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A study on the energy saving of lighting through the development of integrated control of multifunctional shading system

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ABSTRACT

Recently, interest in integrated shading and lighting control, which are building components, is increasing to reduce the energy used in buildings. However, the multi-functional shading system, which has recently been distributed, has a natural lighting function through ceiling reflection by introducing sunlight into the room, but it is difficult to control interworking with surrounding electric lighting and integrated control is impossible due to solar reflection or acquisition. In order to solve this problem, we intend to design and implement an integrated control system for multifunctional shading devices that affect the indoor light environment and thermal environment and are effective in reducing lighting energy. This study can reduce energy in buildings by controlling the temperature through an internally integrated control system for the inflow of sunlight into the room. In addition, integrated monitoring control is possible through real-time power and energy measurement and on-site sensor data management. As a result of this study, 34.5% of lighting energy could be saved through the study of the automated system of integrated control of multifunctional shading devices.

1. Introduction

Interest in alternative energy is increasing due to resource depletion and environmental pollution problems (Chynoweth et al., 2001). The demand for solar systems with excellent potential among new and renewable energy is soaring, especially to reduce building energy, which accounts for about 48% of total energy consumption (Cao et al., 2016). Energy used for various purposes in buildings can be divided into heating and cooling, lighting, ventilation, humidification, hot water, and others, and various efforts are being made to save energy consumed (Omer, 2008). Recently, there has been a growing interest in integrated control of shading and lighting, which are building components, to reduce wasted energy through the building's own control function (Lee and Hong, 2011).

A common component of buildings that affects lighting energy in relation to solar energy is typically a shading device (Tzempelikos and Athienitis, 2007). Shading devices can generally lift blinds, but recently, multi-functional shading devices (collective light louver) have been developed that actively inject sunlight into the room, away from passive simple shading or lighting. However, the multi-functional shading device currently distributed in Korea has a natural lighting function through ceiling reflection due to the inflow of solar energy into the room, but it is difficult to control interlocking with the surrounding electric lighting and cannot be integrated (Chow, 2010). Therefore, despite its excellent energy saving effect, the supply and spread in Korea are still being delayed. To address this problem, we want to design and implement a multifunctional shade system that affects the indoor light and thermal environment. It is effective in reducing lighting energy and an integrated multi-function shade control system that enables an optimal indoor environment with interworking electric luminaires (Su et al., 2021).

The proposed system has energy savings in the building, and integrated control is possible based on real-time power and energy measurement and on-site sensor data. The organization of this paper is as follows. In section 2, we know the technologies applied to the intelligent integrated control system of multi-functional shading devices, and in section 3, we examine the intelligent integrated control system of multi-functional shading devices and evaluate the

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proposed system. Finally, section 4 presents conclusions and future research directions.

Investment in renewable energy businesses and new energy industries is being strengthened to disseminate and spread renewable energy facilities in Korea. After 2020, a mandatory project to install renewable energy facilities is being implemented to supply more than 30% of the estimated energy consumption with renewable energy for buildings with a total floor area of 1,000㎡ or more that are newly built, expanded, or renovated by public institutions (Granzer et al., 2008). There are a total of 16 renewable energy sources, and they need to be designed considering the purpose, facade composition, and flat composition of buildings to be applied due to differences in characteristics such as Unit energy production by energy source, input budget, and installation method

1.1. KNX protocol

KNX protocol is an open standard protocol that applies to building automation through remote control of home appliances such as lighting, blinds, security systems, energy management, and audio video installed inside the building. Originally widely used in Europe, three major home network protocols, BatiBus, European Installation Bus (EIB), and European Home System (EHS), were integrated into one, completing the KNX protocol (ABB, 2020). Later, KNX was approved as ISO/IEC 14543-3 as an international standard protocol. These standard protocols allow compatibility and interoperability to can be ensured for devices developed by different producers. KNX's hierarchy consists of the physical layer, the datalink layer, the network layer, the transport layer, and the application layer, as shown in Fig. 1, according to the OSI layer 7. The following Fig. 1 illustrates the hierarchical structure of KNX (KEA, 2020).

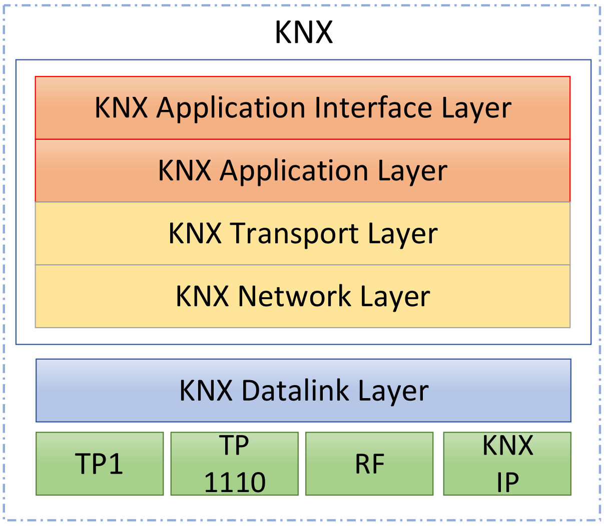


Fig. 1: Hierarchical architecture of KNX

Lighting control technology can be divided into two main categories as follows:

- Switching control: Operation through a light-only relay with on/off control of the light.
- Manual dimming control: Switch can be operated manually (mainly with a dimmer), but not centralized control. Dimming control by sensor: Constant current by a dimming controller by adjusting the brightness of the light sensor, Constant voltage control, or resistance variable control. There is a method of dimming control (Digital control to receive feedback values) through the DALI stabilizer. Fig. 2 illustrates the technology of light control (Kim, 2015).

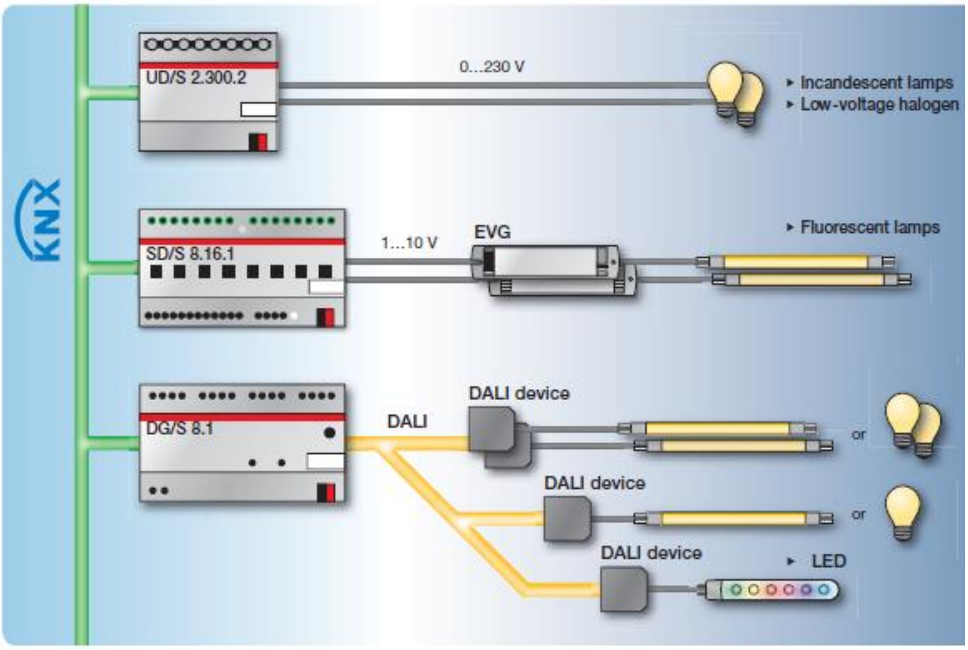


Fig. 2: Control method of lighting

2. Development of an intelligent integrated control systems

2.1. Suggested system configuration

The intelligent integrated control system of multifunctional shading devices proposed in this paper is divided into individual and identification controllers located in clients and integrated control and central control systems located in servers for each group.

Fig. 3 shows the indoor louver-type condensing mining system, Fig. 4 shows the overall configuration of the proposal system, and Fig. 5 shows the integrated UI of the proposal system.

In particular, Fig. 3 uses direct light from external windows as natural light indirect lighting for some artificial lighting replacements and some block solar radiation to reduce the increase in cooling load.

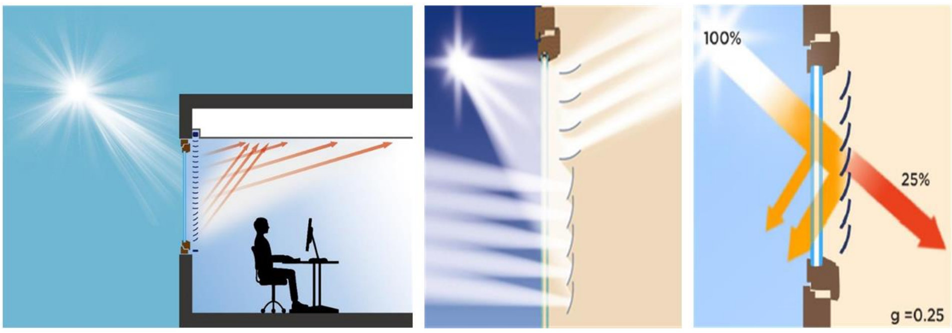


Fig. 3: Indoor louver-type condensing lighting system

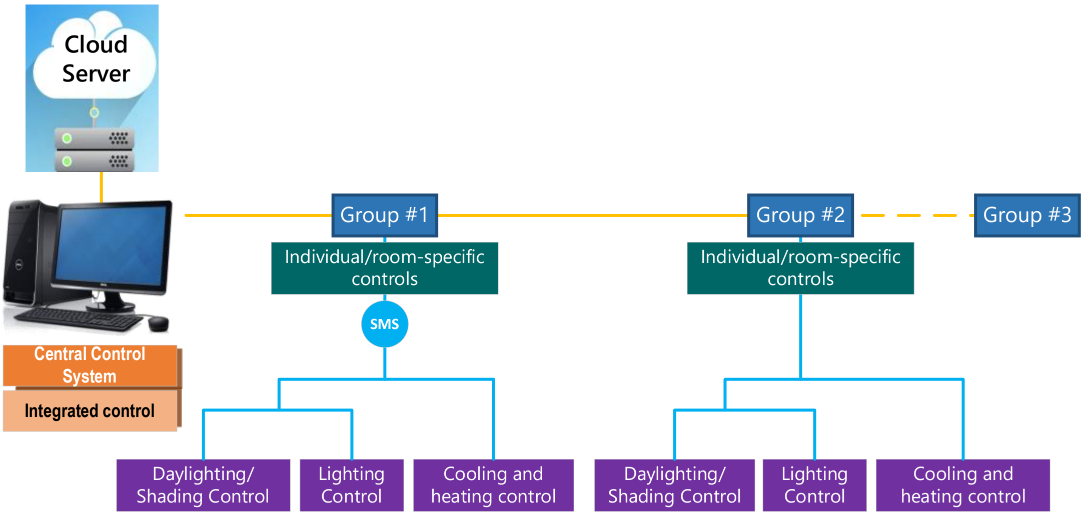


Fig. 4: Architecture of proposal system

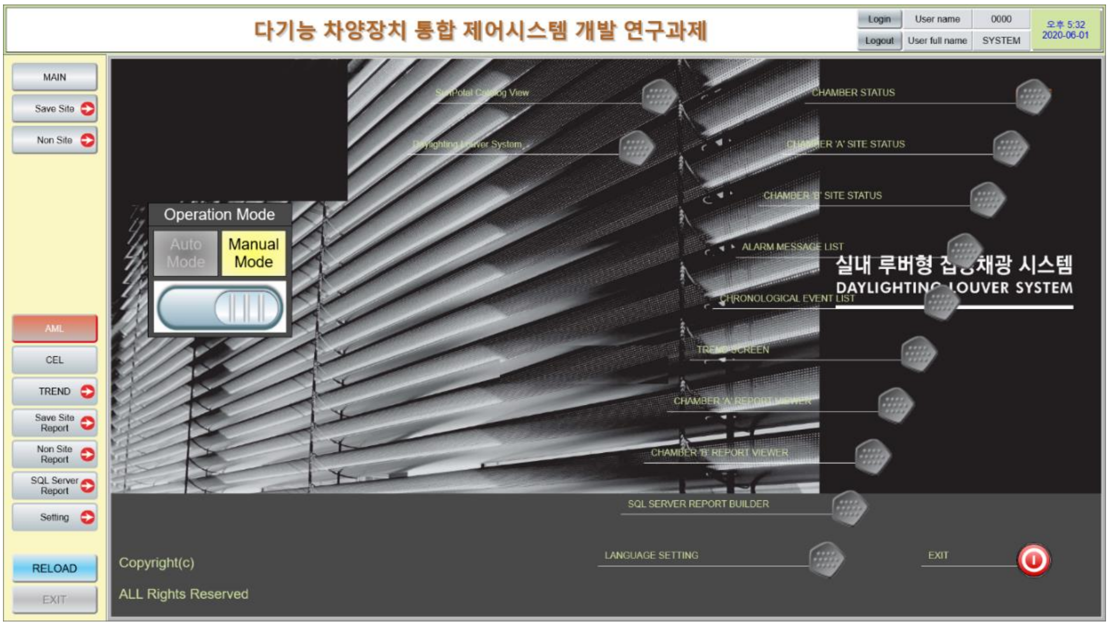
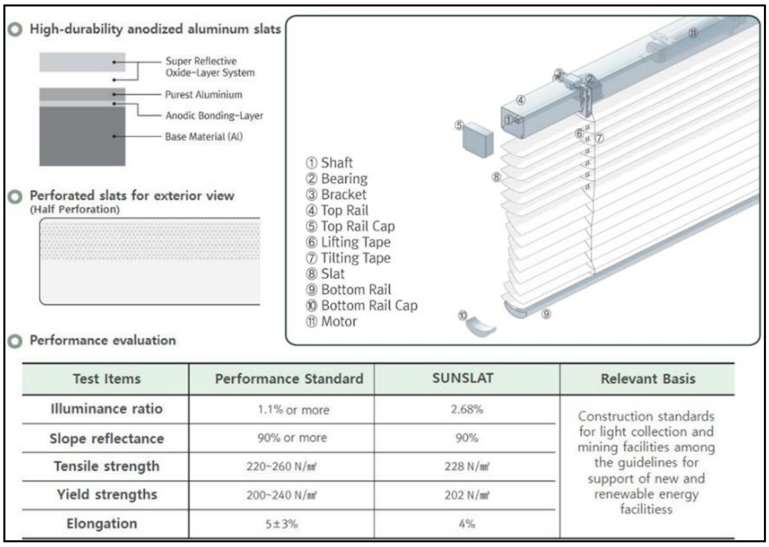


Fig. 5: Integrated UI of the proposal system

Fig. 6 shows the main configuration and name of the indoor condensing louver system, and the indoor louver-type condensing louver system largely consists of four parts: Driving (drive motor, protective cover), slat, lifting wire (up and down movement), tilting wire (slat angle adjustment), and lower support.



Test Items	Performance Standard	SUNSLAT	Relevant Basis
Illuminance ratio	1.1% or more	2.68%	Construction standards for light collection and mining facilities among the guidelines for support of new and renewable energy facilitiess
Slope reflectance	90% or more	90%	
Tensile strength	220~260 N/㎡	228 N/㎡	
Yield strengths	200~240 N/㎡	202 N/㎡	
Elongation	5±3%	4%	

Fig. 6: The main structure of the indoor louver-type condensing-lighting system

The condensing louver is set with different upper and lower slat angles, so that individual upper and lower slat operations are possible when the lifting wire is operated up and down. In the case of the upper slats, the amount of natural light introduced into the room can be adjusted according to the change in the slat angle with high reflectivity (90% or more), and the lower slats can block solar radiation to reduce the cooling load. Fig. 7 shows the slat function and operation method, Fig. 8 shows the control of the inflow of light by changing the slat angle through motor control, and Fig. 9 shows an example of indoor mining inflow according to the shading slat angle control (Song and Kang, 2015; Jeon et al., 2016).

2.2. Suggestion system key features

It is possible to perform an energy saving function by reducing the lighting load rate by controlling natural lighting through the shading controller. Through the Central Control System (SCADA), it is possible to set the condition and temperature of various facilities such as lighting and to perform various additional functions such as manual and automatic. Through interworking with IoT, integrated control is possible using mobile and tablets regardless of the inside or outside of the building (Kim, 2016; Liu, 2016).

Communication: It is adopted as a basis through KNX international standard communication, and is linked through a complex controller so that it can be controlled through a non-standard controller. Solar Tracking System: In order to concentrate sunlight at high density, solar tracking program algorithms allow you to locate the sun and control the optimal slat angle. Fig. 10 shows the solar path diagrams of the northern and southern hemispheres, and Fig. 11 shows the 3D diagram of the sun's motion at a geographical location.

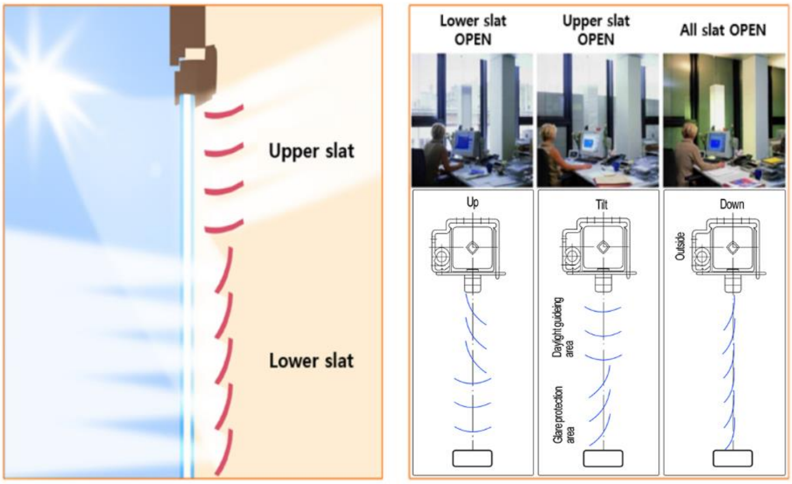


Fig. 7: Slat function and operation method

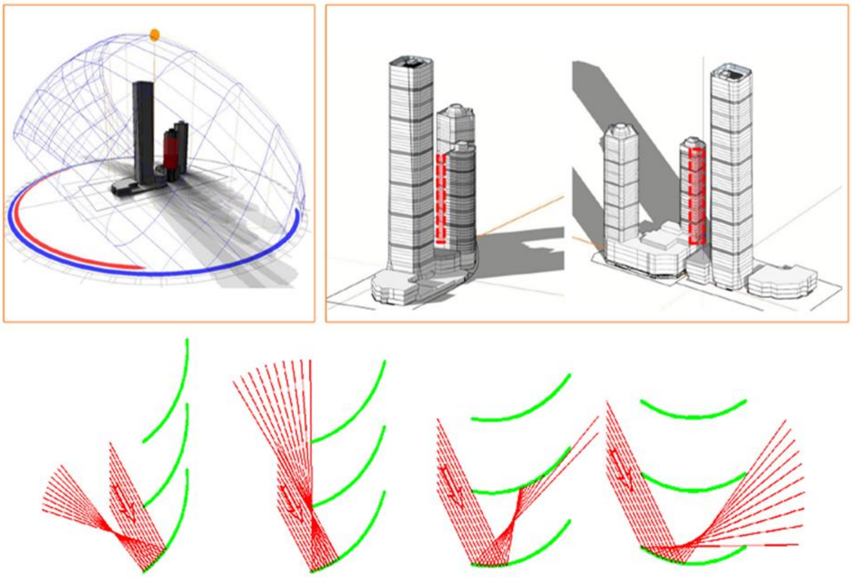


Fig. 8: Due to the change in the slat angle through motor control: Controlling the inflow of light

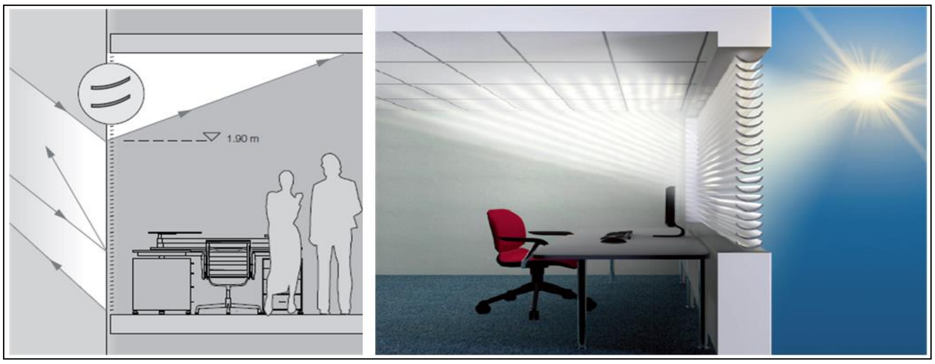


Fig. 9: Example of indoor light mining inflow according to shading slat angle control

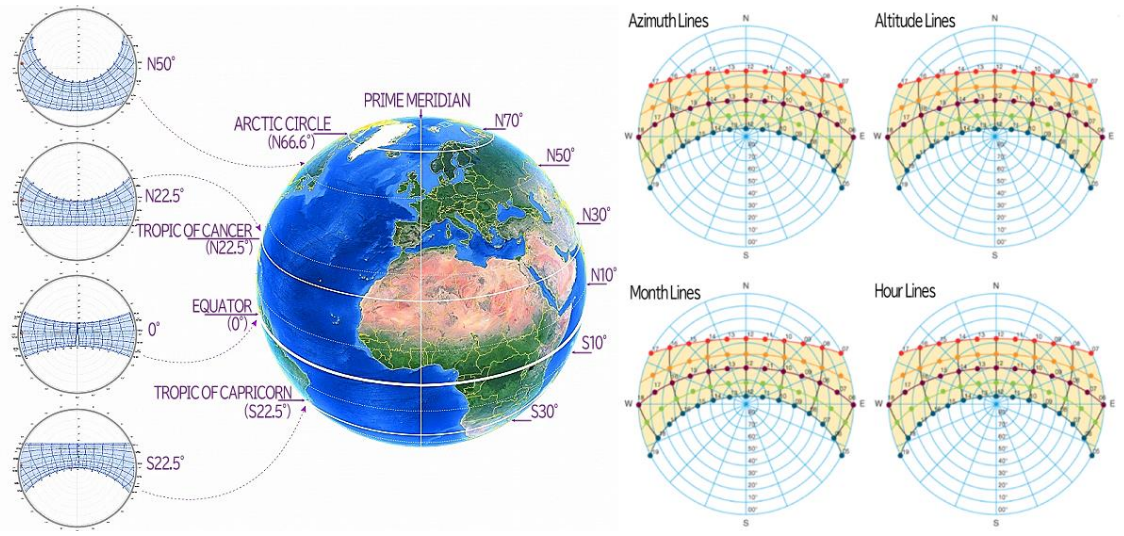
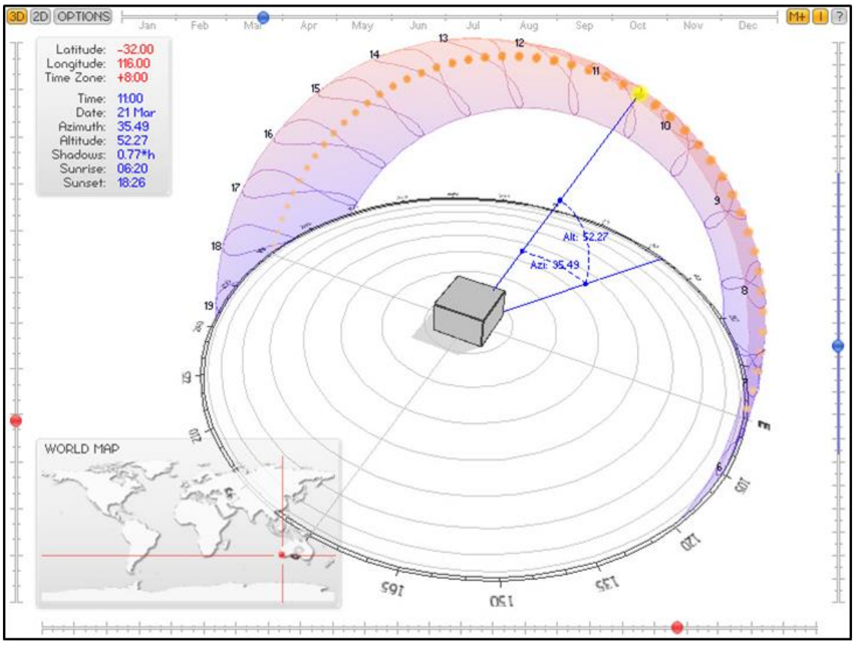


Fig. 10: The solar path diagram of the northern and southern hemispheres

Awning: By adjusting the exterior lighting, energy is saved by securing the illumination required for the room or climate control functions, and Fig. 12 shows the setting UI of the shading device. Lighting: It reduces the lighting load due to room illumination control through shading and Fig. 13 illustrates the setting UI of the lighting device.

HVAC: By adjusting the room temperature through the shading of the external cooling/heating system, the energy of the air conditioning and heating system is reduced, and Fig. 14 shows the HAVC's configuration UI. Controlling the shading device by the sensor: Controlling the shading device by the sensor is divided into weather conditions, indoor illumination, room temperature, and control according to the location of the sun so that weather changes can be detected by safety-related sensors. The drive can be controlled as needed. Fig. 15 shows a control configuration based on a weather sensor weather value.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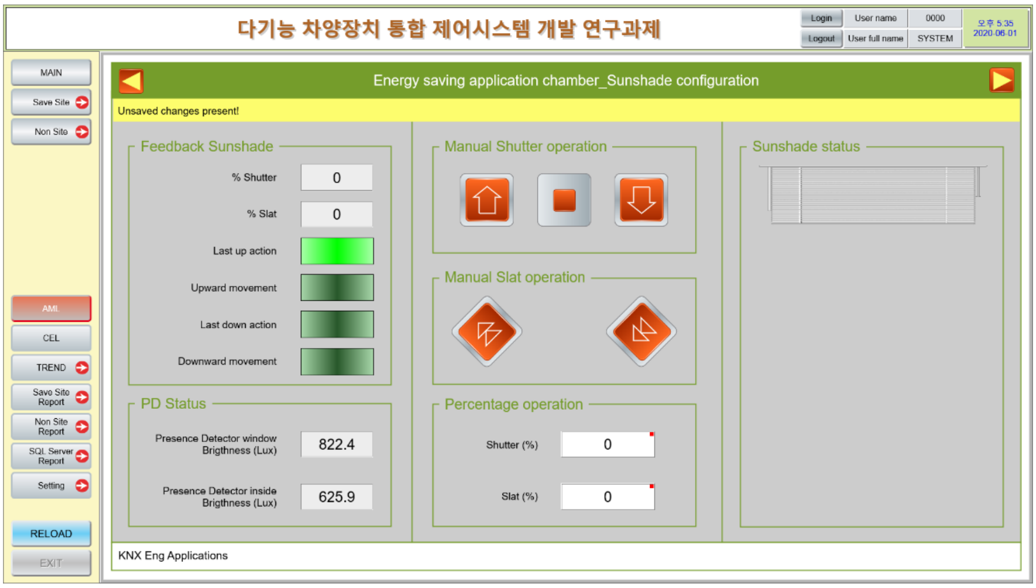
Longitude: 116.00
Time Zone: +8:00
Time: 11:00
Date: 21 Mar
Azimuth: 35.49
Altitude: 52.27
Shadows: 0.77*h
Sunrise: 06:20
Sunset: 18:26

Fig. 11: 3D diagram showing the movement of the sun in a geographical location


다기능 차양장치 통합 제어시스템 개발 연구과제

Energy saving application chamber_Sunshade configuration

Unsaved changes present!

Feedback Sunshade
% Shutter: 0
% Slat: 0

PD Status
Presence Detector window Brigthness (Lux): 822.4
Presence Detector inside Brigthness (Lux): 625.9

Percentage operation
Shutter (%): 0
Slat (%): 0

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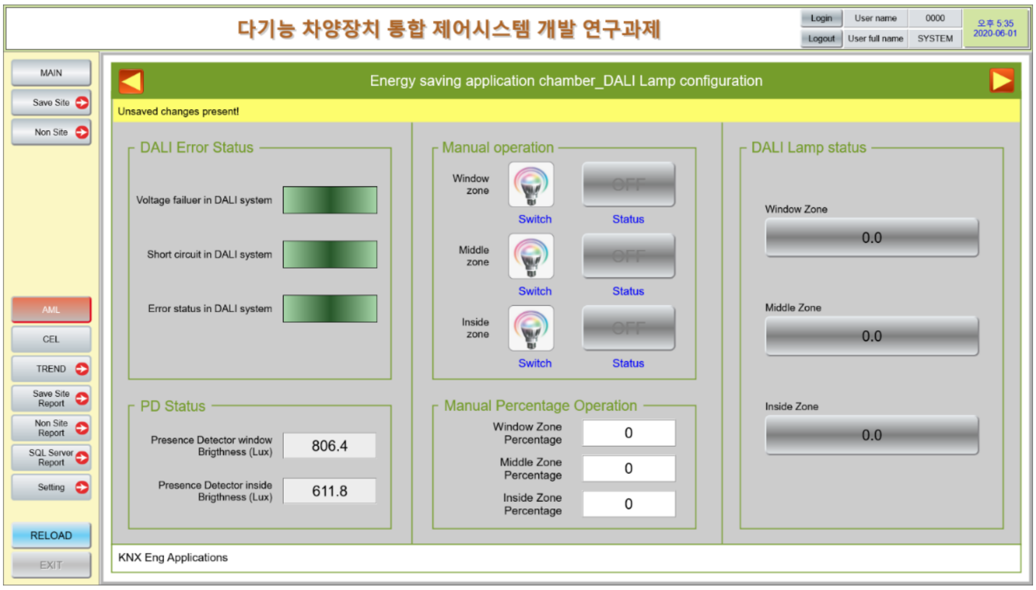
Fig. 12: Integrated UI of the proposal system UI of shading function setting


다기능 차양장치 통합 제어시스템 개발 연구과제

Energy saving application chamber_DALI Lamp configuration

Unsaved changes present!

PD Status
Presence Detector window Brigthness (Lux): 806.4
Presence Detector inside Brigthness (Lux): 611.8

Manual Percentage Operation
Window Zone Percentage: 0
Middle Zone Percentage: 0
Inside Zone Percentage: 0

DALI Lamp status
Window Zone: 0.0
Middle Zone: 0.0
Inside Zone: 0.0

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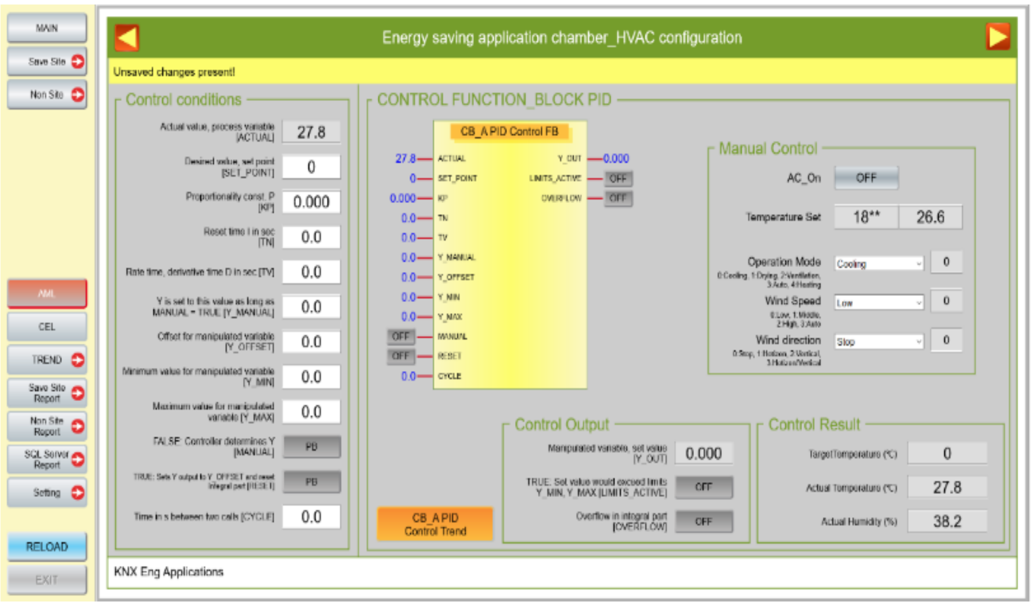
Fig. 13: UI of lighting function setting



Energy saving application chamber_HVAC configuration

Unsaved changes present!

Control conditions

Actual value, process variable [ACTUAL]	27.8
Desired value, set point [SET_POINT]	0
Proportionality const. P [KP]	0.000
Reset time I in sec [TN]	0.0
Rate time, derivative time D in sec [TV]	0.0
Y is set to this value as long as MANUAL = TRUE [Y_MANUAL]	0.0
Offset for manipulated variable [Y_OFFSET]	0.0
Minimum value for manipulated variable [Y_MIN]	0.0
Maximum value for manipulated variable [Y_MAX]	0.0
FALSE: Controller determines Y [MANUAL]	PB
TRUE: Sets Y output to Y_OFFSET and reset integral part [RESET]	PB
Time in s between two calls [CYCLE]	0.0

CONTROL FUNCTION_BLOCK PID

ACTUAL 27.8, SET_POINT 0, KP 0.000, TN 0.0, TV 0.0, Y_MANUAL 0.0, Y_OFFSET 0.0, Y_MIN 0.0, Y_MAX 0.0, MANUAL OFF, RESET OFF, CYCLE 0.0
Y_OUT 0.000, LIMITS_ACTIVE OFF, OVERFLOW OFF

Manual Control

AC_On	OFF	
Temperature Set	18**	26.6
Operation Mode 0:Cooling, 1:Drying, 2:Ventilation, 3:Auto, 4:Heating	Cooling	0
Wind Speed 0:Low, 1:Middle, 2:High, 3:Auto	Low	0
Wind direction 0:Stop, 1:Horizon, 2:Vertical, 3:Horizon/Vertical	Stop	0

Control Output

Manipulated variable, set value [Y_OUT]	0.000
TRUE: Set value would exceed limits Y_MIN, Y_MAX [LIMITS_ACTIVE]	OFF
Overflow in integral part [OVERFLOW]	OFF

Control Result

TargetTemperature (℃)	0
Actual Temperature (℃)	27.8
Actual Humidity (%)	38.2

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Fig. 14: UI of HVAC function setting

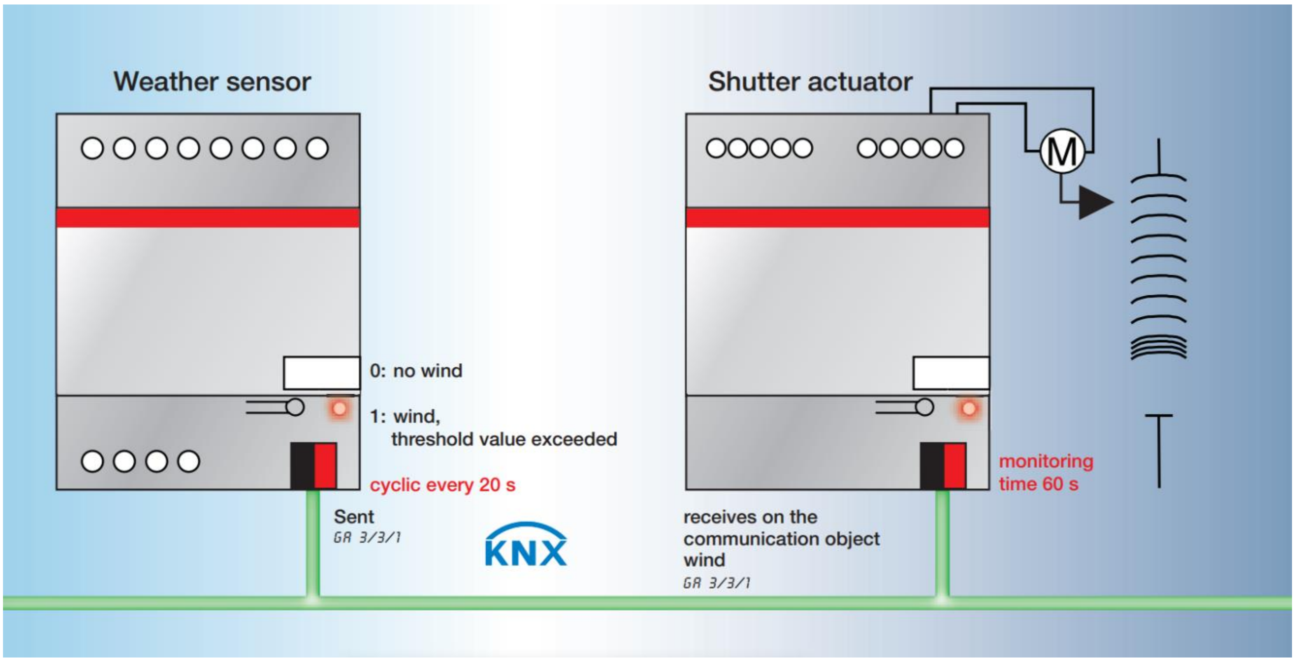


Fig. 15: Control configuration by weather sensor weather value

Composite control: Through the interlocking controller, various sensors and control items can be set, and Fig. 16 shows the composite control setting UI.

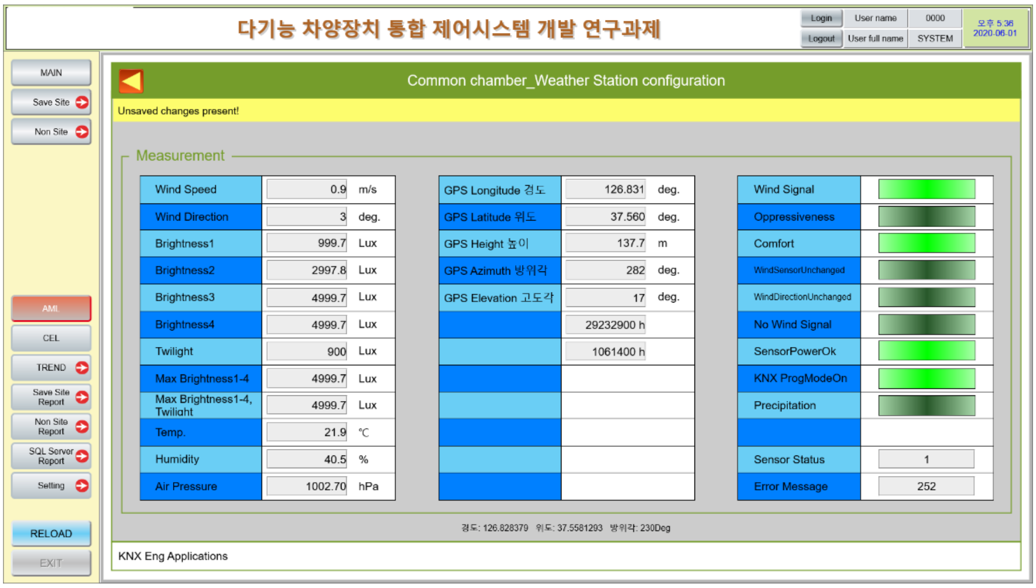
Central Control Device: Interworking with the BEMS (A) system, energy savings can be achieved by the complex control system in the building, and flexible control is possible through the linkage of composite loads based on real-time power and energy measurement, and field sensor data. Fig. 17 illustrates the UI of the SCADA system.

Fig. 18 represents the block diagram of the integrated control unit.

Fig. 19 shows the real-time output according to the data input of the complex control system (SUNSLAT CONTROL SYSTEM), and Fig. 20 shows the output data by converting it into a graph and quantitatively analyzing it to easily review energy conversion.

2.3. Assessment of lighting energy savings in the proposed system

To evaluate the lighting energy saving performance of the proposed system, the indoor test environment, and the lighting energy saving rate of each automatic control was evaluated on a clear day suggested in the Guidelines for Support, etc. of New and Renewable Energy Facilities). Fig. 21 shows the condensing louver modeling, and Table 1 shows the performance evaluation targets.



다기능 차양장치 통합 제어시스템 개발 연구과제

User name	0000	오후 5:36 2020-06-01
User full name	SYSTEM	

Common chamber_Weather Station configuration

Unsaved changes present!

Measurement

Wind Speed	0.9	m/s
Wind Direction	3	deg.
Brightness1	999.7	Lux
Brightness2	2997.8	Lux
Brightness3	4999.7	Lux
Brightness4	4999.7	Lux
Twilight	900	Lux
Max Brightness1-4	4999.7	Lux
Max Brightness1-4, Twilight	4999.7	Lux
Temp.	21.9	℃
Humidity	40.5	%
Air Pressure	1002.70	hPa

GPS Longitude 경도	126.831	deg.
GPS Latitude 위도	37.560	deg.
GPS Height 높이	137.7	m
GPS Azimuth 방위각	282	deg.
GPS Elevation 고도각	17	deg.
	29232900 h	
	1061400 h	

Wind Signal	🟩
Oppressiveness	▨
Comfort	🟩
WindSensorUnchanged	▨
WindDirectionUnchanged	▨
No Wind Signal	▨
SensorPowerOk	🟩
KNX ProgModeOn	🟩
Precipitation	▨
Sensor Status	1
Error Message	252

경도: 126.828379 위도: 37.5581293 방위각: 230Deg

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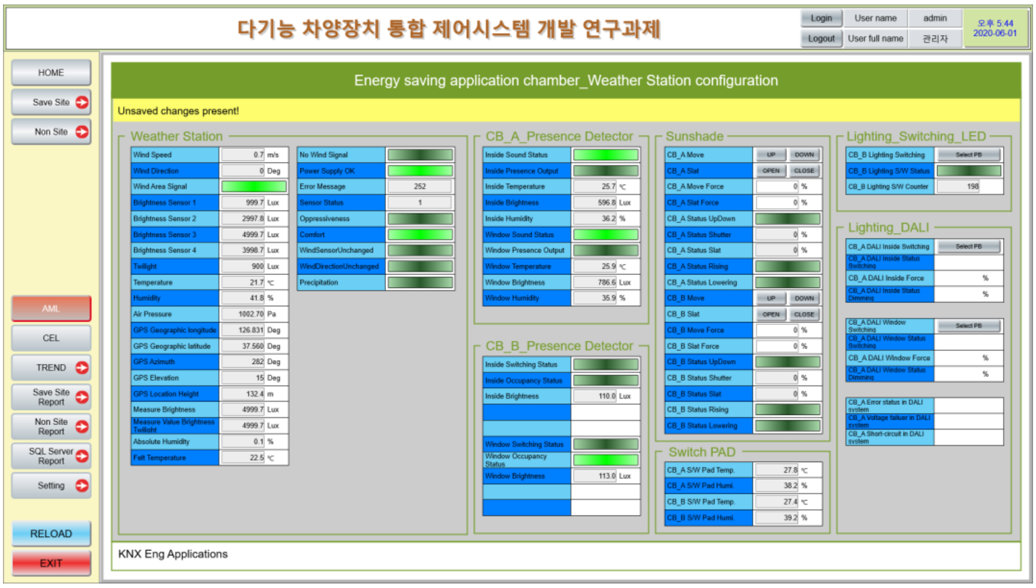
Fig. 16: UI of complex control setting



다기능 차양장치 통합 제어시스템 개발 연구과제

User name	admin	오후 5:44 2020-06-01
User full name	관리자	

Energy saving application chamber_Weather Station configuration

Unsaved changes present!

Weather Station

Wind Speed	0.7	m/s
Wind Direction	0	Deg
Wind Area Signal	🟩	
Brightness Sensor 1	999.7	Lux
Brightness Sensor 2	2997.8	Lux
Brightness Sensor 3	4999.7	Lux
Brightness Sensor 4	3998.7	Lux
Twilight	900	Lux
Temperature	21.7	℃
Humidity	41.8	%
Air Pressure	1002.70	Pa
GPS Geographic longitude	126.831	Deg
GPS Geographic latitude	37.560	Deg
GPS Azimuth	282	Deg
GPS Elevation	15	Deg
GPS Location Height	132.4	m
Measure Brightness	4999.7	Lux
Measure Value Brightness Twilight	4999.7	Lux
Absolute Humidity	0.1	%
Felt Temperature	22.5	℃

No Wind Signal	▨
Power Supply OK	🟩
Error Message	252
Sensor Status	1
Oppressiveness	▨
Comfort	🟩
WindSensorUnchanged	▨
WindDirectionUnchanged	▨
Precipitation	▨

CB_A_Presence Detector

Inside Sound Status	🟩	
Inside Presence Output	▨	
Inside Temperature	25.7	℃
Inside Brightness	596.8	Lux
Inside Humidity	36.2	%
Window Sound Status	🟩	
Window Presence Output	▨	
Window Temperature	25.9	℃
Window Brightness	786.6	Lux
Window Humidity	35.9	%

CB_B_Presence Detector

Inside Switching Status	▨	
Inside Occupancy Status	▨	
Inside Brightness	110.0	Lux
Window Switching Status	▨	
Window Occupancy Status	🟩	
Window Brightness	113.0	Lux

Sunshade

CB_A Move	UP	DOWN
CB_A Slat	OPEN	CLOSE
CB_A Move Force	0	%
CB_A Slat Force	0	%
CB_A Status UpDown	▨	
CB_A Status Shutter	0	%
CB_A Status Slat	0	%
CB_A Status Rising	▨	
CB_A Status Lowering	▨	
CB_B Move	UP	DOWN
CB_B Slat	OPEN	CLOSE
CB_B Move Force	0	%
CB_B Slat Force	0	%
CB_B Status UpDown	▨	
CB_B Status Shutter	0	%
CB_B Status Slat	0	%
CB_B Status Rising	▨	
CB_B Status Lowering	▨	

Switch PAD

CB_A S/W Pad Temp.	27.8	℃
CB_A S/W Pad Humi.	38.2	%
CB_B S/W Pad Temp.	27.4	℃
CB_B S/W Pad Humi.	39.2	%

Lighting_Switching_LED

CB_B Lighting Switching	Select PB
CB_B Lighting S/W Status	▨
CB_B Lighting S/W Counter	198

Lighting_DALI

CB_A DALI Inside Switching	Select PB
CB_A DALI Inside Status Switching	
CB_A DALI Inside Force	%
CB_A DALI Inside Status Dimming	%

CB_A DALI Window Switching	Select PB
CB_A DALI Window Status Switching	
CB_A DALI Window Force	%
CB_A DALI Window Status Dimming	%

CB_A Error status in DALI system	
CB_A Voltage failuer in DALI system	
CB_A Short-circuit in DALI system	

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Fig. 17: UI of SCADA system

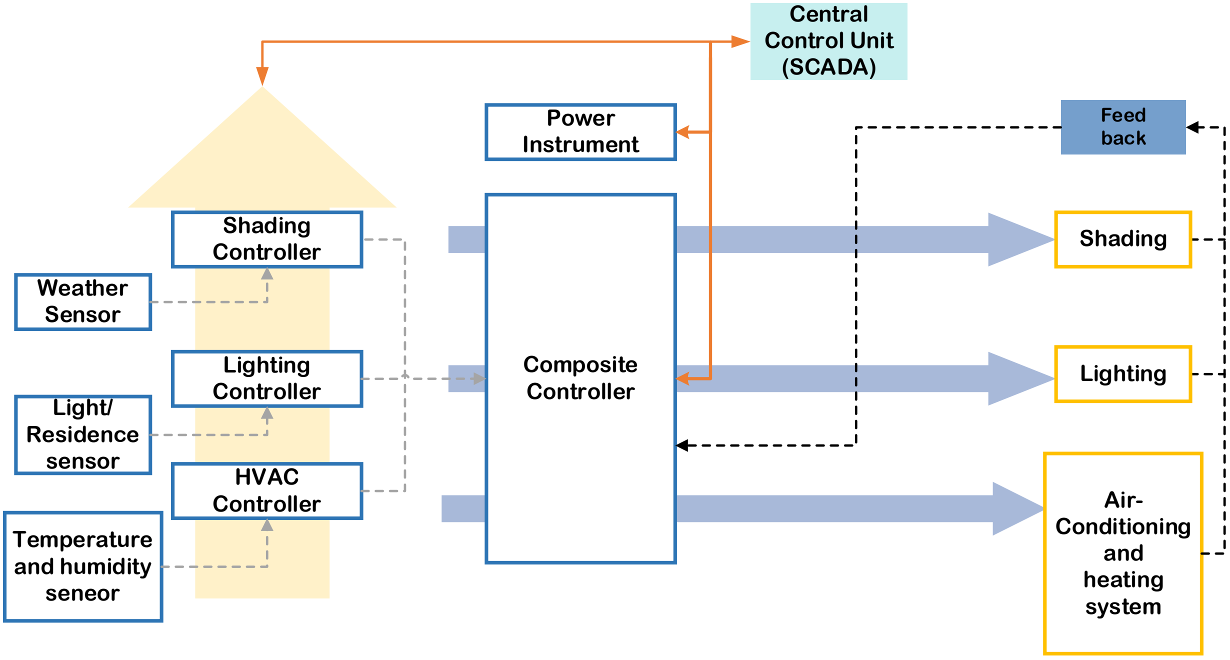
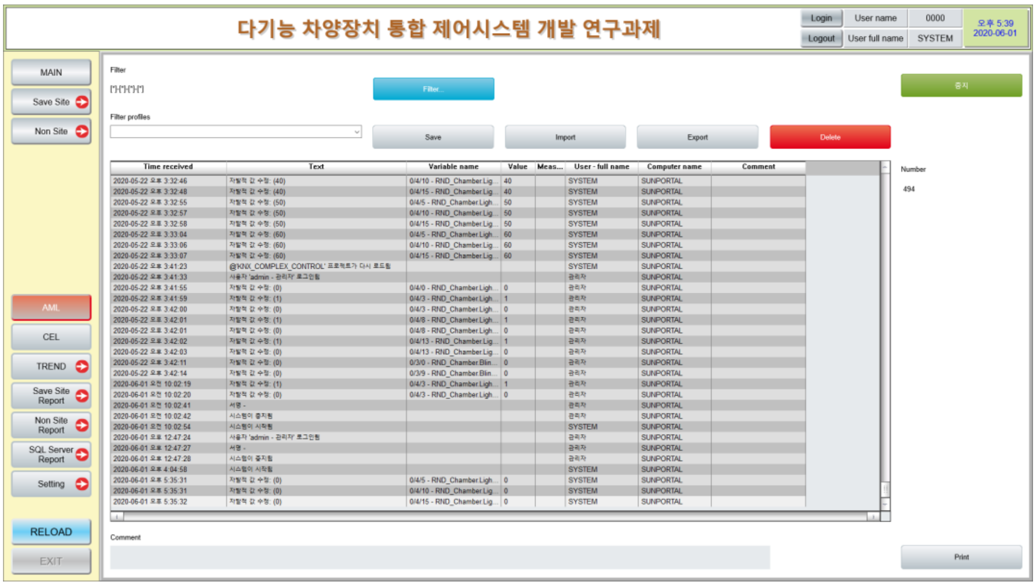


Fig. 18: Block diagram of the integrated control device



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Filter profiles

Number
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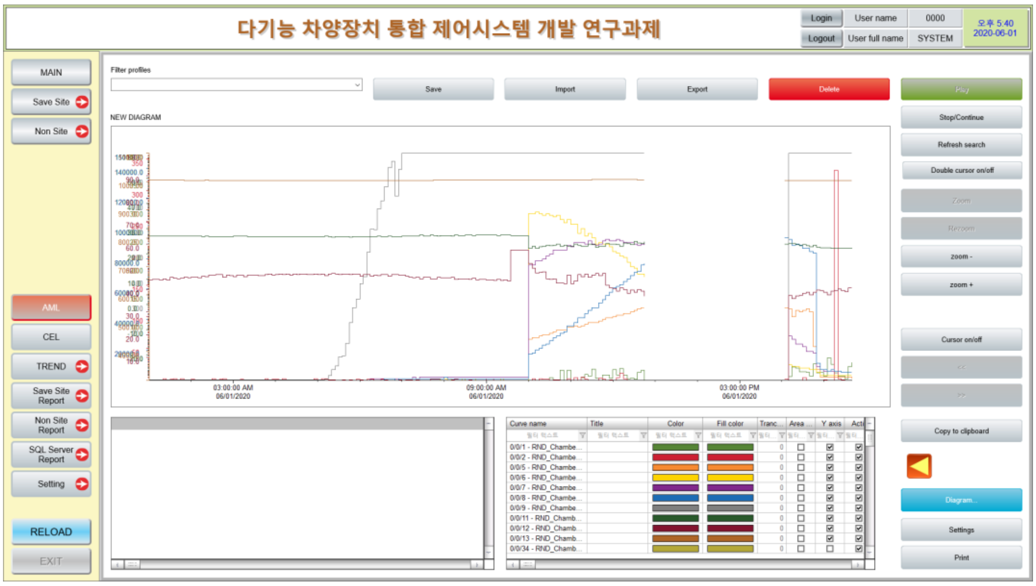
2020-05-22 오후 3:41:33	사용자 'admin - 관리자' 로그인됨				관리자	SUNPORTAL	
2020-05-22 오후 3:41:55	자발적 값 수정: (0)	0/4/0 - RND_Chamber.Ligh...	0		관리자	SUNPORTAL	
2020-05-22 오후 3:41:59	자발적 값 수정: (1)	0/4/3 - RND_Chamber.Ligh...	1		관리자	SUNPORTAL	
2020-05-22 오후 3:42:00	자발적 값 수정: (0)	0/4/3 - RND_Chamber.Ligh...	0		관리자	SUNPORTAL	
2020-05-22 오후 3:42:01	자발적 값 수정: (1)	0/4/8 - RND_Chamber.Ligh...	1		관리자	SUNPORTAL	
2020-05-22 오후 3:42:01	자발적 값 수정: (0)	0/4/8 - RND_Chamber.Ligh...	0		관리자	SUNPORTAL	
2020-05-22 오후 3:42:02	자발적 값 수정: (1)	0/4/13 - RND_Chamber.Lig...	1		관리자	SUNPORTAL	
2020-05-22 오후 3:42:03	자발적 값 수정: (0)	0/4/13 - RND_Chamber.Lig...	0		관리자	SUNPORTAL	
2020-05-22 오후 3:42:11	자발적 값 수정: (0)	0/3/0 - RND_Chamber.Blin...	0		관리자	SUNPORTAL	
2020-05-22 오후 3:42:14	자발적 값 수정: (0)	0/3/9 - RND_Chamber.Blin...	0		관리자	SUNPORTAL	
2020-06-01 오전 10:02:19	자발적 값 수정: (1)	0/4/3 - RND_Chamber.Ligh...	1		관리자	SUNPORTAL	
2020-06-01 오전 10:02:20	자발적 값 수정: (0)	0/4/3 - RND_Chamber.Ligh...	0		관리자	SUNPORTAL	
2020-06-01 오전 10:02:41	서명 -				관리자	SUNPORTAL	
2020-06-01 오전 10:02:42	시스템이 중지됨				관리자	SUNPORTAL	
2020-06-01 오전 10:02:54	시스템이 시작됨				SYSTEM	SUNPORTAL	
2020-06-01 오후 12:47:24	사용자 'admin - 관리자' 로그인됨				관리자	SUNPORTAL	
2020-06-01 오후 12:47:27	서명 -				관리자	SUNPORTAL	
2020-06-01 오후 12:47:28	시스템이 중지됨				관리자	SUNPORTAL	
2020-06-01 오후 4:04:58	시스템이 시작됨				SYSTEM	SUNPORTAL	
2020-06-01 오후 5:35:31	자발적 값 수정: (0)	0/4/5 - RND_Chamber.Ligh...	0		SYSTEM	SUNPORTAL	
2020-06-01 오후 5:35:31	자발적 값 수정: (0)	0/4/10 - RND_Chamber.Lig...	0		SYSTEM	SUNPORTAL	
2020-06-01 오후 5:35:32	자발적 값 수정: (0)	0/4/15 - RND_Chamber.Lig...	0		SYSTEM	SUNPORTAL	

Comment

Fig. 19: Real-time output of result data



Curve name	Title	Color	Fill color	Tranc...	Area ...	Y axis	Acti
필터 텍스트	필터 텍스트	필터 텍스트	필터 텍스트	필터...	필터...	필터...	필터...
0/0/1 - RND_Chambe...		🟩	🟩	0	☐	☑	☑
0/0/2 - RND_Chambe...		🟥	🟥	0	☐	☑	☑
0/0/5 - RND_Chambe...		🟧	🟧	0	☐	☑	☑
0/0/6 - RND_Chambe...		🟨	🟨	0	☐	☑	☑
0/0/7 - RND_Chambe...		🟪	🟪	0	☐	☑	☑
0/0/8 - RND_Chambe...		🟦	🟦	0	☐	☑	☑
0/0/9 - RND_Chambe...		⬜	⬜	0	☐	☑	☑
0/0/11 - RND_Chamb...		🟩	🟩	0	☐	☑	☑
0/0/12 - RND_Chamb...		🟥	🟥	0	☐	☑	☑
0/0/13 - RND_Chamb...		🟫	🟫	0	☐	☑	☑
0/0/34 - RND_Chamb...		🟨	🟨	0	☐	☐	☑

Fig. 20: Graph transformation and output system of data

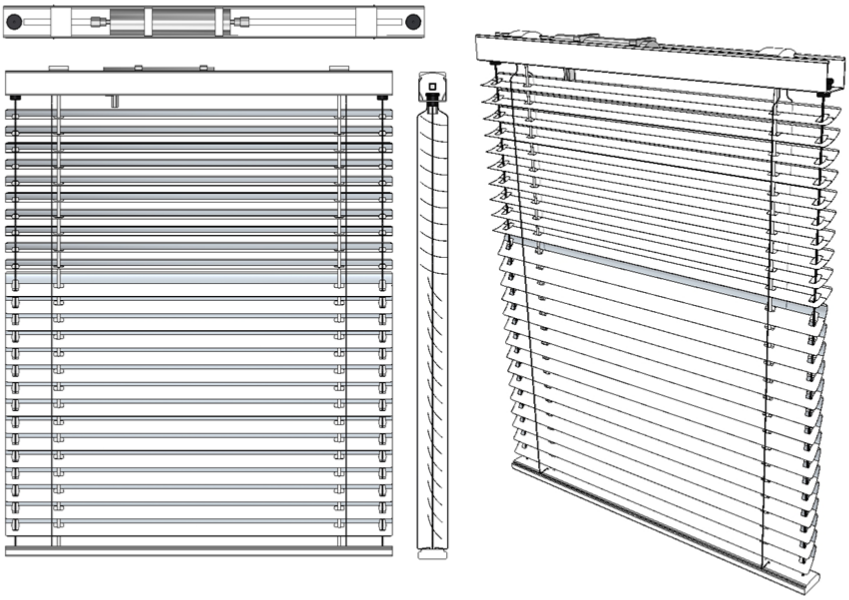


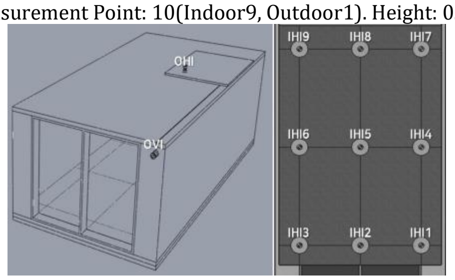
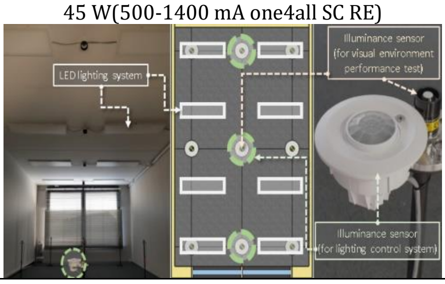
Fig. 21: Photoluminescent louver modeling

Table 1: Target of performance evaluation

the product category	Blind A (Proposed System)	Blind B
Blind Type	Light-collecting louver	Venetian Blind
Installation Location	Indoor	Indoor
Slat Type	Half-perforated	Non-perforating
Slat Width	60mm	60mm
Control Method	Automatic Control	Manual Control

The basic configuration of laboratories and equipment for measuring the rate of reduction of light energy is shown in Table 2. The laboratory consists of an opening with 1.5m x 2.0m plate glass (Clear 5mm, 2 Sets) facing south and a lighting fixture (8 sets) using LED lamps. Each light fixture is installed to control the output light flux of the light fixture according to the amount of light collected from the light sensor for control. The indoor light sensor has nine work surfaces that are 0.85m high from the floor and sensors are installed to measure the illumination level of the external horizontal surface.

Table 2: Composition of laboratory and equipment

Equipment	Content
Light Intensity	•Measurement Point: 10(Indoor9, Outdoor1). Height: 0.85m 
Lighting System	•Lighting: Led lamp •Lighting Density: 12W/m^2 •Number of Lights: 8 •Electricity Consumption: 38W •Lighting Control System: DALI MSensor 02(lighting control), Driver LCA 45 W(500-1400 mA one4all SC RE) 

Comparing the light energy usage of a general blind (Blind B) without automatic control and a proposed system (Blind A) with automatic control, the light fixture consumption power was measured with an average of 99W, a maximum of 122W, and a minimum of 79W for a general blind (Blind B) (Case 4, 5, 6). For the proposed system (Blind A) (Case 1, 2, 3), the light fixture consumption power was measured at an average of 66W, a maximum value of 113W, and a minimum value of 0W. Table 3 shows the power consumption comparison. Light energy usage by the case is derived as shown in Table 4.

Table 3: Comparison of power consumption

Category		Blind A (Suggestion System)	Blind B
light Fixture Power Consumption (W)	Maximum Value	113	122
	Minimum Value	0	79
	Average	66	99

Table 4: Lighting energy consumption by the case (Wh)

Time	Blind A (Suggestion System)			Blind B		
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
10:00	52.9	54.6	50.1	97.5	93.0	94.9
11:00	79.8	82.3	78.0	89.6	92.4	91.7
12:00	80.4	82.1	78.0	93.9	89.8	100.9
13:00	83.0	83.0	78.0	92.2	90.8	94.3
14:00	55.4	52.2	45.4	106.5	97.1	90.0
15:00	20.5	33.7	23.6	104.7	97.1	93.5
16:00	74.5	39.6	70.6	114.5	113.0	99.6
17:00	92.8	86.5	88.1	120.0	117.9	113.6
Sum	539.3	514.0	511.8	818.9	791.1	778.5
Average		521.7			796.2	

The light energy usage of Blind A (suggestion system) is 521.7wh and the light energy usage of the Blind B is 796.2wh, the rate of reduction of lighting energy compared to Blind B in Blind A (proposal system) was analyzed as 34.5% in accordance with Eq. 1.

$$\text{Lighting Energy Saving (\%)} = \frac{(Q_B - Q_A)}{Q_B} \times 100 \quad (1)$$

where, Q_B is Blind B lighting energy usage, and Q_A is Blind A (suggestion system) lighting energy usage.

3. Conclusion

In this paper, an integrated control system for multifunctional shading devices was designed, implemented, and evaluated. The proposed system enables integrated control of shading and lighting devices in the building, and the lighting energy performance according to changes in external environmental conditions could secure a correlation between external illumination and lighting energy.

In the future, research is needed on performance improvement and artificial intelligence-based optimal automation algorithms that enable integrated control based on monitoring systems of energy saving solutions.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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