Proceedings of the International Conference on Heat Transfer and Fluid Flow
Prague, Czech Republic, August 11-12, 2014
Paper No. 37

Experiment Setup for Testing the Control Strategies of Intelligent Glazed Facade

Mingzhe Liu, Kim Bjarne Wittchen
Danish Building Research Institute/Aalborg University
A.C. Meyers Vænge 15, 2450 København SV, Denmark
ml@civil.aau.dk; kbw@sbi.aau.dk

Per Kvols Heiselberg
Department of Civil Engineering, Aalborg University
Sohngaardsholmsvej 57, 9000 Aalborg, Denmark
ph@civil.aau.dk

***Abstract* -** The study aims to verify a simplified method and test control strategies for intelligent glazed facades. This paper gives an introduction on the developed control strategies and describes the experiment setup for testing the control strategies. The control strategies of the intelligent glazed façade includes the control of insulated shutter, internal and external venetian blind, natural ventilation, night cooling and lighting according to both of the indoor and outdoor environment to minimize the energy consumption and optimize the indoor comfort. The experiment is implemented in a full-scale façade element test facility at Aalborg University (DK) to test the feasibility of the control strategies.

National Instrument (NI) CompactRIO is used to acquire measured data (indoor and outdoor air temperature, solar radiation, indoor light level, internal heat load, heating and cooling power, etc.) from different sensors and send signal to control the shutter, blind, ventilation, heating, cooling and artificial lighting. The whole process is realized with the help of Labview.

***Keywords*:** Intelligent glazed façade, Control strategies, Experiment setup, Labview.

1. Introduction

Glazed facades are widely used in modern buildings because of its higher light transmittance and better view for users. However, its solar and thermal properties have significant effects on both the energy consumption and the indoor comfort of buildings. In order to improve the performance of glazed facades to improve the indoor comfort level and fulfil the future energy regulation, the intelligent façade or the facades with controls of different technologies are being investigated and developed. Different characteristics of façade can be dynamic and controlled according to both the requirement of the indoor environment and the change of the outdoor weather conditions. Experiment studies need to be conducted to verified test the calculated performance and developed control strategies of the intelligent glazed façade.

Bessoudo et al. (2010) and Tzempelikos et al., 2007 and Tzempelikos et al., 2010 studied how shading devices effect thermal comfort in offices with glazed façades in a cold climate in Montreal-Canada. They studied interior glazing and shading temperature, operative temperature and radiant temperature under different variables such as Venetian blind, roller shade, and blind rotated angles. The study showed that shading devices could improve thermal condition in cold and sunny conditions. Many researchers studied the effect of using of shading devices on thermal comfort, energy consumptions and daylight performance of buildings (Freewan et al., 2009, Tzempelikos and Athienitis, 2007, Chou, 2004, Dubois, 2003, Lee et al., 1998, Wong and Agustinus Djoko, 2004, Sutter et al., 2006 and Yoo and Lee, 2002).

Numerical studies were conducted with the help of a simplified method developed to calculate the energy and comfort performance of the room with dynamic façade (Liu et al., 2012, 2013, 2014). The integrated method need to be verified by experiment measurements. Kuznik et al. (2011) did experiment measurement to validate numerical model of double skin façade. Fuliotto et al. (2010)

The experimental studies finished before focused on the investigation of the control of single or more of the façade elements controlled separately. It is necessary to conduct investigations of a holistic control of both façade system and building services including different technologies. The influence of the control strategies is evaluated on both the energy consumption and the indoor comfort level.

Therefore, the study was performed to test the holistic control strategies of the intelligent glazed façade containing different functions (solar shading, window shutter, natural ventilation and night cooling). The control of the facade was also integrated with building services (heating, cooling, ventilation and lighting) to optimize the comfort performance and minimize the energy demand of buildings.

2. Developed Control Strategies

Fig.1. shows the completely developed control strategies of the intelligent glazed façade for all the technologies during both the occupied and unoccupied hours.

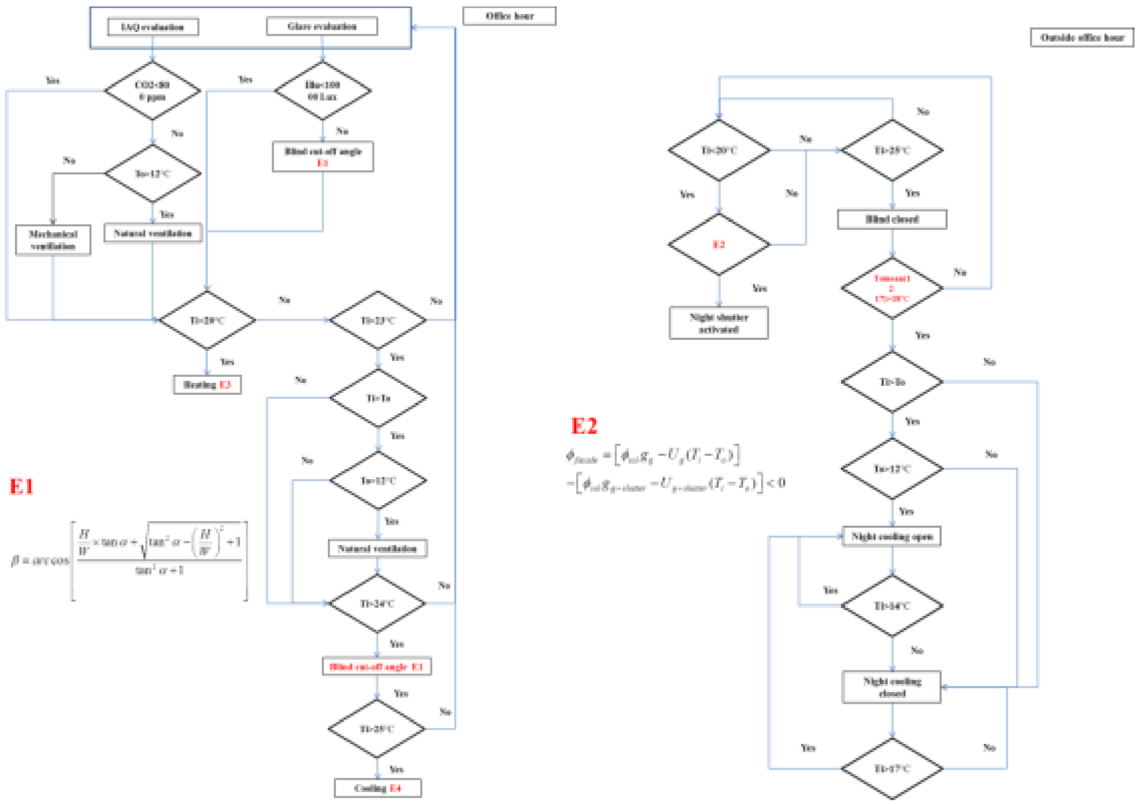

Fig. 1. Control strategies for office room with external blind during occupied hour and unoccupied hour. The detailed control setup of different control technologies are described below.

2.1. Night Shutter

External shutter was installed and activated to cover the glazed façade outside the office hour. Table 1 shows the layout and the properties of the glazing with external night shutter.

Table 1. Layout and material of the façade with night insulation outside.

Position	Material	Conductivity	IR emissivity outdoor	IR emissivity indoor
Outside	Polystyren 100mm	0.05 W/mK	0.09	0.09
Cavity	Air 110mm	-	-	-
Middle	Planilux 4 mm SGG	1 W/mK	0.837	0.837
Cavity	Argon 15 mm	0.017 W/mK	-	-
Inside	PlTutran 4 mm SGG	1 W/mK	0.04	0.837

The control of night shutter is active during the unoccupied hours when the indoor air temperature is below 20 °C. The insulating shutter is controlled as a function of an evaluation of the energy balance across the façade. The evaluation is in the calculation performed for the heat loss across the façade excluding infiltration. In order to realize the use of the insulating shutter technology requires the measurement of internal and external temperature, incident irradiance, and internal loads.

$$\phi_{facade} = \left[\phi_{sol} g_g - U_g (T_i - T_o)\right] - \left[\phi_{sol} g_{g+shutter} - U_{g+shutter} (T_i - T_o)\right] < 0 \quad (1)$$

Where ϕ_{facade} is heat flow through the façade. ϕ_{sol} is the solar radiation on the glazed facade. g_g is the solar transmittance of the glazing. U_g is the U-value of the glazing. T_i is the indoor air temperature. T_o is the outdoor air temperature. $g_{g+shutter}$ is the solar transmittance of the glazing together with the shutter. $U_{g+shutter}$ is the U-value of the glazing together with the shutter.

2.2. Blind Control

The risk of glare was evaluated by Wienold (2007). Blind was used to prevent glare problem during the occupied hour and reduce the solar transmittance through the façade during the unoccupied hour. Tilt angle of the blind depends on its different function. The tilt angle of the blind during occupied hour is calculated by equation (2) from previous research Liu et al (2013) to cut the direct solar radiation, which could both improve the visual comfort and maximize the daylight transmittance through the blind.

$$\beta = arc\cos\left[\frac{\frac{H}{W} \times \tan\alpha + \sqrt{\tan^2\alpha - \left(\frac{H}{W}\right)^2 + 1}}{\tan^2\alpha + 1}\right] \quad (2)$$

Where β is the angle between the slat and the horizontal plan. α is the solar altitude angle. H is the height between the slats. W is the width of the slats.

During unoccupied hour, the blind is controlled to be closed if the indoor air temperature is above 24°C.

2.3. Natural Ventilation

The glazed façade is open when the indoor temperature exceeds 23 °C. The control is active only when the outdoor temperature is lower than the indoor temperature and the outdoor temperature is above 12 °C. The ventilation rate is assumed to be 1 l/s per m^2.

2.4. Night Cooling

The night cooling control is active in terms of opening the window if the average outdoor air temperature between 12:00 to 17:00 is above 18 °C and the indoor air temperature is higher than the outdoor air temperature. The control of night cooling can precool the room and help to balance the cooling peak during the day time. In order not to overcool the room so that the indoor air temperature in the morning is too low, the night cooling is inactivated when the indoor air temperature is below 14 °C. However, it is reactivated when the indoor air temperature comes back to 17 °C.

2.5. Heating and Cooling

Heating and cooling installations are controlled to secure the set-point temperature in the office space. The heating and cooling needs for the office room in every time step (hour) can be calculated by the simplified model according to hourly heat gain and heat lost. The set points for heating and cooling are 20 °C and 26 °C, respectively. Detail Equations for calculating the heating and cooling needs are shown in the EN 13790 and a previous paper Liu et al (2013).

2.6. Lighting

Artificial lighting of the office building had on-off control according to the illuminance level at the reference point mentioned before. The lighting control was performed in all the control conditions. The set point of the lighting is 250 Lux. The calculation of the inlluminance level at the reference point was described in a previous paper Liu et al (2013).

Table 2. Setup of building services and indoor conditions.

Internal load of people	100 W
Lighting power (on/off)	60W
Setpoints for the heating	20 °C
Setpoints for the cooling	25 °C
Mechanical ventilation rate (office hour)	1.2 l/sm^2
Setpoint of lighting	300 lux

3. Experiment Setup

A simplified method and control strategies of the intelligent glazed façade has been developed. Their performance need to be validated by the measurements performed in the test facility "The Cube" at Aalborg University. The measurements are implemented in the full-scale test facility consisting of façades and rooms (The Cube at Aalborg University) (Kalyanova et al. 2008) (Fig. 2.). The test facility has one south-facing room with the internal dimension of 2.76 × 2.75 × 3.6 m^3 (H×W×D). The glazed facade systems face south and have a dimension of 2.76×1.6 m^2.

Fig. 2. Full-scale façade test facility (Cube) in Aalborg University.

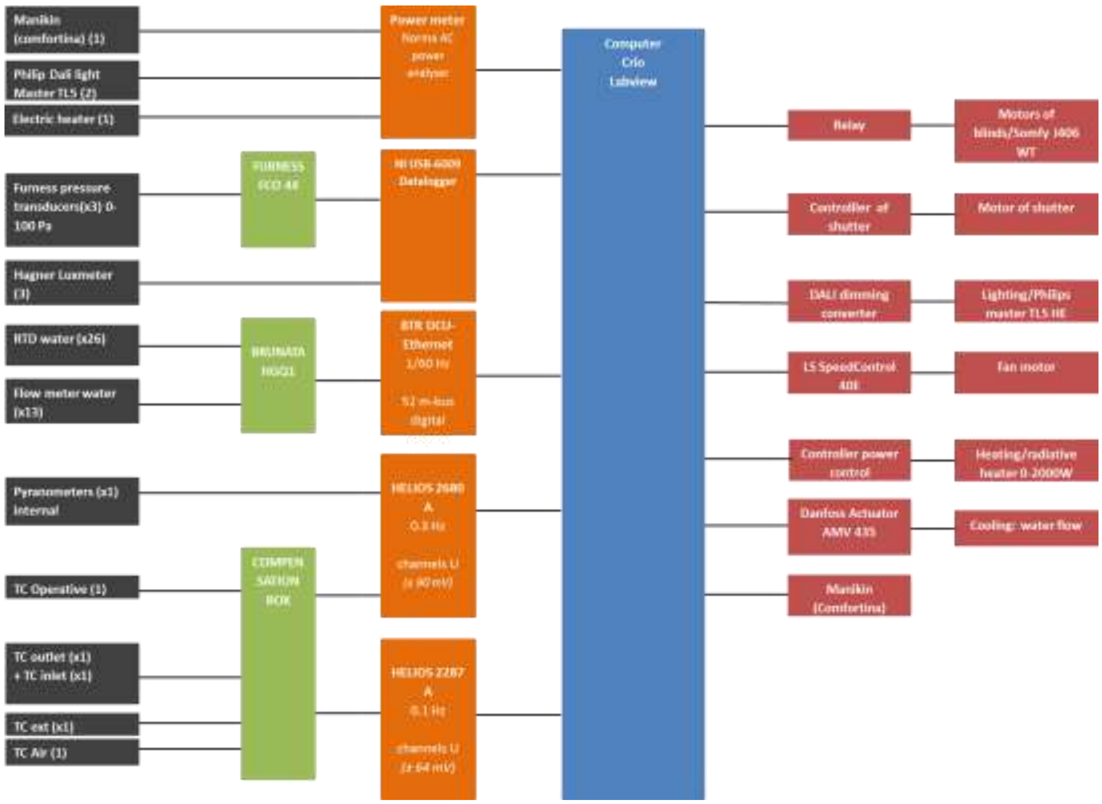

Fig. 3. Experiment setup for testing the control strategies of the intelligent glazed façade.

The glazing type used in the experiments is a double glazing unit with a 22 mm argon-filled cavity and low-e coating on the internal pane. The glazing is fitted with polystyrene on the external side of the window, generating a cavity between the glazing system and the polystyrene. The layout of the double glazing unit with night insulation is shown in table 1.

The surrounding internal surfaces are built up of 15 mm plywood and are painted white, apart from the floor, which is made of 150 mm concrete. The heat loss due to infiltration is minimized to a minimum by sealing all joints with silicon.

Fig. 3 shows the setup of the entire system to collect measured data from different sensors and to control different elements and devices. All the instruments can be integrated and controlled together according to different measurements. The system is flexible and visible to implement different control strategies by ourselves.

Temperatures are measured using thermocouples type K. The temperature is logged using Helios data logger connected to an ice point reference. The calibration of the thermocouples is done using a reference thermometer with an accuracy of 0.01 °C, insuring an accuracy of 0.6 °C for the thermocouples. All thermocouples were connected to a compensating box in order to increase accuracy in measurements Artmann et al (2008). The thermocouples measure internal surface temperatures of the glazing, shielded from the outside to prevent solar irradiance from influencing the measurements. The thermocouples measure the air temperature at 0.1, 0.6, 1.1, 1.7 and 2.65 m high. In order to decrease the influence of radiation on the measurement of air temperature, the thermocouples are silver-coated and protected by a mechanically ventilated silver shield.

The room is heated by a maximum 1 kW electrical convective heating system controlled to heat the air to keep the air temperature stable. There are other internal heat sources like artificial lighting and manikin in the room. The cooling is controlled using Danfoss AME435 actuator. The achieved temperature is between 20 and 25 °C.

Irradiance is measured using CM21-pyranometer, CM11-pyranometer and BF3- pyranometer. BF3 is placed externally measuring the diffuse and global irradiance on a horizontal surface. CM21 and CM11 pyranometers are placed in each of the test cells, measuring transmitted irradiance through the glazing system. The pyranometers are prior to the installation calibrated in reference to CM21, which is calibrated in sun simulator and corrected by Kipp&Zonen B.V Kalyanova et al (2008).

4. Conclusion

Result of numerical method shows that the energy consumption of buildings with the control strategies of intelligent glazed façade can be decreased to less than 25 KWh/m2 per year, which complies the requirement of building class 2020 in Denmark. The experiment test is still going on. Initial test shows that the entire system works well under the control of the CompactRIO and Labview design. All the devices react quickly enough as required in a building. The most advantage of the system is that it is flexible enough to integrate different instruments and devices and to implement different control strategies without the help of a control engineer and programmer. The system is a powerful solution to conduct complex control of building elements processing signal of different instrument. With the view interface, the software can visualize what is happening during the experiment and make it easy for researchers to realize their idea.

Acknowledgements

This paper is based on research conducted in a PhD project supervised by Senior Researcher Kim Wittchen, Danish Building Research Institute (SBi) and Professor Per Heiselberg, Department of Civil engineering both at Aalborg University, Denmark. The PhD is part of the Strategic Research Centre for Zero Energy Buildings at Aalborg University and financed by the Danish aluminium section of The Danish Construction Association, Aalborg University and The Danish Council for Strategic Research, under the Programme Commission for Sustainable Energy and Environment. The experimental work is finished under the help of Hicham Johra.

References

Artmann N., Vonbank R., & Jensen RL. (2008). Temperature Measurements Using Type K Thermocouples and the Fluke Helios Plus 2287A Datalogger, DCE Technical Reports, nr. 52, Aalborg University. Department of Civil Engineering, Aalborg.

Bessoudo M., Tzempelikos A., Athienitis A.K., Zmeureanu R. (2010). Indoor thermal environmental conditions near glazed facades with shading devices – part i: experiments and building thermal model. Building environment, 45, 2506-2516.

Chan A. (2012). Effect of adjacent shading on the thermal performance of residential buildings in a subtropical region. Appl Energy, 92, 516-22.

Fuliotto R, Cambuli F, Mandas N, Bacchin N, Manara G, Chen Q. (2010). Experimental and numerical analysis of heat transfer and airflow on an interactive building facade. Energy Build, 42, 23-8.

Gomes MG., Santos A., Rodrigues A.M., (2014). Solar and visible optical properties of glazing systems with venetian blinds: Numerical, experimental and blind control study. Build Environ, 71, 47-59.

Kalyanova O., Heiselberg P., (2008). Experimental Set-up and Full-scale measurements in the ‘Cube'.

Kim D., Park C. (2009). Manual vs. optimal control of exterior and interior blind systems. 1663-70.

Kuznik F., Catalinac T., Gauzered L., Woloszyn M., Roux J. (2011). Numerical modelling of combined heat transfers in a double skin façade – full-scale laboratory experiment validation. Applied thermal engineering, 31, 3043-3054.

Liu M., Wittchen K.B., Heiselberg P., Winther F.V. (2012). Development of Simplified and Dynamic Model for Double Glazing Unit Validated with Full-Scale Facade Element. PLEA 2012 Lima Peru-Opportunities, Limits & Needs.

Liu M., Wittchen K.B., Heiselberg P.K., Winther F.V. (2013). Development of a simplified and dynamic method for double glazing façade with night insulation and validated by full-scale façade element. Energy Build, 58, 163-171.

Liu M., Wittchen K.B., Heiselberg P.K., Winther F.V. (2014). Development and sensitivity study of a simplified and dynamic method for double glazing facade and verified by a full-scale façade element. Energy and Buildings, 68, 432-443.
Liu M., Wittchen K.B., Heiselberg P.K. (2014). Development of a simplified method for intelligent glazed façade design under different control strategies and verified by building simulation tool Bsim. Building and Environment, 74, 31–38.
Shen H., Tzempelikos A. (2012(. Daylighting and energy analysis of private offices with automated interior roller shades. Solar Energy, 86, 681-704.
Shen H., Tzempelikos A. (2012). Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading. Build Environ.
Skelly M., Wilkinson M. (2001). The Evolution of Interactive Facades: Improving Automated Blind Control. Whole Life Performance of Facades, 129-42.
Tzempelikos A., Athienitis A.K. (2007). The impact of shading design and control on building cooling and lighting demand. Solar Energy, 81, 369-82.
Van Moeseke G., Bruyère I., De Herde A. (2007). Impact of control rules on the efficiency of shading devices and free cooling for office buildings. Build Environ, 42, 784-93.
Wienold J. (2007). Dynamic simulation of blind control strategies for visual comfort and energy balance analysis. 1197-204.