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Optimized Blind Control Method to minimize Heating, Cooling and Lighting Energy

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Abstract

Energy saving has become a hot issue all over the world. To minimize the energy use in buildings, the cooperative control coupled with heating, cooling, lighting and blind control system was proposed in this study. The blind condition is optimized to minimize the total energy of heating, cooling and lighting.

In this study, the control behaviors and energy saving effect of the proposed system were evaluated by field measurement. The results show that the proposed control system reduces the cooling energy demand by about 40.8% and 19.6% of the lighting energy compared to the conventional control system with maintaining the same thermal comfort level. The total energy saving rate reached 29.7%.

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Keywords: Cooperative control; Heating; Cooling; Lighting; Blind control; Optimization

1. Introduction

The energy used by HVAC systems accounts for 51% of the total required energy and 25% for lighting in office buildings [1]. Therefore, it is an important issue to reduce energy consumption for HVAC and lighting in building sector all over world. Many research has been accomplished on energy reduction through the efficient control of lighting and blind systems [2,3,4].

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In this study, the cooperative control system composed of HVAC, lighting and blind control is proposed. The configuration of the system, control algorithm, and effect of the energy savings with/without the cooperative control system were evaluated through field measurements.

2. System description

Fig.1 shows the concept of the cooperative control system. As shown in Fig. 1, when the blind within the perimeter is open in summer, solar radiation inflows and lighting energy is reduced due to the increase of daylighting. However, this condition is accompanied by an increase in the cooling load due to the solar radiation introduced into indoors. On the other hand, when the blind is closed and the daylight is blocked, the cooling load will be reduced due to the decrease in solar radiation, but the illumination level in the perimeter will decrease. As a result, lighting energy will be increased to maintain a certain level of indoor illumination.

For the control strategy of the cooperative control system, the heat gain by global irradiation and illumination by exterior illumination are calculated at the same time. Based on the energy prediction model for the heat inflow, other required heating and cooling energy, and the illumination energy, an optimum blind condition (open rate and slat angle) that can minimize indoor total energy for heating, cooling and lighting is calculated, and then the blinds are controlled (Fig. 2).

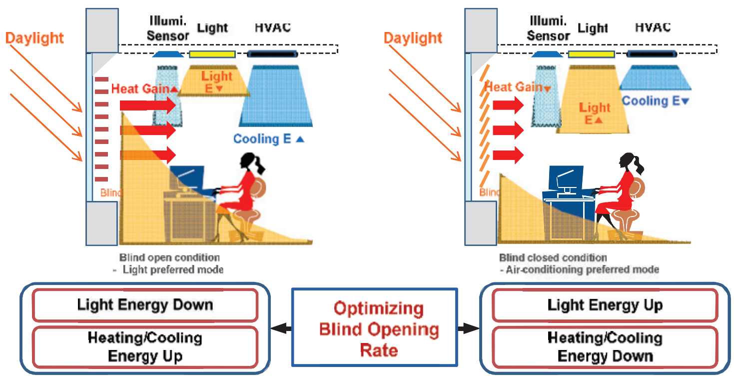


Fig. 1. The relation between energy demand for heating, cooling, lighting and blind condition

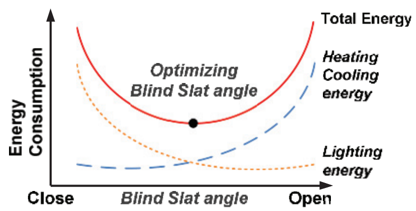


Fig. 2. Optimized control of the blind condition and slat angle

3. Measurements

Fig. 3 shows the experimental room located on the second floor of a small office building in the dimension of 9.2m (depth) × 6.5m (width) × 2.9m (height), with an exterior glazing ratio of 40% (24 mm pair glass). Long term measurements were accomplished to estimate the performance of the cooperative control system compared to the conventional air-conditioning and lighting system.

Systems were composed of an variable refrigerant flow (VRF) system including two indoor unit and 1 outdoor unit, and an energy recovery ventilator (ERV) system (500 CMH, 180W) and the lighting system included 8 sets of florescent lamps (32W) that are level adjustable, with 2 sets in a group, and perform on/off control by detector sensors for each group, and the dimming control can automatically adjust the brightness based on the set illumination level.

The two sets of blinds in each room are venetian blind. The slat width is 50 mm and the distance between slats is 43 mm. If the slat angle is 0°, the solar light becomes blocked when the incident angle of the sun is greater than 45°. The angle of the slat can be adjusted by increments of 5° by the user.

To measure the indoor environment of the experimental room using system control sensors, a temperature/humidity sensor, a luminance sensor, a CO_2 sensor, and an airflow sensor were installed at 1.1m height in the center of the room. The luminance sensor was installed right inside of the blind (0m), 1.5m, and 3.5m from the blind, and the irradiation sensors were installed at two locations, one outdoor, and one at 2.0m inside from the blind. In addition, thermocouples were installed at 21 locations to evaluate the room temperature changes by irradiation travel distance. Detailed experimental conditions are provided in Table 1.

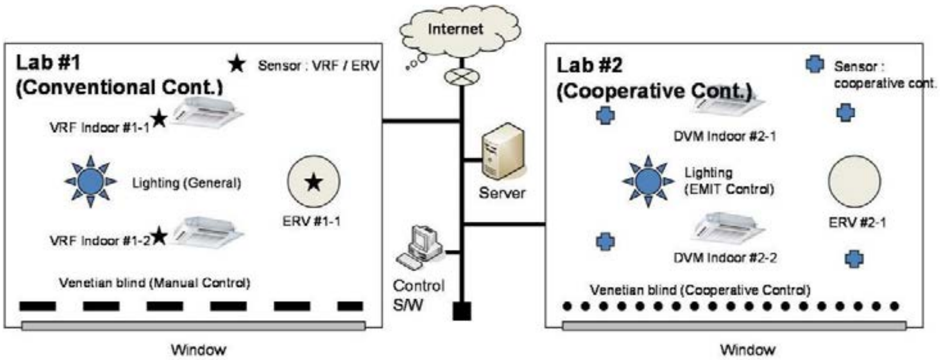


Fig. 3. Measurement system layout ; (a) Lab 1- conventional control, (b) Lab 2-cooperative control

Table 1. Experiment conditions

Contents	Lab 1	Lab 2
Subjects or residents	7	8
Control method	Conventional (Set-point Temp.)	Cooperative control
Blind	Open	Auto
Lighting	On(Constant)/Off	On(Dimming)
Ventilation system	Middle (Normal : Only Ventilation)	
Cloth insulation(clo)	0.4 Clo (Common Wear in Summer)	
Metabolic rate(met)	1~1.1 met (sitting)	
Subject survey interval	20 minutes	
Measurement items	Temperature, RH, air-velocity, Illumination, Motion Detect, CO_2	

Experiments were conducted from July 27, 2010 to August 5, 2010 between the hours of 10:00 am and 06:00 pm. Lab 1 was operated by the set temperature control, which is the conventional control method. Lab 2 was operated by the cooperative control applying the energy prediction model derived from the subject experiment of another study. In this study, 15 subjects were involved in the survey. Following a discrete seven-point scale [5] and six-point scale [5], the thermal sensation and the thermal comfort of the subjects were evaluated, respectively. The thermal perception of the subjects was recorded once every 20 minutes.

4. Results

4.1. Indoor thermal environment

The measurement data of outdoor temperature, humidity and indoor thermal environment (air temperature, relative humidity, air velocity) for each lab are shown in Fig. 4. The maximum outdoor temperature was 33.3 ºC and the experiments were conducted under a typical summer climate in Korea.

Fig. 5 shows the temperature changes in the area between the perimeter and the interior. In the case of Lab 2, some temperature difference was observed in the perimeter by the introduction of irradiation from blind control. When the blind blocks the direct sunlight and the temperature control by cooling system, the temperature difference between the perimeter and interior was 0.54 ºC on average while the difference was 1.26 ºC when the blind is open. This effect was due to the cooperative control which controlling the blind with optimization logic.

Fig. 6 shows the cooling system operation mode. There are five operation modes for the cooling system (1: automatic, 2: cooling, 3: heating, 4: air flow, 5: dehumidification). Lab 1 was fixed as the cooling mode, and the perimeter of Lab 2 was cooled by continuously switching between the cooling mode and dehumidification mode, but the interior was only dehumidified, which resulted in different operation of the air conditioning for the interior and the perimeter

4.2. Lighting control behaviors

Fig. 7 shows the changes in blind slat angles and indoor artificial illumination levels for Lab 2. Lighting was controlled by the cooperative control in Lab 2 and the indoor illumination was constantly maintained at the 555 lux level by using appropriate daylight in response to the outdoor illumination, and by controlling the output of lighting fixtures with a dimming controller to meet the designed level of 555lux. In addition, by turning off the lightings of the group by a detector sensor when residents were absent, up to 19.6% of lighting energy could be saved in Lab 2 compared to that of Lab 1.

4.3. Energy use and thermal comfort

Fig. 8(a) shows the results of energy consumption by equipment. The cooperative control with the addition of blind and lighting control by the energy optimization model saved about 29.7% more energy compared to the conventional control system.

Fig. 8(b) presents the results of the comfort survey. Indoor thermal environment was controlled within a less than 20% dissatisfaction rate and maintained a similar level of thermal comfort both the set-point temperature control (Lab 1) and the cooperative control (Lab 2). The cooperative control logic developed in this study can maintain the thermal comfort level of room residents at a similar level to that of user in set-point temperature control, and has the effect of reducing energy at the same time.

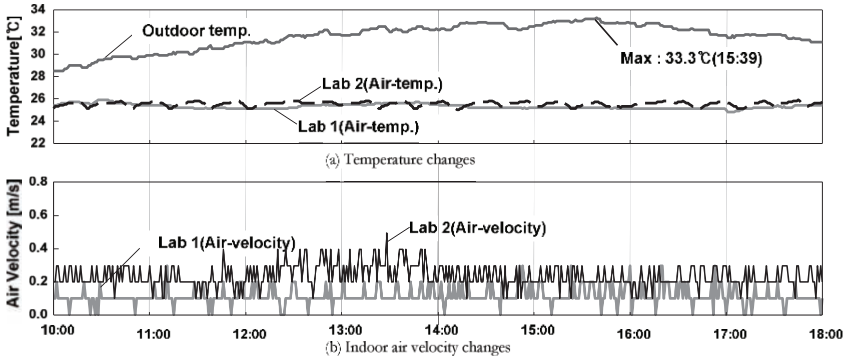
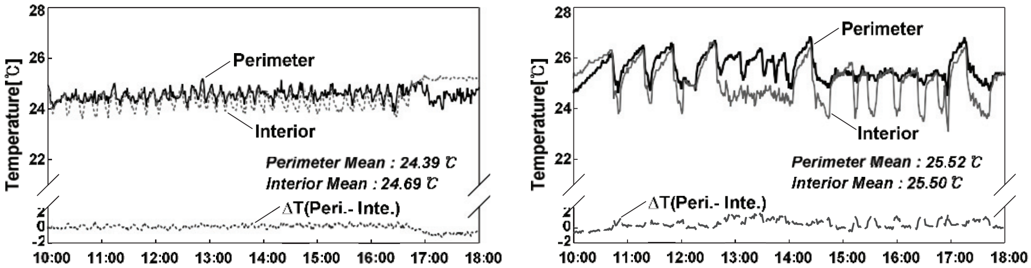
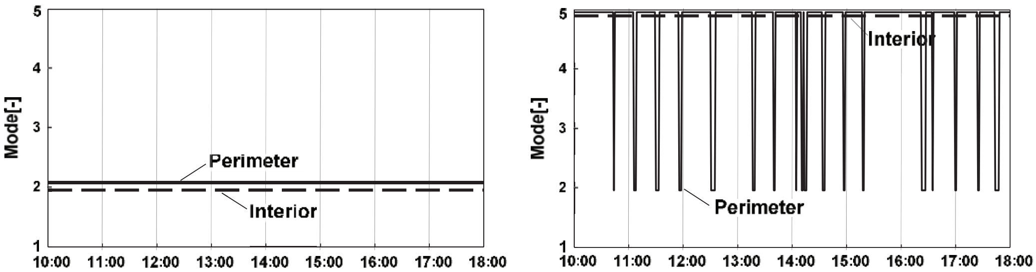


Fig. 4. Indoor and outdoor thermal environment changes



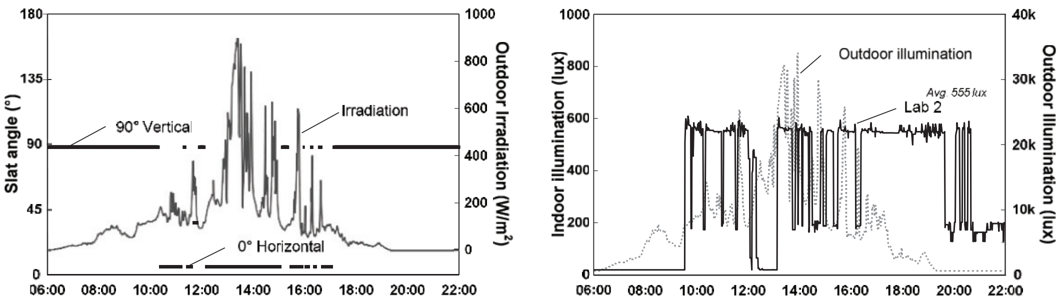
a) Lab 1(Set-point temp. control) b) Lab 2 (Cooperative control)

Fig. 5. Indoor temperature changes of perimeter and interior zone



a) Lab 1(Set-point temp. control) b) Lab 2 (Cooperative control)

Fig. 6. Cooling system operation mode



a) Blind slat angle changes b) Indoor artificial illumination changes

Fig. 7. Lighting and blind control behaviours based on cooperative control (Lab 2).

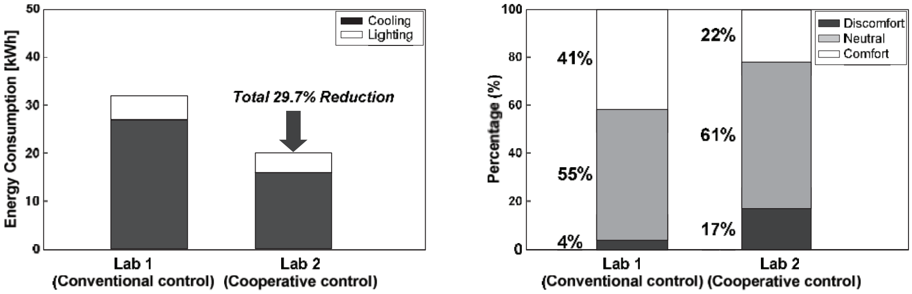


Fig. 2. (a) Total energy saving effect; (b) Thermal comfort level

5. Conclusions

This study investigated the energy saving effect of the cooperative control system, composed of air-conditioning system, lighting system and blind system. Indoor environmental changes in the perimeter zone by the inflow of outdoor irradiation, illumination, and heat source were controlled by the cooperative control system in optimizing the blind condition to minimize the sum of cooling and lighting energy.

The long-term measurements were accomplished to compare the indoor thermal and light control behavior, energy use, and thermal comfort of the residents in summer.

The results showed that the thermal comfort of residents could be kept comfort as well as the reduction rate for cooling was about 40.8% and 19.6% for lighting when the cooperative control was applied compared to that of conventional control method. The total 29.7% energy savings realized with the cooperative control method.

Acknowledgements

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