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Simulation Study of a Smart Factory Lighting and Shading System

Wing Siong Lee[1], Asiah Ismam[1], Faris Kamaruzaman[1], Yi Leang Lim[1], Keng Wai Chan[1,*]

[1] School of Mechanical Engineering, Universiti Sains Malaysia Engineering Campus, Penang, Malaysia

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ABSTRACT

Insufficient and uneven light distribution in the workplace affect the quality of work that requires high precision. In addition, inadequate lighting not only affects the health of workers but is also linked with a condition called 'Sick Building Syndrome'. The artificial light in factories is commonly manually controlled, resulting in energy wastage. Hence this paper presents a smart lighting and shading system to create both comfort lighting and energy-efficient factory environment. Three-dimensional modelling simulations were built using Tinkercad and Revit. The control system built utilizes the motorized skylight solar shades and the artificial high LED Bay, which able to adapt with the fluctuating factory lighting condition. If the light enters the factory through the motorized shade on the factory ceiling is insufficient or uneven, the artificial light will be switched on. The implementation of both mechanisms managed to improve the light distribution evenness and keep the light intensity level in the factory in the range between 885 lux and 1306 Lux from 9am to 6pm, while from 6pm onwards at average of about 900 lux. Furthermore, the electrical energy consumption is reduced significantly during the daytime as the control system has utilized the sunlight as part of the light source for the factory. The smart system can save as much as 22.39%, or 55.2128kWh from 9am to 7pm. In conclusion, the smart lighting and shading control system has proven the effectiveness theoretically, and the objectives were achieved.

1. Introduction

Insufficient and uneven light distribution in the workplace can have a great effect in quality of work especially when doing the work that requires high precision. Inadequate lighting not only affects the health of workers [1], causing symptoms like eyestrain, migraine and headaches, but is also linked with a condition called 'Sick Building Syndrome' [2]. Nowadays, the artificial light in most of the factory is controlled manually without any control system which will result in the waste of energy as the light source is at full load once it is switched on.

The potential for power efficient has made the use of automated lighting controls such as sensors in advanced buildings [3,4]. Most of the manufacturing factory halls are equipped with a manually controlled lighting system, though there are some high technology automated lighting systems available in the market. The light intensity level of the existing common lighting system at the

* *Corresponding author.*
E-mail address: kengwai.chan@usm.my

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workplace is impossible to be adjusted as the standard system does not come with a proper control system. This leads to an undesirable working environment to the workplace [5]. In additional, an uneven light distribution throughout the utilities and the workplace might affect the quality of work and also the worker efficiency. Increasing the number of light sources might be able to achieve the optimum light intensity level at the factory workplace. However, without a proper control system can result in energy wastage as well which will increase the expenses of the factory [8]. Therefore, this paper is focusing on building a smart lighting and shading system that utilizes two mechanisms, namely the control of the motorized skylight solar shade, and the application of adjustable high LED bay [6]. And LED lamps is an eco-friendly option to decrease the greenhouse gas emission [7]. The building comfort control system monitors both mentioned mechanisms, to achieve an optimum lighting level, hence excessive power usage can be avoided [8].

2. Methodology

In general, a system was designed to get feedback based on the light intensity level at the factory workplace. The operation flow of the system goes by, firstly the detection of current lighting intensity level by the light dependent resistor (LDR sensor) at each workstation area in the factory. Then the motorized shade will receive signal impulse from the sensors and response accordingly. Commands will be sent to the motor controller and the LED driver from the microcontroller (Arduino), to control the opening length of the motorized shade and the power supply of the LED light [9, 10].

At this level, there will be two possibilities of receiving the signal, either high light intensity level or low intensity level. If the signal is high, the motorized shade will close gradually according to how much the light needs to reach the optimum light intensity level. Based on the Occupational Safety and Health Administration (OSHA), the optimum range of the light intensity level in the industrial factory workplace area is 900-1150 lux [11-13]. When the system is responding to a 'high' signal, the system will automatically close the shade until it reaches the range of the optimum lux being set inside the program. In contrast, if the signal received is low, the motorized skylight solar shade will open gradually, allowing sunray to pass through the skylight, until the light intensity level reaches an optimum level [14, 15]. Based on the specification of the Skylight 2 FlexShade®, the gap is 73mm on three slide-variable gaps due to fabric bundle diameter on roller end [16]. So, if the light intensity is yet to be sufficient, the LED light (High Bay LED) will be switched on and be adjusted until the optimum light intensity level.

2.1 Electrical Modelling

An electrical circuit of the system was modelled and simulated by using Tinkercad, as shown in Figure 1. The design mainly focused on the sensor that will give the feedback to the movement of the shade motor. The circuit design consists of two LDRs, LDR1 to detect the light intensity level at the working floor one, while LDR2 sense the level of incoming sunray and to differentiate weather it's day, night or cloudy. Then, two push button switches acted as the upper limit and lower limit at the frame of skylight to avoid the shade from damage. Next, motor played the main role to control the opening and closing of the shade in response to the feedback from the sensor. LED light represents the artificial light, mainly to aid if the sunlight entering through the skylight shade was insufficient. The motor driver acted as a small Current Amplifier whose function was to convert a low-current control signal into a higher-current signal that can drive a motor.

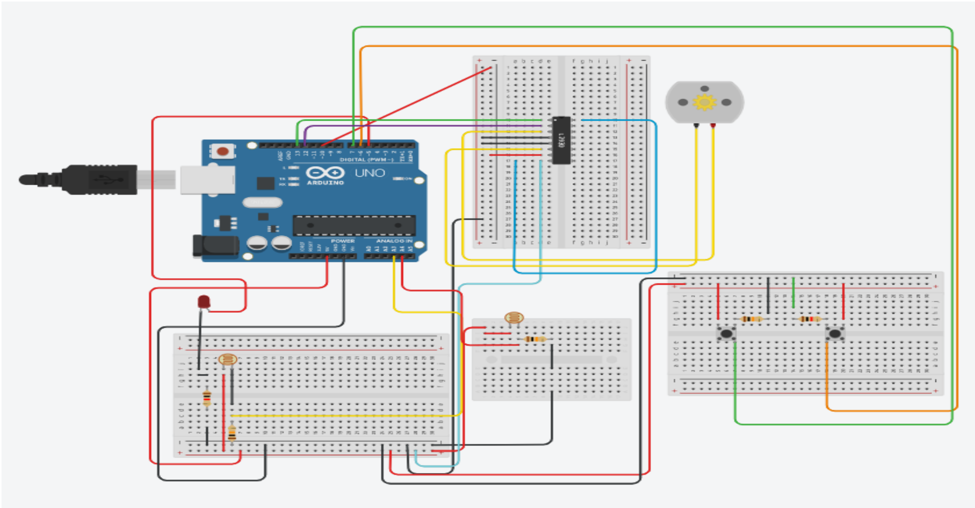

Fig. 1. Breadboard diagram for the system in Tinkercad

2.2 Control System Simulation

A factory of 2592 m^2 was modelled using Revit. First, the floor plan is inserted into Revit, then the beam structure of the factory was drawn by using the beam system function. Finally, other components such as walls, roof, doors and skylight windows were drawn or inserted to the beam structure of the factory as shown in Figure 2.

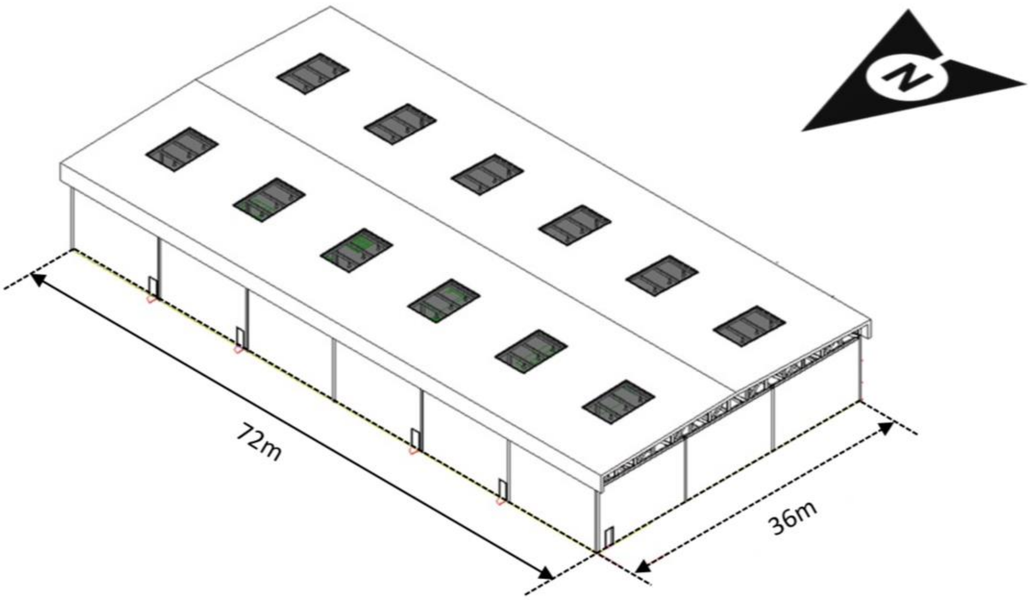

Fig. 2. Factory CAD model after inserting the walls, roof, doors and skylight

In Revit, a light intensity analysis was conducted first to determine the input condition for the subsequent simulation. A light intensity level analysis without artificial light was done at 9am, 12pm, 3pm and 6pm. The factory was divided into 12 zones, F1 until F12 since there was a total of 12 motorized shade in the factory. Twelve cameras were placed at each zone as shown in the Figure 3 and 4 to observe and obtain the interior light intensity level.

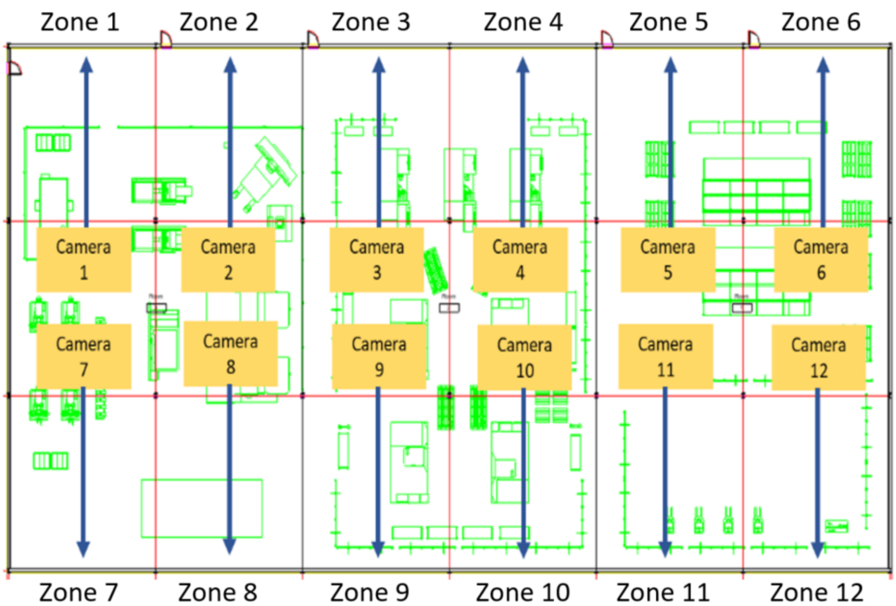

Fig. 3. Camera setup in the factory

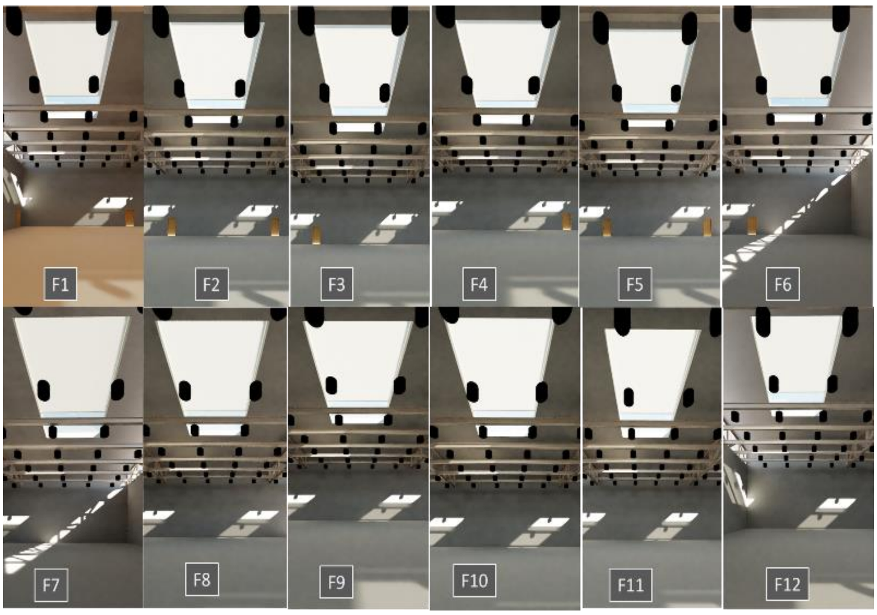

Fig. 4. Actual interior view from the cameras inside of the factory

Two sensors were located at each zone. Sensor LDR1 was located near to the ground to detect the workplace light intensity level while the sensor LDR2 was placed near to the shade and roof to detect the incoming sunlight intensity level. The light intensity level detected by each LDR and served as the input data for Revit Dynamo. Once the input condition was obtained, a setup of the feedback control nodes to control the LED lights and the motorized shades were modelled in Revit Dynamo. The input condition was typed into a blank code block as shown in the Figure 5. Every single line in each block represents the LDR value for each zone. All the input values were connected to their respective zone nodes for feedback control.

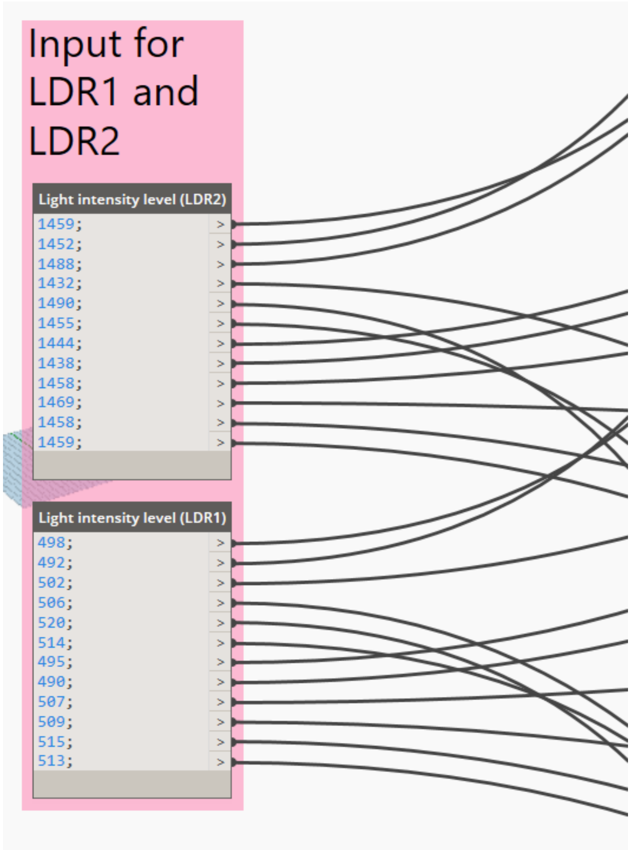

Fig. 5. Code block in Revit Dynamo for entering the input condition

As shown in Figure 6, the input values from the LDR1 and LDR2 were connected to the feedback control nodes. For the feedback control of shade (Feedback control for LDR2), a code block was used with the if loop statement. From the coding, when the LDR2 value was lesser than 200 or more than 2000, the shade returned to 6.1 indicating it was completely closed. As the LDR2 value below 200, the outdoor light is negligible to be light source for indoor, fully closed shade may avoid the escape of the indoor artificial lights; while LDR2 value more than 2000, the excessive sunlight might cause an uneven light distribution which is undesired in a comfort lighting system. Meanwhile, when the LDR2 value was between 200 and 500, the shade returned to 0, indicating it was completely opened to allow sunlight to enter the factory.

For the feedback control of LED light (Feedback control for LDR1), the mapping function handled the feedback signal from LDR1. When LDR1 value was high due to the increase in the internal light intensity, the power supply to the LED light was reduced. Conversely, when the LDR1 value was low, more power was supplied to the LED light to ensure that the light intensity level inside the factory was maintained at the optimum level. When the value of LDR1 was 1000, it corresponded to the power of 20W whereas when the value of LDR1 was 0, it corresponded to the power of 50W. In short, the values after feedback control were sent to their respective element so that the element was adjusted based on the values obtained to maintain the optimum light intensity level of the factory. This can be done by using the “ElementSetParameterByName'' nodes in Revit Dynamo. The “Select Model Element'' node was used to choose the component that was controlled and the “Parameter Controlled” node selected the parameter to be controlled for that component.

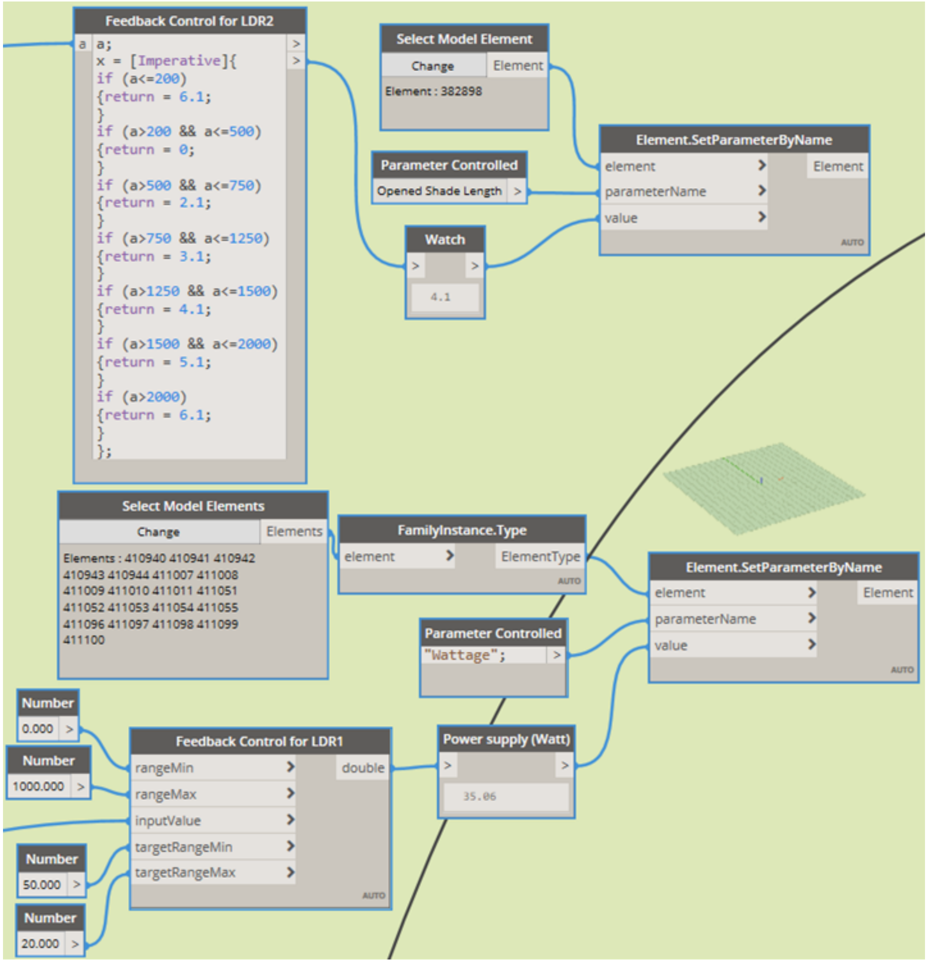

Fig. 6. Feedback control nodes in Revit Dynamo

3. Results

3.1 Light Intensity level of the Factory

The light intensity level for every zone is shown in Figure 7. From 9am to 12pm, the light intensity levels of LDR1 and LDR2 from 9am to 12pm were in the range of 288-960 lux and 1150-1883 lux, respectively. While from 12pm to 3pm, the light intensity levels of LDR1 and LDR2 were in the range of 107-470 lux and 1673-2225 lux, respectively; and from 3pm to 6pm, the light intensity levels of LDR1 and LDR2 were in the range of 176-520 lux and 519-1490 lux, respectively. From 6pm onwards, as the sun set, the light intensity levels of LDR1 and LDR2 have dropped below 26 lux and 78 lux, respectively.

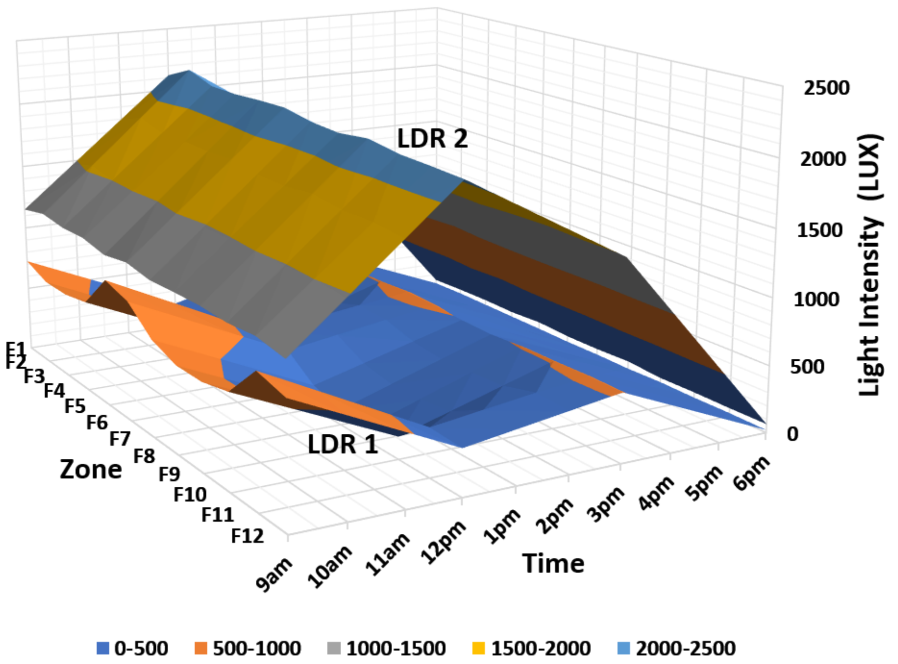

Fig. 7. Light intensity level of LDR1 and LDR2 of the factory

3.2 Output Light Intensity Level

The (final) output light intensity level for every zone is presented in Figure 8. From 9am to 12pm, the light intensity level has increased from range between 288 and 960, to range between 885 and 1235. While from 12pm to 3pm, the light intensity level has increased from 107-470 lux to 1264-1306 lux, and from 3pm to 6pm, the light intensity level has increased from 176-520 lux to 1008-1299 lux. From 6pm onwards, as the outdoor light is low, below 26 lux, the artificial lights has increased the light intensity level to 878-910 lux, or average of about 900 lux in the entire factory.

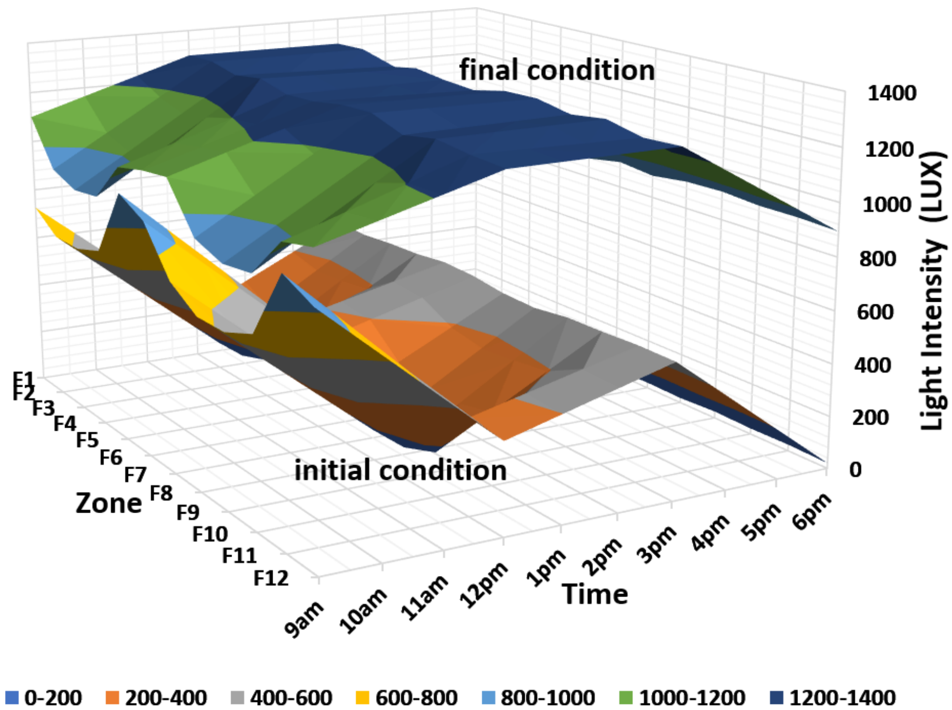

Fig. 8. Comparison of initial and final light intensity level in the factory

Figure 9 shows the lighting power consumption from 9am to 6pm for all 12 zones. The total power consumption from 9-10am is the lowest (13.33kWh) while 6pm has the highest consumption (24.322kWh), about 82% higher compared to 9am. Worth mentioning that the total power consumption increases gradually from 9am to 12pm due to the limitation of the shading system. Despite 12pm has the highest light intensity at LDR2 (2122 Lux in average), direct sunlight is unfavourable to the factory floor as the intensity is too strong and unevenly distributed. Hence, the shades have to be fully closed. Anyway, with the installation of the smart shading and lighting system, the factory can reduce 22.39% (or 55.2128kWh) of energy from 9-7pm.

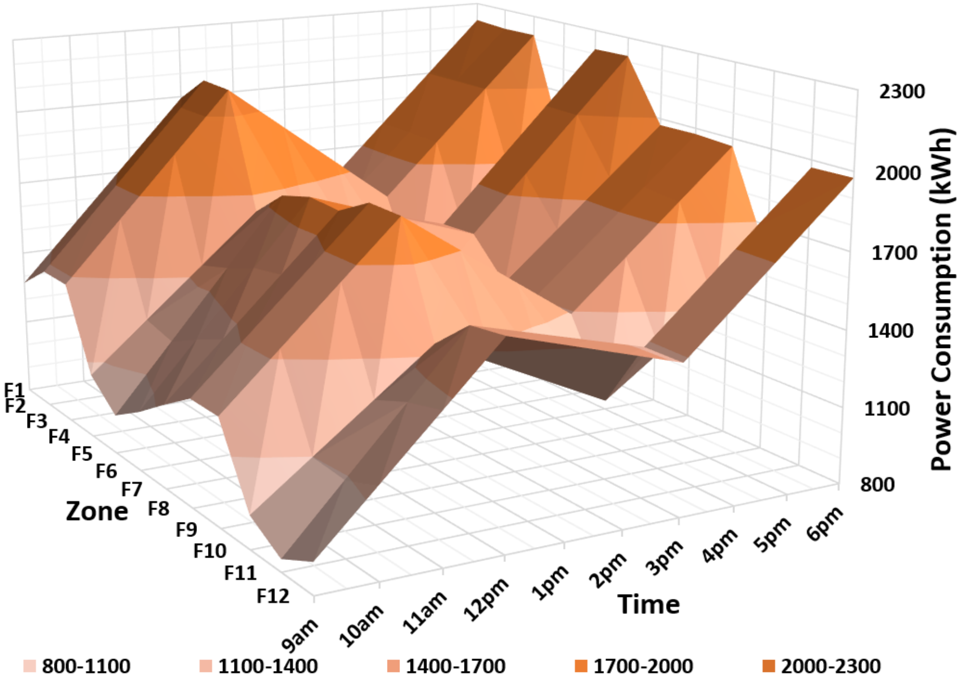

Fig. 9. Power consumption according to the responses of control element

4. Conclusions

A factory smart lighting and shading system was served as the building comfort control system, in which consists of LDR sensors to detect the change of light intensity level during daytime the working hours. Commands were sent to the motor controller and the LED driver from the Arduino, to control the opening length of the motorized shade and the power supply of the LED light. An Arduino coding was run in the TINKERCAD simulation and the effectiveness of this control system was shown by light intensity analysis from the Revit simulation. As the control system was implemented, the factory has achieved the optimum lighting level, and the light was distributed evenly throughout the factory floor. From 9am to 6pm, the light intensity level was in the range of between 885 lux and 1306 Lux, while from 6pm onwards, the average light intensity in the factory was about 900 lux. The brightness of the LED light was adjusted to a sufficient level with the control system which means excessive power supply can be avoided. This led to energy saving in terms of electricity, the smart system can save as much as 22.39%, or 55.2128kWh from 9am to 7pm. In conclusion, the smart lighting and shading control system has proven the effectiveness theoretically, and the objectives were achieved.

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