Low-Cost Innovative Prototype of Automatically Adjustable Sun Louvers

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Abstract

The energy crisis and global warming nowadays drive many issues of architectural practice and research fields. One of effective strategies in reducing the heat inside buildings, is to design enclosure responsive to the climate and radiation from the sun. Today, few of intelligent systems imparted to the innovative building skins, have been already developed in the product market, however; these device sunfortunately cannot be offered to all consumers due to their advanced technology and expensive cost. This issue brings up the question how it could be possible to develop the climate responsive building skins by low-cost technology and budget. This research therefore proposes the low-cost innovative prototype of automatically adjustable louvers with real-time solar tracking system. The prototype is composed of steel blades installed with inexpensive adjustable prefab hinges, solar tracker system with light sensor, and local microcontroller board. Applying LUX sensor to measure the light resistant meter and passing the signal to control panel for rotating the louver-blade according to the direct sunangle, is proposed as the key solution for efficiency sun louvers for real-time climate. Also designing the algorithm code on microcontroller board based on Open-source software (OSS), makes this prototype possibly low-cost comparing to other adjustable louvers. This exterior shading devicewith simple, uncomplicated, and economical systems can be installed into both existing buildings and new constructions, and hopefully be an ideal part of the “green” architectural solution affordable for every single households.

Keywords: low-cost innovative prototype, automatically adjustable sun louvers, climate responsive architecture, exterior shading device

1. Introduction

The energy crisis and global warming nowadays drive many issues of architectural practice and research fields. One of effective strategies in reducing the heat inside buildings, is to design enclosure responsive to the climate and solar radiation from the sun. Facades comes to be crucial element to energy consumption and comfort in buildings. Integrating intelligent system in facade design is an effective way to achieve low energy buildings (Ochoa & Capeluto, 2008). As many researches on intelligent facades in sustainable architecture, facade element as main position interfacing between interior and exterior, contribute up to approximately 36% of energy consumption in hot climates (Haase & Amato, 2006).

Also, in research field of building envelope technology, Kathy Velikov and Geoffrey Thün analyzed the conceptual paradigm and development of high-performance building skins in "Responsive Building Envelopes: Characteristics and Evolving Paradigm" (Velikov & Thün, 2013). The evolution of the building envelope as a focus of design innovation in the twentieth century parallels advancements in envelope engineering and building science, as well as developments in computer engineering, cybernetics and artificial intelligence. In fact, this contemporary understanding of the building skin has absolutely changed the way in which architects approach building design, having shifted questions of performance away from the traditional formal and physical properties of building envelopes to reposition the discourse within a more expansive definition of how they behave. Exemplifying both research and design projects, the article try to redefine 4 specific terms such as smart, intelligent, interactive, and responsive, which all related to creating responsive building envelopes.

One of the critical design-built projects in development of intelligent building envelopes which somehow related to this research, is TU Darmstadt's 2007 Solar Decathlon House built by Technische Universität Darmstadt. The design incorporated an exterior building skin comprised of computer controlled wooden louvers with integrated photovoltaic panels that generated power while shielding the interior of the house from the sun. Although this Solar Decathlon House did not yet apply the solar tracking system for real-time louver control, but it makes an important breakthrough in the field of engaging advanced technologies and building automation system into residential buildings.

Today, few of intelligent systems imparted to the innovative building skins, have been already developedand launched in the product market, however; these devices unfortunately cannot be offered to all consumers due to their advanced technology and expensive cost as mostly the same as other eco-friendly products in the market, especially in Thailand. This issue brings up the question how it could be possible to develop the climate responsive building skins by low-cost technology and budget.

As all know about current approach of

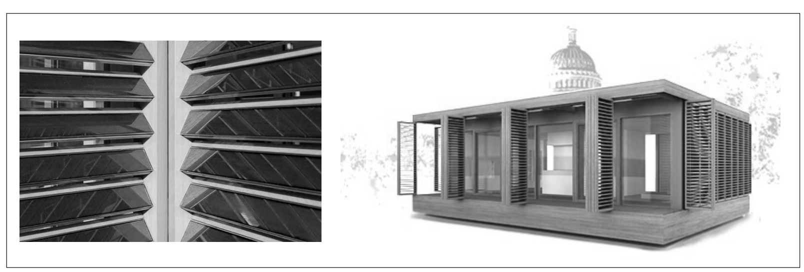


Figure 1. The prototype home built by Technische Universität Darmstadt for the 2007 US Solar Decathlon Competition.

Sustainable Architecture or Green Architecture, its definition is attempt to minimize the number of resources consumed in the building's construction, use and operation, as well as curtailing the harm done to the environment through the emission, pollution and waste of its components (Ragheb, El-Shimy & Ragheb, 2016). Inspired by this definition; the application of an appropriate technology in order to allow the building to take advantage of the natural environment, whether it is wind or sunlight (as we all know in Passive Design) and using Active Design as only needed, this research proposes the low-cost innovative prototype of automatically adjustable louvers with real-time solar tracking system. The main purpose is to integrate Active Design as the control system to transfer minimized electrical energy for adjusting the angle of louver blades that naturally responds to the dynamics of the direct sunlight on the one hand; while gaining maximum energy saving for air-conditioning cost on the other as shown in Figure 2. Therefore, the key to obtaining maximum efficiency is strategic implementation of both passive and active systems working together.

Enhancing the efficiency of solar radiation protection into the building, the operable sun louvers can be gained the indirect natural daylight in the same time. With emphasis in the low-cost technology, the prototype is composed of steel blades installed with inexpensive adjustable prefab hinges, solar tracking system with digital light sensor, and local microcontroller board. Applying LUX sensor to measure the light resistant meter and passing the signal to control panel for rotating the louver-blade according to the direct sun angle, is proposed as the key solution for efficiency sun louvers for real-time climate. Also designing the algorithm code on microcontroller board based on Open-source software (OSS), makes this prototype possibly low-cost if compared to other adjustable louvers in the market.

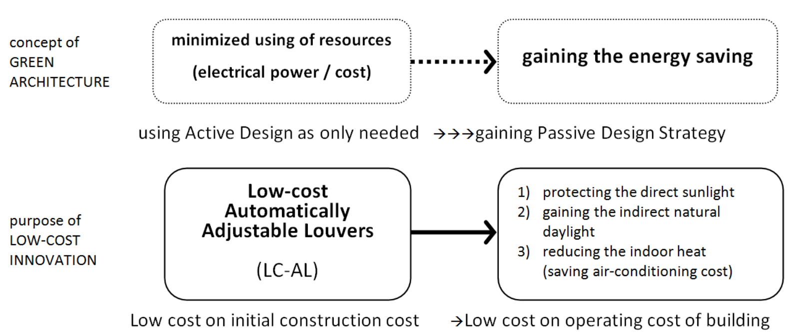


Figure 2. Conceptual framework of low-cost innovative prototype of an automatically adjustable sun louvers.

This exterior shading device with simple, uncomplicated, and economical systems can be installed into both existing buildings and new constructions, and hopefully be an ideal part of the "green" architectural solution affordable for every single households. With easily installation as other readymade electric household equipment, this DIY (Do-it-yourself) shading device would be raised the awareness of energy concern in Thai society. The low-cost innovation of automatically adjustable sun louvers therefore would be considered as one of the important ways following the idea in "sufficiency economy philosophy" of Thailand.

2. Objectives

As followings below are the objectives of research of low-cost innovative prototype of an automatically adjustable sun louvers:

1. To analyze the Sun tracking system on adjustable louvers and related control devices for both hardware and software which are based on low-cost technology and building materials.
2. To invent the prototype of low-cost automatically adjustable sun louvers with real-time solar tracking system.

3. To propose the readymade prototype of automatically adjustable louver panel as DIY (Do-it-yourself) shading device which can be easily installed into both existing and new households. By this way, the low-cost innovation would encourage the society the awareness of energy concern with the affordable solution according to "sufficiency economy philosophy" in Thailand.

Figure 3. Jalousies window, originally designed by Van Ellis Huff in 1939, used for tropical climate housing in Florida.

3. Background and research methodology

In this research, the innovative prototype has been developed to focused on efficiency solar radiation protection from direct sunlight into the building. The main concept of this proposed deviceis that it should be composed of local raw materials which generally be available in the market and low budget, and also the processing of design on programming code in microcontroller board should be possibly found on Open-source software (OSS) whose source code is released under a license in which the copyright holder grants users the rights to study, change, and distribute the software to anyone and for any purpose (St. Laurent, 2008).

Figure 4. Exemplary projects applying the jalousies hardware set as low-cost outdoor shading device, designed by co-author, Srisak Phattanawasin; 4C House (2007) on the left and the top right, and Automotive Engineering Workshop Building at Thammasat University (2015) on the bottom right.

As preliminary study, the prototype further implemented the low cost prefab hinge set of adjustable louvers which is normally used for 6 mm. glass blade in jalousies window (Figure 3). Changing material status from transparent blade to be solid blade such as wooden plank or fiber-cement board, makes this jalousies hardware set possibly adapted for the low-cost outdoor shading device applied in exemplary projects designed by co-author, Srisak Phattanawasin (as shown in Figure 4).

With easy access of current computer technology, the hand-cranked control of hinge set could be placed by automatic control integrated of low-cost sensor and programming codebased on Open-source hardware and software. The procedures of experimental research are following:

1. Data collecting and reviewing on all hardware and equipments such as prefab hinge set of adjustable louvers, blade material as well as frame which are available in the local market.Comparing the price and performance of each types of louver and materials. All components selected should be accordingly matched with the control system and electronic equipments in terms of cost, material weight, motor driver's power as well as stability.

2. Analyzing the software and control system.Especially, the solar tracking systems have been reviewed and analyzed for developing the control system in terms of low-cost budget and reliable performance. Also studying in details of electronic components such as light-sensitive sensors (LDR - Light Dependent Resister and LUX sensor), microcontroller, motor driver, as well as actuator, is very important for designing the prototype of an automatically adjustable sun louvers.

3. Developing the concept and designing the prototype. After review on both hardware and software tools, the experiments on constructing many mock-up models through the final prototype were conducted to examine both the algorithm code in control system and the performance of real-time automatically adjusting of blade angle synchronized with LUX sensor. The process of trial and error finding an appropriate value of illuminance, has been set up as a key default for code programming. And finally, the final prototype has been built to proposed how to be installed in an existing building and operated as sun louver device.

4. Prototype concept and working flowchart

The development of prototype concept is determined the real-time solar tracking system as the independent variable which control the movement of louver angle related to the real-time direct sunlight. This control system is composed of 3 significant factors; such as 1) movement mechanisms of louver device, 2) electronic hardware, and 3) software system which run by algorithm code to measure changeable light meter and translate to be rotating control of louver-blade angle. The dependent variable is precision and accuracy in prototype working system which controls adjustable louver to protect direct sunlight passing through the building inside, and also this outdoor louver should be easy to be installed as other DIY (Do-it-yourself) home equipments, and absolutely be low cost of production.

In the study of control system for an experiment prototype, the application of following theories and concepts have been thoroughly reviewed.

4.1 Solar tracking system

The solar tracking systems mostly have been developed for devices that need to receive energy directly from the sun; for example, an electrical power generated by solar cell. The application of light sensor tracking the movement of sunlight source, is one of the most effective way with low-cost production.This same concept can be therefore applied for tracking the sunlight direction to prevent the solar radiation passing through the building (Lopkerd, 2015).

4.2 Light detecting technology

To study the application of light sensor which is most available in local market in low price, but effective. The two types of light sensor have been reviewed and tested; one is LDR (Light Dependent resistor), and another is LUX sensor (digital light sensor). In this experiment, the result of both types was considered to select for the component in prototype design.Normally LDR is considered to be very low cost equipment, however its deriving number of illuminance value has no reference unit and also has be shown in range between 0 to 1024 which depending on varies electronic circuit connectors and referent default of light resistant values. Meanwhile LUX sensor (digital light sensor) having even higher price but still affordable, could be measured in LUX units and is possibly determined the referent default of light resistant values for control system.

4.3 Programming code of algorithm

An algorithm code of detecting and tracking the sunlight direction is related with the type of the light sensor. By preliminary test of this research, the comparative analysis of the different values between the variable position and orientation in louver-blade installation, would be reviewed to develop the appropriate code for control system. The design concept of real-time solar tracking initiates by comparing between the numeric value of illuminance from 2 main sensor positions vertically; the bottom one (L1) will be received the sunlight even the louver is closed, although the upper one (L2) will be get the sunlight when the louver is opened up. The numeric difference of 2 light sensor above can be defined in 3 conditions to control automatically real-time opened or closed louver depending on sunlight angle, as followings (see Figure 5):

Condition # 1: Protecting the direct sunlight and gaining the indirect sunlight, is normally day-time condition; the control system is in stop movement.

Condition # 2: Sunlight angle starts to be higher position in the morning; the direct sunlight cannot get through the louvers, so the control system will be in open direction.

Condition # 3: Sunlight angle changes to be lower position in the afternoon; the direct sunlight can get through the louvers and get inside the building behind, so the control system will be in close direction.

During the design and development process, the working system can be concluded as shown in the following flowchart (Figure 6). Starting from the detection of sunlight source, the digital light sensor (L1, L2, L3) measured the light illuminance values in LUX unit (lx), and then transmitted all data to microcontroller to be calculated comparatively by algorithm code (decoding LUX data to choose condition of motor control), and finally translated the result via motor driver and linear actuator accordingly, to control the louver-blade angle automatically as real-time sunlight direction.

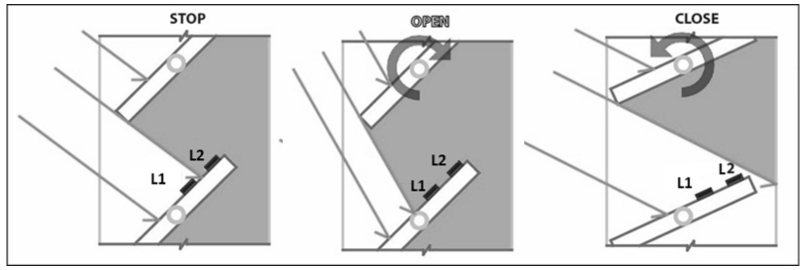


Figure 5. Diagram showing the initiate concept of 3 defining conditions from 2 light sensors (L1 & L2) which related to real-time solar tracking.

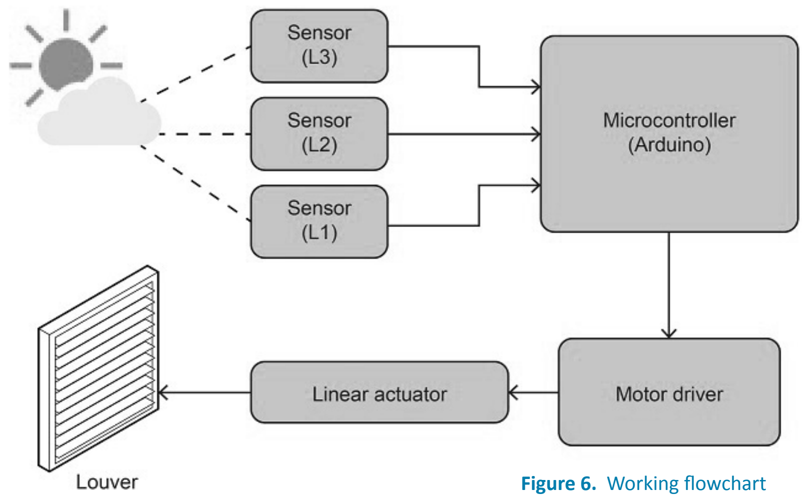


Figure 6. Working flowchart demonstrating how the prototype operates from the sunlight sourceto an automatically adjustable louver in real-time changes.

5. Prototype components and installation

After reviewing all equipments and materials, many mock-up models have been assembled to test both working control system (software) and louver-blade movement (hardware) in the lab. The main components for prototype finally are following:

5.1 Digital light sensor (LUX sensor)

Comparative analyzing between LDR (Light Dependent Resistor) and Digital light sensor, the research found that applying Digital light sensor gained more accuracy outcome than LDR and can be measured in numeric values of illuminance (lux unit) which is very necessary in writing the programming code of algorithm to control as defining conditions. For the prototype, TSL2561 module which can be measured the illuminance values in range between 0 to 40,000 LUX, is applied by installing on the louver-blade surface (L1 & L2) and mullion (L3).

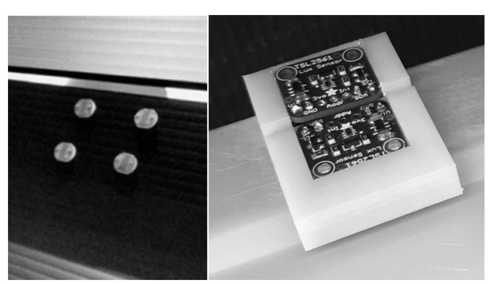


Figure 7. LDR (Light Dependent Resistor) and LUX sensor (Digital light sensor).

While as 2 light sensors (L1 & L2) attached on vertical positions in the louver-blade, is calculated for comparative LUX units which are finally defined in 3 conditions to control automatically real-time opened or closed louver depending on sunlight angle, the 3rd sensor (L3) installed on mullion surface, is used for setting the reference value from the sunlight angle at each time interval. For this proposal device, the reference value is arranged on 8,000 lux as numeric index of optimum values to define open or close condition.The reason is that 8,000 lux is the outdoor illuminance average of overcast sky conditions in a tropical climate such as Thailand. (David, Donn, Garde & Lenoir). This index of illuminance value need to be set up for controlling the program conditions, and also could be changed to be suitable with other climates in different countries.

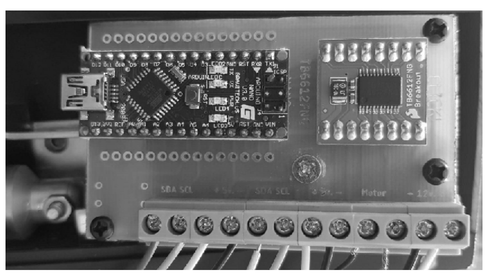


Figure 8. Arduino Nano (microcontroller) and TB6612FNG (motor driver).

Figure 9. Linear Actuator.

5.2 Microcontroller

According to the Open source hardware and software, Arduino board has been selected due to its properties in programming such as easy, convenient and not complicated (Schwartz, 2014). Transmitting the data from microcontroller to an actuator in back-and-forth direction, the system need to be passed through a motor drive circuit (TB6612FNG module) which has tiny size and can be suitable for electrical power related to the actuator's. In circuit designing for efficiency, safe, and compact, the connecting line between microcontroller and motor driverwith systematic wiring to sensors, actuator, and power outlet, need to be placed on PCB (printed circuit board) to support all electric loop and connector conveniently as shown in Figure 8.

5.3 Actuator

Actuator is normally the sensor responder via microcontroller. In this prototype, the linear actuator (Figure 9) is selected due to its high power for relatively driving a set of 11 steel louver-blades (9,350 grams) and also its case feature that has the moist protection for motor inside. To consider on the control mechanism of louver and possibility to be installed in aluminium mullion, this linear actuator run by direct current on 12 volts, has sufficient torque to bedriven the louver-blade weight in 750 N. with 100 mm. moving distance.

5.4 Algorithm code

For running the control system of louver, algorithm code need to be determined to make the right sequence of programming which has following protocols (Figure 10);

Step # 1: Declare & Initialize - to define all variables (lux units from light sensor) and transmit to an actuator.

Step # 2: Comparison - to calculate all variables by comparative analyzing their status and control conditions among lux units from L1, L2, & L3 which refer to an established value; in this case, 8,000 luxis numeric reference value to define open or close condition (this value can be adjusted to be fit for other conditions and climates).

Step# 3: Control Hardware - after receiving each condition to control, the data has been transmitted to control the linear actuator moving up or down vertically which related to the louver-blade angle.

In comparison stage, the light sensor status from variables will be evaluated in 2 conditions (as shown in Table 1); if measured lux units are higher than the index value (8,000 lux), the system will be closed to protect the direct sunlight. On the other hand, if measured LUX units are lower than or equal to the index value (8,000 lux), the working system will be driven to open up the louver-blade angle. Therefore the comparative system analysis from 3 light sensors can be estimatedin 8 conditions by 3 operative results such as stop, open and close, to move the linear actuator up and down and sequentially tilted the louver-blades opened or closed.

5.5 Louver hardware set (hinge set, blade, and frame)

Normally the low-cost prefab hinge set have been produced in types of turning and pushing crank to control the louver-blade angle, meanwhile the channel, clip and hand-crank are made of both aluminium and steel, together withboth 4" and 6" width parallel glasslouver-blade. But for this prototype, after reviews all types and materials of hardware, the 4" steel hinge-clip with pushing hand-crank is selected to be developed and designed since this type can be tilted open wider than turning crank one (open to 180 degree tilt angle). Also due to changing the opacity properties from glass to steel louver-blade, the steel hinge-clip and channel are more suitable than aluminium in terms of their weight support and reliability.

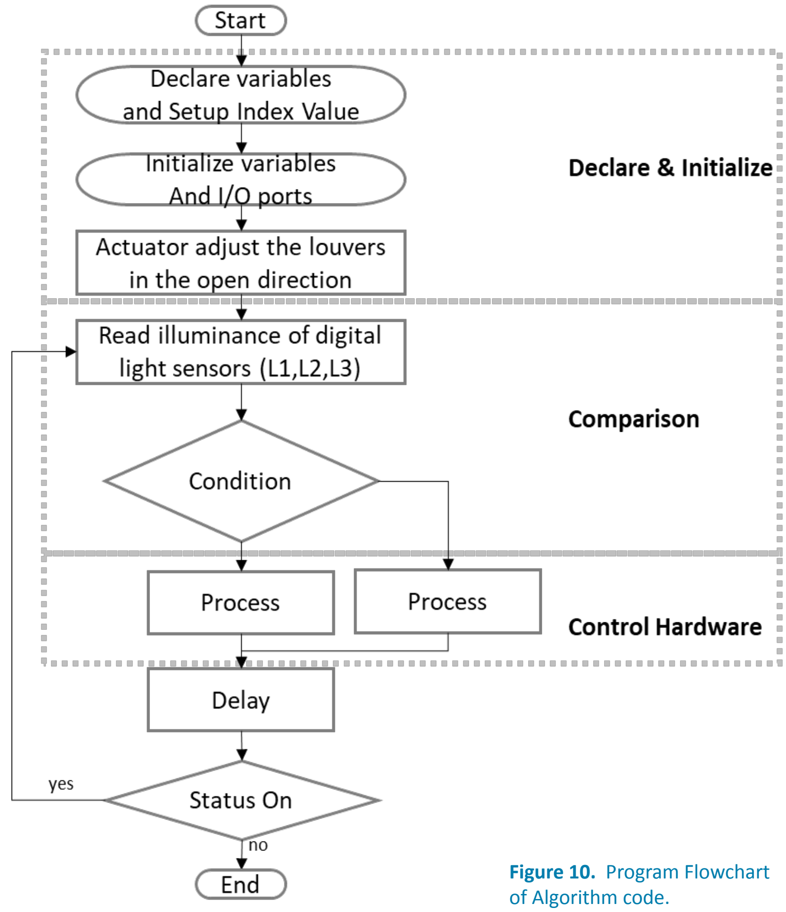


Figure 10. Program Flowchart of Algorithm code.

Table 1. Control conditions of adjustable louvers by tracking sunlight from LUX sensors (L1, L2 and L3) and measured comparing to the index value of illuminance (8,000 lux).

	illuminance value state							
Sensor L1 status	H	H	L	L	H	H	L	L
Sensor L2 status	H	H	L	L	L	L	H	H
Sensor L3 status	H	L	H	L	H	L	H	L
Louver direction	Close	Close	Close	Open	Stop	Stop	Close	Open
H = Higher than the reference value								
L = Lower than or equal to reference value								

For the louver-blade material, even aluminium has its advantage in light weight but when focusing on low-cost concern, the typical steel blades produced in construction market are more cheaper than folded-up aluminium blades. Thus, 2 mm. thickness steel louver-blade built up in typical corrugated flat shape to make thin panel more strengthen with light weight property, is finally selected for the prototype; each steel louver-blade in 1 meter wide has 850 grams weigh.

In frame designing process, the construction criteria are low-cost, durable, light-weight, and having the hollow tube-like owning to its installation of electric wire and control equipments such as a microcontroller board, as well asan actuator. Therefore typical 2” x 4” rectangle aluminium is selected for the louver frame. Except for the side mullion which has control systems inside, 2” x 4” U-shaped frame with sliding side-cover, is designed to be easily installed and can be uncovered up for the future maintenance.

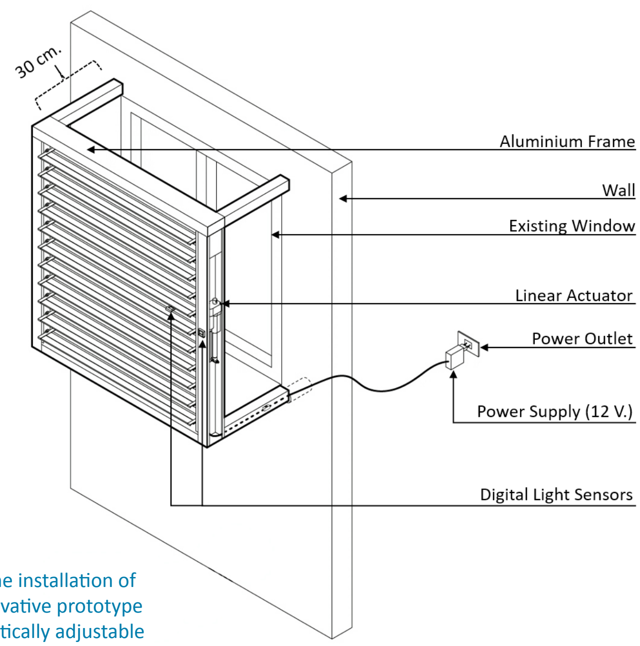


Figure 11. The installation of low-cost innovative prototype of an automatically adjustable sun louvers.

5.6 Installation

The prototype louver frame is currently constructed in 0.90 (W) x 1.00 (H) meters to fit with standard size of typical windows in any households both old and new buildings. For concerning on how to install with existing house’s window, 30 cm. long aluminiumarms on 4 corners of the frame, are supplemented for attach to the building, and also this 2”x 2” square frame is housed for electric wire to be connected to power outlet (via DC power adaptor on 12 volts) inside the building. As completed set of louver prototype including the control system inside,its total weight is only 15 kilograms which could be easily installed by DIY anchor screws support. The outdoor louver prototype will be built attached to reinforce concrete wall or steel stud which framing the existing window as shown in Figure 11. As the experiment process, the mock-up stand for hanging the louver prototype (Figure 12) was built for test run on different orientations of window and convenient to be transferred.

Figure 12. Mock-up stand for hanging the prototype of an automatically adjustable sun louvers.

Connecting control system to louver blade, 2 light sensors (L1 & L2) built in plastic case will be clipped to actual blade to catch sunlight and measure value of illuminance, due to their relations of position as mentioned above in the algorithm code for control system. This plastic case designed for easily sliding in steel louver-blade profile, should be not less than 15 cm. far from the control mullion to avoid the cast shadow of 2” x 4” frame and is as shortest length as possible for wiring installation.

While as L3 light sensor will be attached on the mullion surface to synchronize the data programming with L1 and L2 sensor. Figure 13 shows how these three light sensors (L1, L2 & L3) will be installed in louver-blade and mullion accordingly.

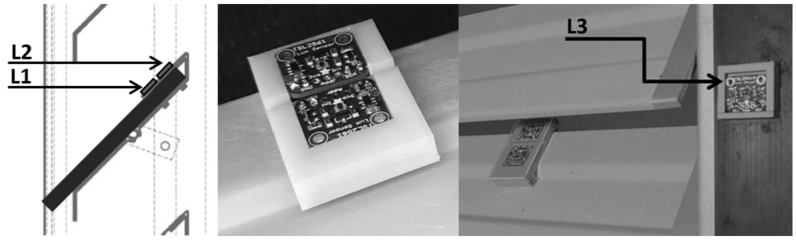
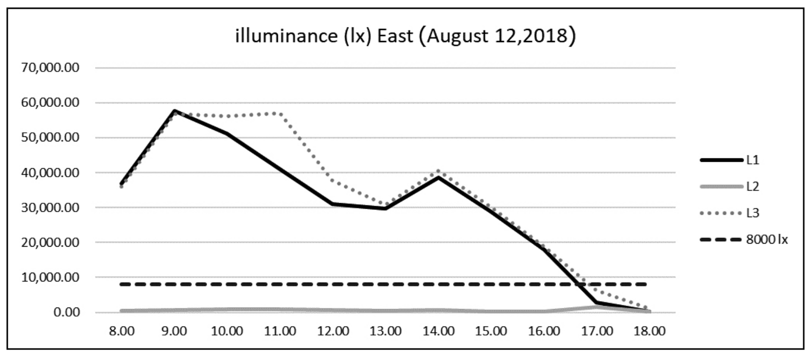


Figure 13. Installation of light sensor (L1, L2, & L3) on the louver-blade and frame accordingly.

6. Evaluation of prototype

After building the mock-ups and prototype, the final test run has be set up to evaluate the performance of working system, which mainly focusing on tracking the direction of sunlight and has an accuracy output as adjusting the louver-blade angle in real-time conditions. The results of each experiment can be summarized in the graph of the illuminance values from 3 light sensors module (see sample of comparative graphs on Figure 14-17). The duration of test run started from 8.00 am. until 5.00 pm. as working hours period, and also located in 4 different orientations such as the North, South, East and West directions with geographic coordinates on: 14°04’06.1”N 100°36’30.9”E.

From Figure 14 - 17, the graphs demonstrates that the actuator will drive to change the louver-blade angle preventing the direct sunlight when sensor catching the illuminance values over than 8,000 LUX. On the other hand, the louver-blade will be fully opened when the sky is cloudy or overcast condition. From these graphs, the research found thattest run examining the control system automatically, works as the same conditions as coding in algorithm. For all 4 orientations, whenever the illuminance value by light sensor L1 and L3 are higher than 8,000 lux, the louver-blade will be tilted to close to protect the direct sunlight; meanwhile light sensor L2 will always be lower than 8,000 lux which is reference value in coding.



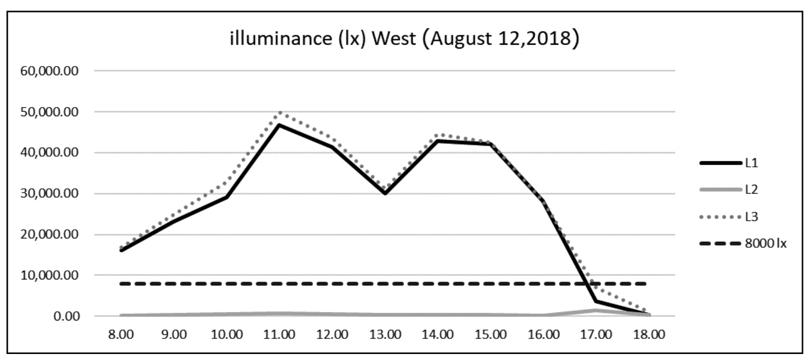


Figure 14. Comparative graph showing measured values of illuminance of light sensors in prototype located in different orientations during August. (East & West)

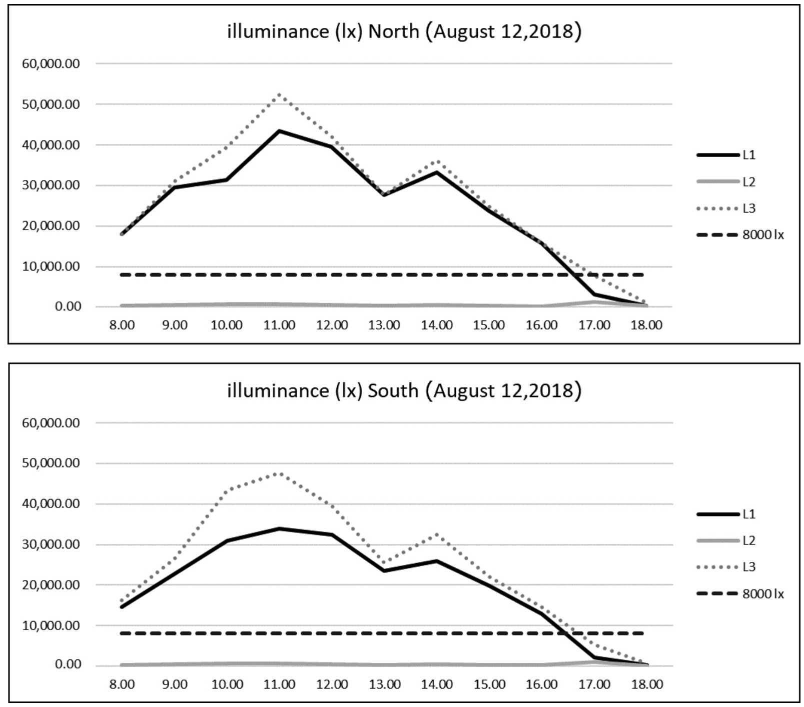


Figure 15. Comparative graph showing measured values of illuminance of light sensors in prototype located in different orientations during August. (North & South)

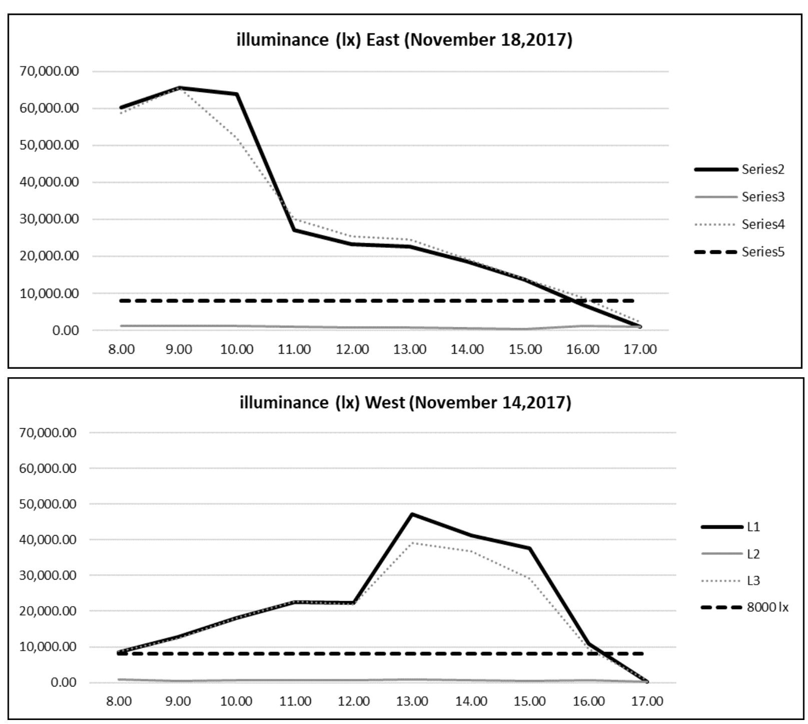


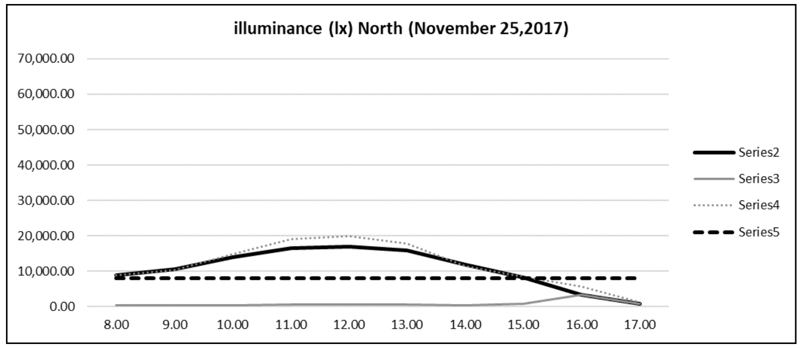
Figure 16. Comparative graph showing measured values of illuminance of light sensors in prototype located in different orientations during November. (East & West)

Furthermore, when we compared the graphs from two seasons (raining season in August and winter season in November), especially in South orientation, the illuminance value in November are much higher than in August apparently. The reason can be explained by 2 explicit factors in daylight's facts; one is that the Sun in November encircling pass the South in very low angle (that experiment's day close to Winter solstice on December 21) which effects to the high lux of illuminance. Another, the sky condition in November is more clearer than in August which is always raining and overcast. Therefore these daylight's facts relatively demonstrated that the performance test of louver prototype is very reliable.

For the cost calculation of production of automatically adjustable sun louver prototype (Table 2), its average price in Thai Baht per square meter is still lower than other louver brands without any control system; moreover, its cost is much lower than the imported semi-automatic shading devices in construction market due to import fees and taxes. As preliminary survey on shading device product market (Table 3), all programmed louvers without the solar tracking system for real-time conditions, are mostly very expensive and hardly affordable for general population. Whereas this readymade prototype which is easily installed as other DIY tools, could be produced in low-cost budget due to its low-cost hardware and software, and it would be more inexpensive if the product has been developed in the level of industrial manufacturing.

7. Conclusions and future work

As above discussion in this paper, intelligent facades may not be necessary to be always expensive because this low-cost innovative prototype of automatically adjustable sun louvers has some proofs in both efficiency and affordability. Applying LUX sensor to measure the light resistant meter and passing the signal to control



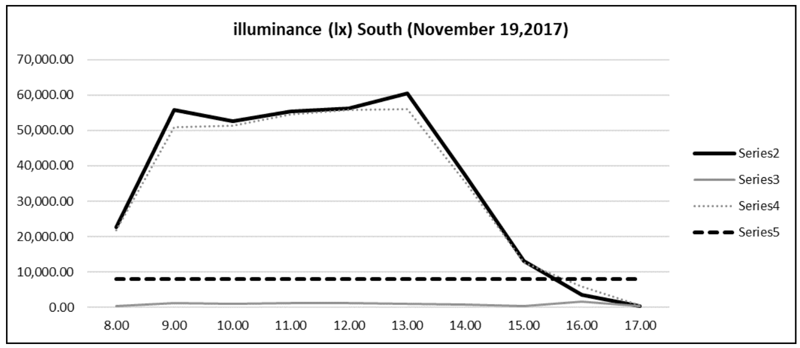


Figure 17. Comparative graph showing measured values of illuminance of light sensors in prototype located in different orientations during November. (North & South)

Table 2. Production cost of prototype per unit. The table indicates cost of each item both in control system and louver equipment.

Description		Unit	Cost/Unit (Baht)	Cost (Baht)	Cost (Baht)
Control System					
	Microcontroller (Arduino)	1	600	250	
	Light Sensor	3	150	450	
	Linear Motor	1	2,400	2,400	
	Adaptor 12 Volts	1	350	350	
	Wiring & Packaging	1	1,500	1,500	4,950
Louver Equipment					
	Louver & Blade	1	1,500	2,882	
	Aluminuim Frame	1	3,000	3,000	5,882
Total					10,832

Table 3. Comparative price among other brands of louver (both manual and automatic control) in construction market of Thailand.

Band	Blade Material	Mechanism	Cost (Baht)/sq.m.
MVP Four Stars	Aluminium	Rotation (manual)	12,500
Zimplex	Aluminium	Lever (manual)	14,800
Hunter Douglas	Aluminium	Semi-Auto (remote control)	50,000

panel for tilting the louver-blade opened or closed according to the direct sun angle, is proposed as the key solution for efficiency sun louvers for real-time climate. Also designing the algorithm code on microcontroller board based on Open-source software (OSS), makes this prototype possibly low-cost comparing to other adjustable louvers. This exterior shading device with simple, uncomplicated, and economical systems can be installed into both existing buildings and new constructions, and hopefully be an ideal part of the "green" architectural solution affordable for every single households.

For the future work plans, the researchers will continue to develop this innovative louver prototype possibly run by solar cell instead of electric power consuming. By this way, if we could fight against the heat from solar radiation by the solar energy itself, it would be the same as an English proverb saying "tit-for-tat strategy", and hopefully be net zero-cost of charge and energy at the end. The concept of passive design will be fully achieved by self-sustainable architecture coexisting within the nature. As written in the article "Responsive Building Envelopes: Characteristics and Evolving Paradigms"(Velikov & Thün, 2013), whenever we concern about the guidelines to reduce energy consumption in buildings as much as possible, the intelligent building skinin the future should be built of some material and technology which can generate self-powering and self-actuating.

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