes the reflective glass pane face inward on surface 3. Thus, solar radiation will be trapped between the two glass layers, which can increase the air temperature in the cavity between the two glass layers and also increase the internal glass surface temperature, Figure 2. This new window design then would help in solving the condensation problem in windows and improve the comfort level. At the same time, the new design would also increase solar heat gain through the windows during the heating season.

The new window requires minor changes to existing window designs. Figure 1 shows typical window construction. This double hung window was originally designed to rotate around its horizontal hinge for cleaning and natural ventilation purposes. Figure 2 shows the proposed modifications to the window, which allows for reversing its glass faces.

PERFORMANCE TEST METHODOLOGY

Computer simulation and field-testing were used to test the energy saving in using the new reversible window. The computer simulation model compared

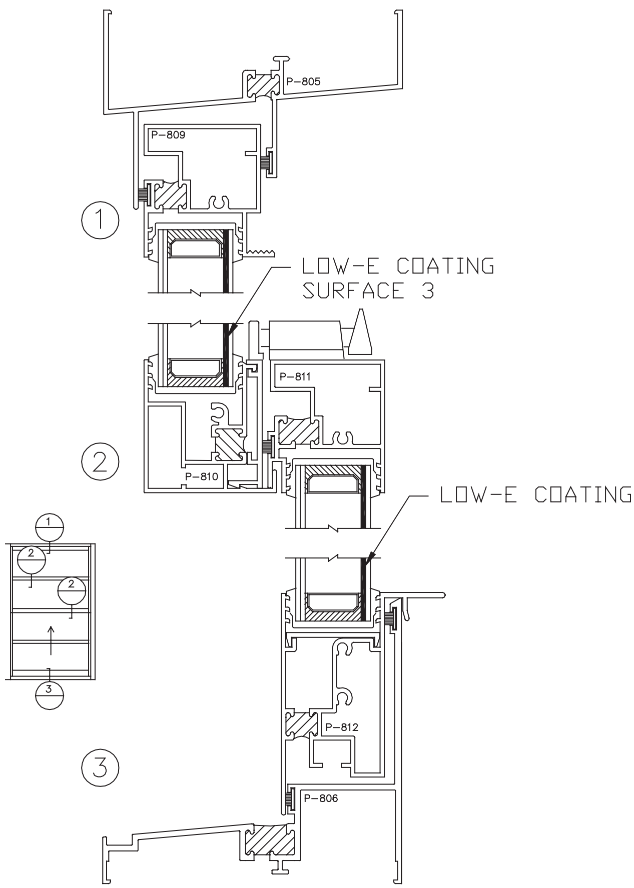


FIGURE 2. The proposed new window construction which is used in test cell two. Source: Online catalog, Boyd Aluminum Manufacturing Co.

the annual energy saving in both a conventional low-e window (conventional) and the reversible window (new), but with the low-e coating applied to different surfaces as explained below.

In order to validate the simulation model, two identical test cells were constructed, placed in the outdoor environment, and monitored. Each test cell consists of 2m x 2m x 2m high chamber with a 2m x 2m window facing south. The walls of the test cells were constructed of 12.5mm gypsum board on the inside, 75mm polystyrene thermal insulation between 38mm x 89mm wood studs, vapor barrier, and white vinyl siding on the outside. The windows used in the test cells consist of two layers of 6mm clear glass with 13mm argon gas in between. In test cell one, the low-e coat was applied on surface 2 consistent with Figure 1. In test cell two, the low-e coat was applied on the surface 3 consistent with Figure 2. The low-e glass that was used in the test cells has the following properties:

Tsol 0.357	Rsol1 0.447	Rsol2 0.274,
Tvis 0.752	Rvis1 0.0397	Rvis2 0.0536

The properties of the clear glass pane which was used in the test cells are as follows:

Tsol 0.770675	Rsol1 0.069976	Rsol2 0.0702
Tvis 0.883	Rvis1 0.080	Rvis2 0.080

where:

Tsol = Solar transmittance of the glazing layer

Rsol1 = Solar reflectance of the glazing layer, exterior-facing side

Rsol2 = Solar reflectance of the glazing layer, interior-facing side

Tvis = Visible transmittance of the glazing layer

Rvis1 = Visible reflectance of the glazing layer, exterior-facing side

Rvis2 = Visible reflectance of the glazing layer, interior-facing side

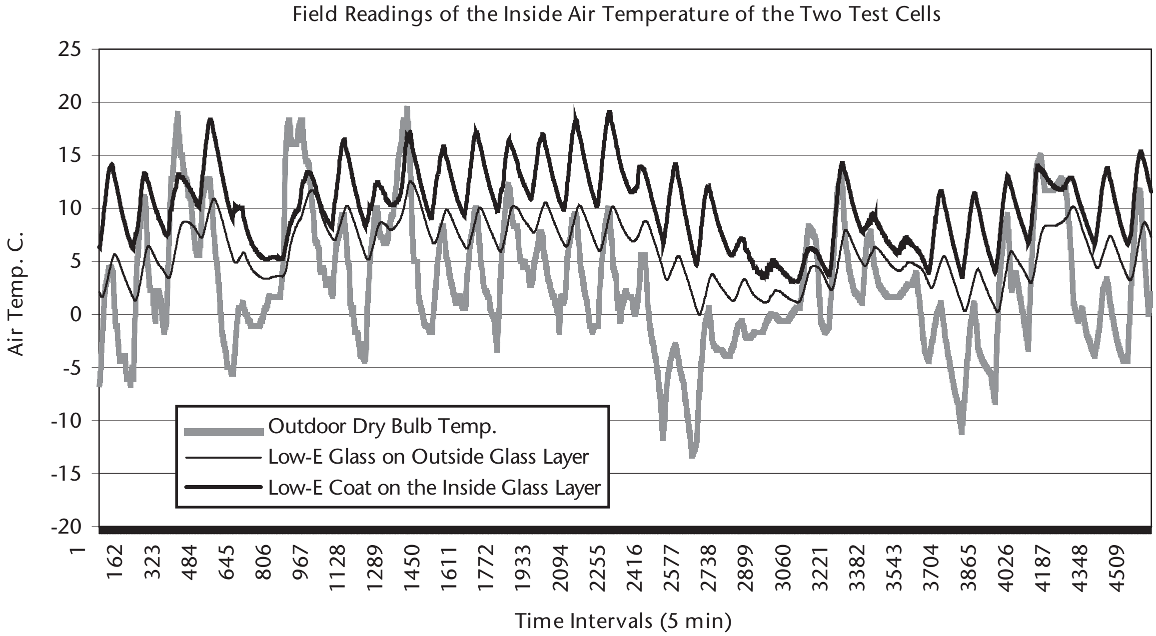
To insure similar conditions in both cells, the two test cells were placed in the outdoor environment for a period of ten days before collecting data. One thermocouple was installed inside each test cell and also in a shaded area outside the test cells to measure the outside air temperature. The thermocouples were connected to a data-logger to record the air temperature readings (Figure 3). Since the scope of the field test was to validate the simulation model, and to test the performance of the reversible window, the test cells did not contain air conditioning or internal heat gain.

TEST CELL THERMAL SIMULATION

First, the window properties were tested using WINDOW 5.2a software. This software is a state-of-the-art computer program developed at Lawrence Berkeley National Laboratory (LBNL) to determine the thermal and solar optical properties of glazing and window systems. This software uses algorithms consistent with ASHRAE SPC142 and ISO15099 (Window 2006). Second, the test cells were simulated using BEANS simulation tools. BEANS is a comprehensive building energy simulation software developed and used by Arup Company (BEANS 1997). To validate the simulation model, the weather data file used in the simulation was modified to match the weather conditions during the simulation. The air temperature was modified to match the measurements in the field. Solar radiation and wind speed data were modified to match the data that was obtained from the nearest local weather station which was approximately 30 miles from the test site. To calibrate the simulation results, the indoor air temperature of the measured test cells was compared to the readings obtained from the building simulation. Infiltration rates and some material properties of the test cell were also modified for calibration purposes. After calibration, the difference between the measured and the simulated indoor air temperature was 4%.

After calibrating the simulation model, weather data for Raleigh, North Carolina was used in the simulation. This location has mild winters and relatively hot and humid summers. The default comfort indoor conditions were used in the simulation with no internal heat gain. The test cell was simulated using different BEANS energy analysis tools. BEANS tools include the ROOM simulation tool, which simulates thermal comfort and mean radiant temperature inside the room, WINDOW simulation tool, which simulate heat transfer through windows, and the THERM simulation tool that simulates the annual heating and cooling load of the test cell. The simulation model was verified with the field data which represent light weight construction.

FIGURE 3. Field data of the air temperature inside test cell one (low-e glass on outside glass layer), test cell two (low-e coat on the inside glass layer) and the outside air temperature.



Since the BEANS simulation tool uses the mean average hourly weather data in the simulation, the new reversible window was simulated for a full month without reversing the window glass during the simulation. In real life, users can reverse the window face during hot days or as required, which leads to more energy saving than the computer simulation may predict. Users can also reverse the window face during cold hours, which may also save energy and improve comfort. However, it was not possible to simulate these activities with the BEANS simulation tools.

RESULTS

WINDOW 5.2a software results showed that when the low-e coating was applied on surface 2 as in test cell one, the window performance was as follows:

U value: 1.35 W/m^2-K SHGC: 0.35
Vt: 0.67 RHG: 264.89 W/m^2

When the low-e coating was applied on surface 3 as in test cell two, the window performance was as follows;

Uvalue: 1.35 SHGC: 0.45 Vtc: 0.67
RHG: 336.58 W/m^2

where:

RHG = Relative Heating Gain
SHGC = Solar Heat Gain Coefecient
Vt = Visible Transmittance

These results suggest that in the presence of solar radiation, the net relative heat gain from the window in test cell two was 71.7 W/m^2 or 27% more than that of test cell one. The field testing and annual thermal simulation were used to predict the potential annual energy saving of the new window. When comparing the field readings of the indoor air temperature in the two test cells under the same outdoor weather conditions, the average air temperature in test cell two was 5.9°C, while the average air temperature in the test cell one was 10.17°C. This suggests significant heat gain was achieved when locating the low-e coating towards the inside as in test cell two versus placing the low-e coating towards the outside as in test cell one (Figure 3).

Since many of the proposed characteristics of the reversible window are similar to the regular low-e window, the simulation results showed that both test cells performed the same during the cooling periods.

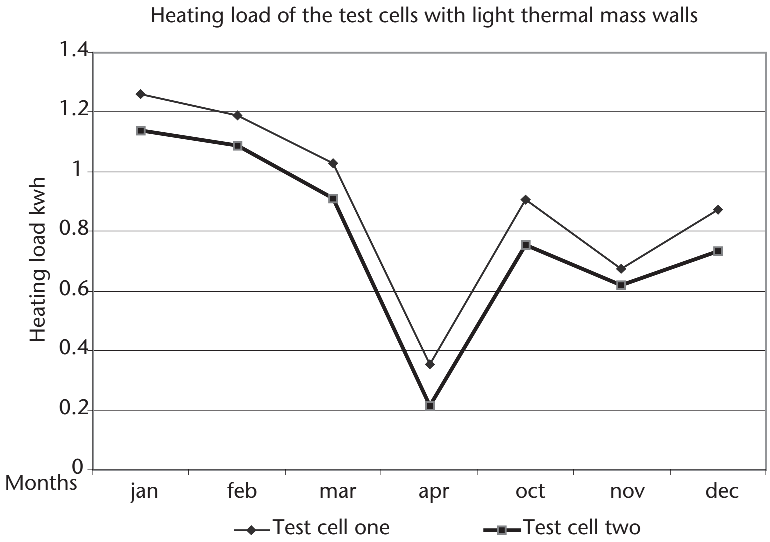


FIGURE 4. Summary of the simulation results that show the average heating load of test cell one and test cell two with light thermal mass walls.

The required heating energy to maintain the air temperature in the test cells within the comfort level during the heating season (heating load) in both test cells was examined. During the heating season, the heating load of the test cell one was approximately 13% higher than that in test cell two, see Figure 4. The simulation model was modified to represent heavy weight construction. The simulated test cell walls were replaced with 203mm concrete masonry units, 75mm polystyrene and 12.5mm gypsum board on the inside. When heavy weight construction is used, the simulation results showed that the heating load in test cell one was approximately 38% higher than that in test cell two, see Figure 5. The simulated hourly solar radiation which is transmitted through the new window in test cell two and that for the conventional window in test cell one are presented in Figure 6 and Figure 7 respectively. During the heating season and in the presence of the solar radiation, higher solar transmission rate in both long wave and short wave spectrums were obtained when using the new window as in test cell two (Figure 6) over the conventional window as in test cell one (Figure 7). Thus, the new window increases the heat gain through the window and reduces the heating load during the heating season.

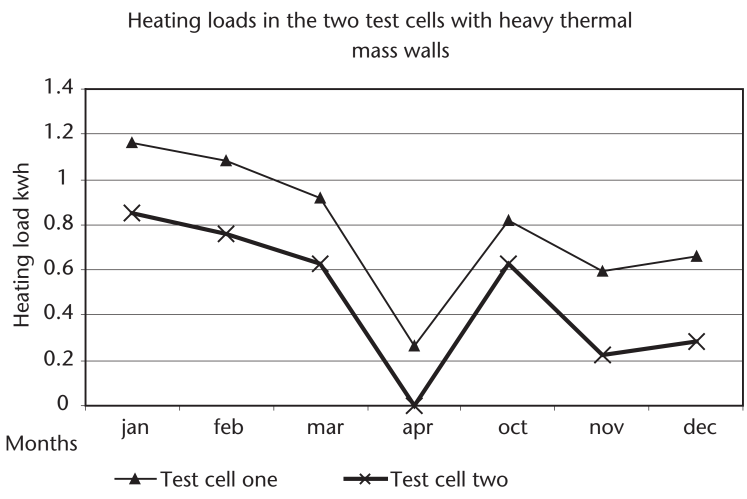
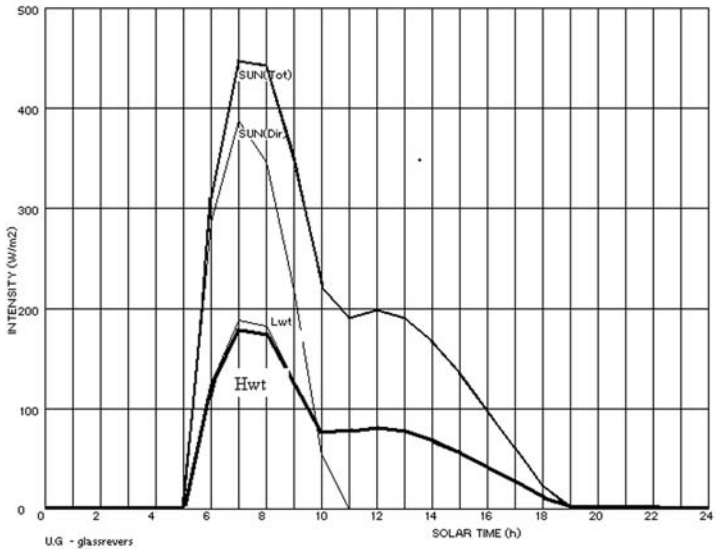


FIGURE 5. Summary of the simulation results that show the average heating load of test cell one and test cell two with heavy thermal mass walls.

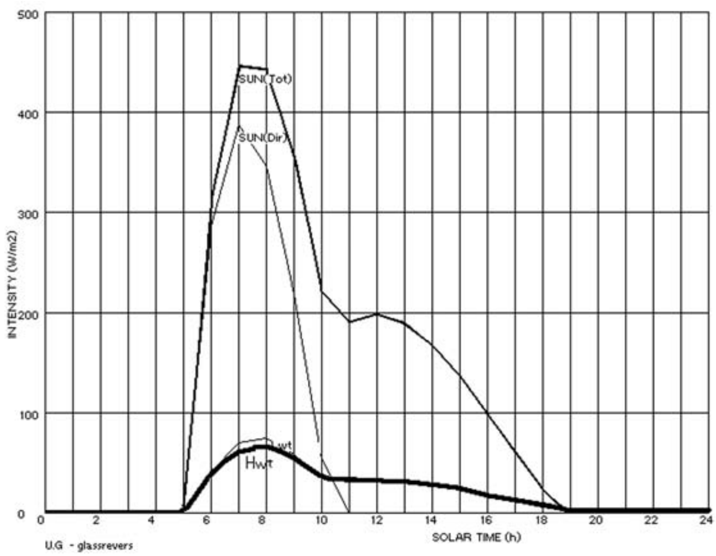
FIGURE 6. Simulation results of the solar radiation transmission through the new window as installed in test cell two.



Sun(Tot): Total solar radiation transmission
Sun(Dir): direct solar radiation transmission
Lwt: long wave radiation transmission
Hwt: Short wave radiation transmission

The research results also suggest that the reversible window design can reduce condensation on windows significantly. For example, during winter and when the indoor air temperature in a typical building is 18°C and the relative humidity is 40%, the psychometric chart shows that condensation would occur on the glass when its temperature reaches 5.5°C. During the field test period, the glass temperature of cell one reached a temperature of less than 5.5°C for 11% of the testing time compared to 46% of the testing time in test cell two. Although these results suggest a significant increase in glass surface temperature, the test cells were not maintained at comfort conditions during the testing period. Thus, the condensation effect may vary in controlled environments. The simulation results also showed an increase in the glass surface temperature with the low-e glass facing inside. During the heating period, the simulation results showed that when low-e coating was on surface 3 as in test cell two, the inside

FIGURE 7. Simulation results of the solar radiation transmission through a standard low-e window as installed in test cell one.



Sun(Tot): Total solar radiation
Sun(Dir): direct solar radiation
Lwt: long wave radiation transmission
Hwt: Short wave radiation transmission

glass surface temperature reached up to 12°C higher compared to that in a window with the low-e coating on surface 2 as in test cell one. Exterior walls were also simulated and showed that the interior surface temperature of the external walls was similar to the internal surface temperature of the glass window. This suggests that the condensation would unlikely occur on the interior window surface.

CONCLUSION

The proposed new window design showed significant improvement in energy performance over the similar conventional windows. Field testing and simulation results showed notable increase in the heat gain through the new adaptive window during the heating season without increasing the cooling load during the cooling season. The inside thermal quality of the space also seems to be enhanced with higher comfort level when using the new window.

The field tests and simulation results suggested that condensation problems on windows would be reduced when using the new window design. This research presents an example of modifying existing double hung low-e window construction to increase its thermal efficiency. Importantly, windows designed with adaptive low-e glazing have a marginal increase in the initial window cost. The concept of the adaptive window can also be implemented in many other window and door types. The new window design is most suitable for residential applications and in applications where double hung movable windows are used. More research is needed to implement the same concept on larger glass facades and fixed windows.

REFERENCES

Abaza, H. 2000. "Integrating Solar Radiation, Thermal Mass, Thermal Insulation, and Natural ventilation in Buildings." *Proc., ROOMVENT2000*. Reading, UK. October 12, 2000, pp. 135-161.

ASHRAE. 1997. *ASHRAE Fundamentals Handbook*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers 1997.

ASHRAE. 1989. *ASHRAE Standard 90.1: Energy Efficient Design of New Buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1989.

Bally, Marcel A. 2002. Energy efficiency breakthroughs for commercial glazing. *Construction Specifier,* 55(11) (November 2002), pp. 71-82.

BEANS. 1997. "A method to predict thermal comfort at any point in a space." *OASYS Ltd*, developed by ARUP Research and development, London.

Boyd. 2006. Boyd company online CAD files for window design, http://www.boydaluminum.com/. Date accessed: November 3, 2006.

Goldner, R. B. 1988. Thin film solid state ionic materials for electrochromic smart window glass. *Solid State Ionics*, 28-30 (Sept. 1988), pp. 1715-1721.

Glassonweb. 2006. Technology Electronic Smart Glasses. http://www.glassonweb.com/articles/article/192/. Date accessed: November 3, 2006.

Kato, Kazuhiro. 2003. Study on Thermochromic VO2 Films Grown on ZnO-Coated Glass Substrates for "Smart Windows" (School of Science and Engineering, Aoyama Gakuin University); Part 1: Regular Papers and Short Notes and Review Papers, v 42, n 10, October 2003, pp. 6523-6531.

Kosny, J. 1998. Performance check between whole building performance criteria and exterior wall measured clear wall R-value, thermal bridge, thermal mass, and air tightness." *ASHRAE Transactions*, 104(2), pp. 328-442.

Pacific Gas and Electric Company. 2006. "Energy-Efficient Window Glazing Systems for Commercial Facilities." *A technical summary* http://www.pge.com/003_save_energy/003c_edu_train/pec/.../online_rc.shtml. Date accessed: November 3, 2006.

Window. 2005. WINDOW5 simulation software. http://windows.lbl.gov/Software/window/52/SysDebugInfo.html. Date accessed: November, 3, 2006.

Zyabnev, A. M. 1995. Sun characteristics of flashed photochromic glass. *Glass and Ceramics* 51(11-12), July 1995.