A Lighting Controller for LED Lamp Cooperated with Daylighting in Thailand

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Abstract

This research aimed to develop a lighting controller for LED lamps cooperated with daylighting (LCTL) for replacing the lamps that were installed near windows. This device would control LED lamps to work appropriately at daylight levels. The results revealed that the developed device could control the lighting of LED lamps cooperated with daylighting between 0 and 338 lx. This device consumed about 18.83 W. It could save 9.17 W of energy when compared to a 28 W T5 fluorescent lamp. The measurement and calculation of the energy saving of this device showed that it could save approximately 0.23 kWh/lamp/day. A computer simulation was employed to analyze the daylighting through windows in two levels, i.e., high and low transmittance of glazed window. The simulations showed that the device could save 66 kWh/lamp/year for a high transmittance window. The device could save 21 kWh/lamp/year from the north side, 35 kWh/lamp/year from the south side, and 33 kWh/lamp/year from the east and the west sides for low transmittance window. Further studies would adapt this device into microcontroller-based systems, integrated LCD to monitor a setting illuminance and a work plane illuminance. A wireless control system would be used for this system.

Keywords : Lighting control, LED lamp controller, Energy saving

Introduction

An increasing demand in the development in economy, industry and society in Thailand has resulted in an increase in energy requirement every year. In 2012, the maximum demand of Thailand was approximately 26,121 MW, which it was increased 368% from 1990, while the rest power generation was approximately 6,169 MW (EGAT, 2013). Thailand has a 15 years renewable energy development plan (2008-2022) to increase the usage of renewable energy up to 20.3% of the total energy usage in 2022 (DEDE, 2008). Thailand has enacted an act for promotion of energy conservation since 1992 (Ministry of Energy, 1992). The royal decree on designated building and a set of ministerial regulations was enacted in 1995 (B.E. 2538) (Ministry of Energy, 1995a; Ministry of Energy, 1995c). The law mandates issuance of ministerial regulations for energy conservation in large commercial buildings. Thailand's building energy code was gazetted and implemented on new and existing large buildings (Ministry of Energy, 1995b). The code comprises mainly of performance-based requirements on building envelope system, lighting system and air-conditioning system. The earlier study found that air-conditioning and electric lighting typically accounted for 50-60% and 20-30%, respectively, of the electricity consumption of a commercial building in Thailand (Chirarattananon, 2005).

According to the electricity consumption mentioned above, if buildings reduce the lighting energy consumption, it will result in an increase energy efficiency of building. As Thailand is located in the tropics, most part of the country receives the highest global illuminance in April, with a monthly average of hourly values of about 80-100 klx, and 44.1% of the total area of the country receive the yearly average of hourly illuminance in the range of 75-80 klx. The areas, which receive the highest global illuminance are in middle part of the central region of the country and the lower part of the south (Janjai, 2004). Generally, recommended interior illuminance for office is 300-500 lx with existing daylight. However, daylighting will initiate the cooling load, visual comfort and thermal comfort (Chirarattananon and Chaiwiwatworakul, 2006).

As electrical energy saving in lighting system comes in many ways, an automatic lighting control device is one efficient way. To date, as LED lamps are in the state of the art, they exhibit high efficacy and long life. Some types of LED lamps can even replace the conventional lamps. Thus, the objective of this research was to develop a lighting controller for LED lamps cooperated with daylighting.

Materials and Methods

Designing of a lighting controller

A lighting controller for LED lamps cooperated with daylighting (LCTL) was aimed to control a work plane illuminance level, which comprised of 5 parts, i.e., photo sensor saw-tooth wave generator, voltage comparator, switching device, and LED lamps module, as shown in Fig. 1.

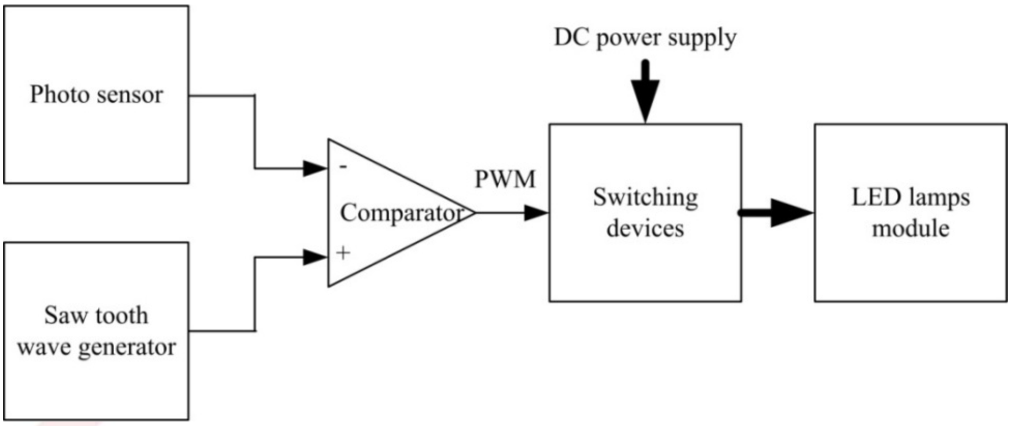


Figure 1. Block diagram of a lighting controller for LED lamps cooperated with daylighting.

A pulse width modulation technique (PWM) was used in the design of LCTL to operate a LED lamps module. Its lighting level would be conversed the daylight. The PWM signal generated by a comparator compared a photo sensor voltage (V_{Photo}) with a saw-tooth voltage (V_{Saw}). The LED lamps were turned on when the photo sensor voltage was less than the saw-tooth voltage for the duration of $t_{LED\text{-}on}$, as shown in Fig. 2.

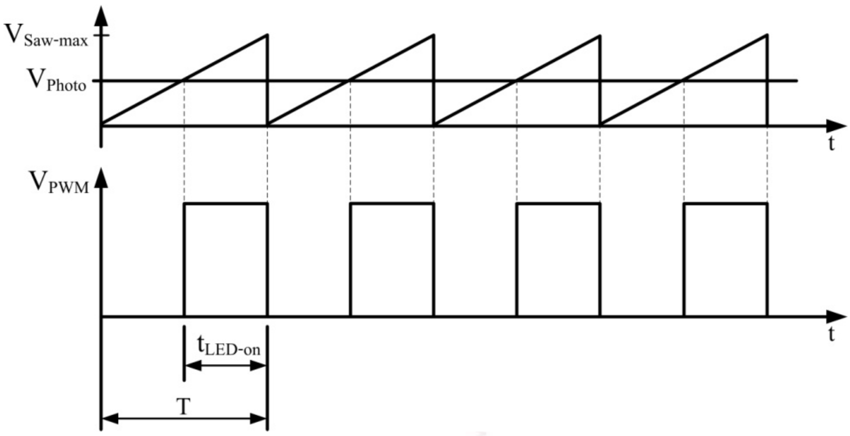


Figure 2. Showing the diagram of pulse width modulation signal.

A photo diode OPT310M was used as the photo sensor. It had a spectral sensitivity in the rage of visible light (380-780 nm), which was appropriated for this research, as shown in Fig. 3. The sensor was converted light into electrical voltage. This voltage was gained in the rage of 0-10 volts.

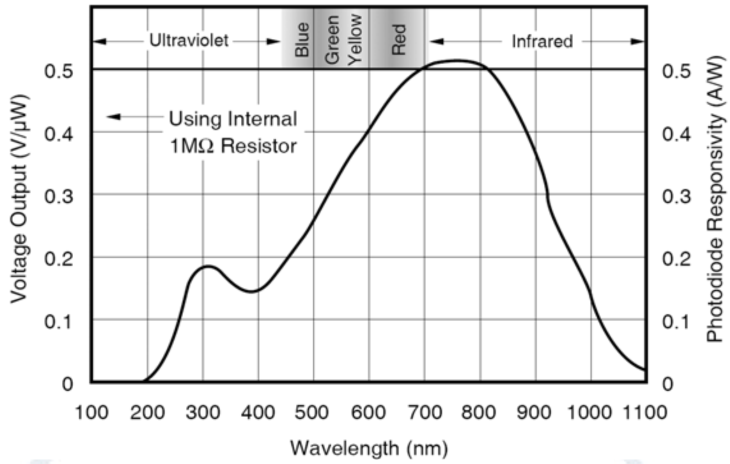


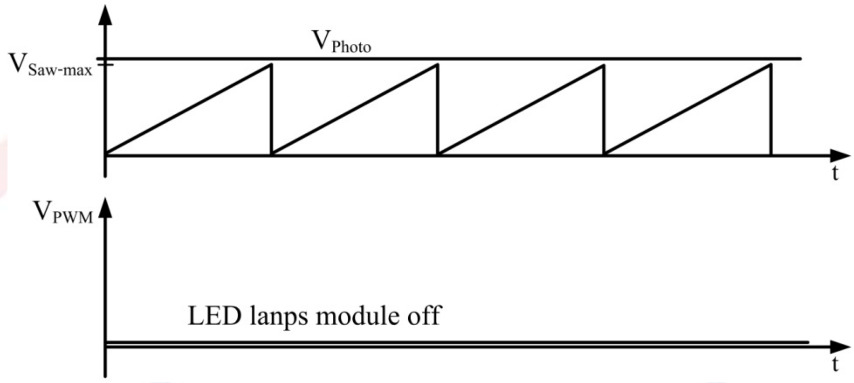
Figure 3. Showing the spectral responsively of selected photo diode (Burr-Brown Corporation, 1994).

A 555 timer circuit was generated the 10 kHz saw-tooth signal at the maximum voltage of 9 volts. A voltage of 12 volts were supplied the circuit. A 10 nF capacitor and a 10 kΩ resistor were used. The frequency of the saw-tooth signal can be calculated from:

$$f = (V_{cc} - 2.7)/(R \cdot C \cdot V_{pp}).$$

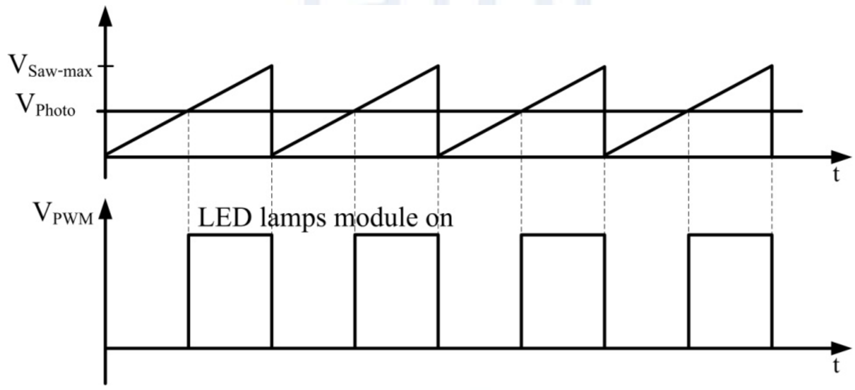
Where V_{cc} was the supply voltage and V_{pp} was the maximum voltage of the saw-tooth signal.

An operational amplifier LM311N was used as the comparator, and the output must pull up with a resistor. The LCTL was maintained a work plane illuminance at 300 lx. The comparator operated the LED lamps in 2 modes, i.e., turn off mode, which occurred when the work plane illuminance exceeded 300 lx, where the PWM mode the illuminance was less than 300 lx, the LCTL would turn-on the LED lamps to supplement the lack of daylight, bringing it up to 300 lx.



a. Turn off mode (E> 300 lx)

Figure 4. Diagrams showing the PWM signal output from the comparator circuit.



b. PWM mode (E< 300 lx)

Figure 4(con't). Diagrams showing the PWM signal output from the comparator circuit.

A power MOSFET MTP12N10E was used as a switching device. It can be handle a current of 12 amperes and a voltage of 100 volts. The LED lamps module was constructed from 324 supper bright LEDs as shown in Fig. 5. A light flux of nearly 28W T5 fluorescent lamp was obtained. A complete schematic diagram of LCTL is shown in Fig. 6.

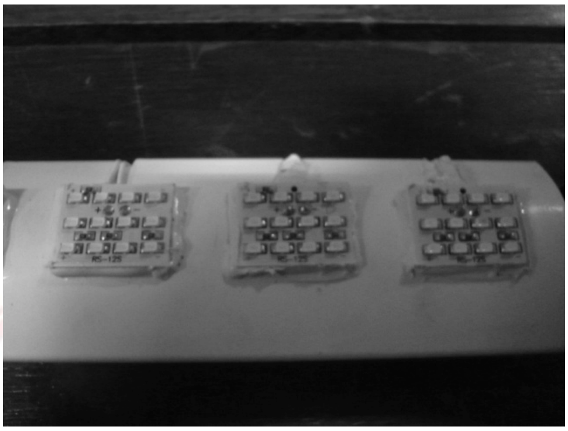


Figure 5. Showing LED lamps module.

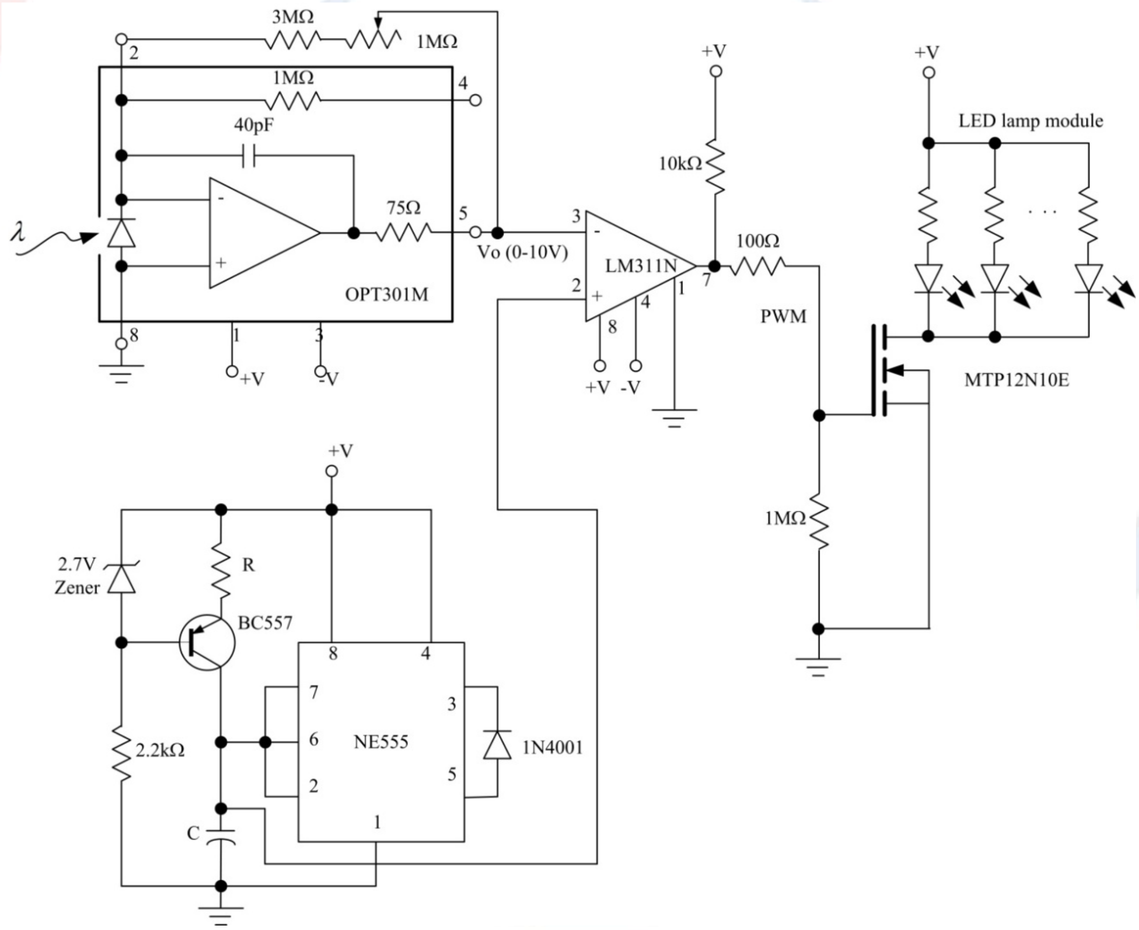


Figure 6. Schematic diagram of a lighting controller for LED lamps cooperated with daylighting.

Calculation for the investigation of the saving of LCTL.

In our study, the calculation of daylight illuminance through double pane window with internal fixed-angle slats was done followed the procedure adapted by Chaiwiwatworakul et al. (Chiwiwatworakul et al., 2009). The calculation of reflection of light flux on surfaces of slats was described in the Engineering Reference of Energy Plus (US-DOE, 2009). The ASRC-CIE sky model was adopted for calculating the result-diffuse skylights on slat surfaces and the luminances of the sky patches viewed through the slats by points in the simulated room (Chiwiwatworakul et al., 2009).

Experimental setup

The experiments were conducted at a full-scale building equipped with double pane window with internal fixed-angle slats (DWFS). The illuminance sensors were connected to a data logger. Records of required data were obtained from a daylight and solar radiation measurement station installed on the roof of a nearby building. The test building was located in King Mongkut's University of Technology Thonburi (KMUTT), Bang Khun Tien Campus (latitude 13.4°N and longitude 100.3°E).

Configuration of the test building and fenestration.

The experiment was set up to measure the work plane illuminance in the room installed with the DWFS on the South façade. The windowpanes were green glass (tinted float) of 6 mm thickness. The size of the windowpane was 2550 x 1540 mm, with the gap of about 100 mm. The windowpanes were installed in the aluminum frame with the lower edge located about 900 mm above the floor. The aluminum slats were white with the width of 50.4 mm. Optical properties of blind slats and windows glasses were measured using a spectrophotometer. The visible reflectance of each slat was 0.7. The visible transmittance and reflectance of each 6 mm tinted float (green) glass were 0.42 and 0.05, respectively.

The daylight measurement station.

The daylight measurement station was installed at KMUTT, Bang Khum Tien campus since 2009. The illuminace sensors were supplied by Eko of Japan. Beam normal illuminace and diffuse illuminance were measured directly by suntracker as shown in Figure 7. All measured data were acquired by the data acquisition system (DAQ) of National Instrument Inc., and recorded onto a computer hard disk at 1-minute interval.

Figure 7. Showing a photograph of the daylight measurement station at KMUTT, Bang Khun Tien Campus.

The illuminance measurement and data acquisition system.

Five illuminance sensors were placed about 750 mm above the floor at 10, 30, 50, 70, and 90% depth in the middle of the window to measure work plane illuminance. All illuminace sensors were supplied by Licor.

The data acquisition system (DAQ) was developed from National Instrument Inc. All measurement data from illuminance sensors were acquired by the NI-DAQ system and recorded onto the computer hard disk at 1-minute interval. Both computers of NI-DAQ system (station and test building) were synchronized with an Internet time.

a. South façade of the test building

b. The interior of the experimental room

Figure 8. Photographs showing configurations of the test building at KMUTT, Bang Khun Tien Campus.

Table 1. Details on the experimental room and the surrounding environment

Item	Internal dimension(m)	Material	Reflectance	Transmittance
Interior				
Wall	5.90 x 2.56 (E and W walls) 2.75 x 2.56 (N and S walls)	Gypsum board	0.7	-
Ceiling	5.90 x 2.75	Gypsum board	0.7	-
Floor	5.90 x 2.75			
Window	2.55 x 1.54	Tinted float (Green)	0.05	0.42
Environment				
Ground		Green grass	0.2	-

Table 2. Slat properties used in the experiment

Blind description	Color	Slat width (mm)	Slat spacing (mm)	Slat reflectance[a]	Slat abrorptance
Aluminum	White	50.4	40	0.7	0.3

Remark [a] Measured at wavelength from 300 to 2,700 nm.

Results

Saving of the LCTL.

An experiment for the LCTL was conducted. Two light sources were used as follows: the LCTL, LED lamps installed with lighting fixture on a ceiling, its height was 2 meters from a work plane level, and the incandescent lamp with a dimmer, use for simulating the daylight, the illuminance can be varied from 0 to 450 lx. In case of night time, the LCTL consumed a power of 18.83 W, at a work plane illuminance of 182 lx. In the case when the daylight exceeded 338 lx, the LCTL would turn-off the LED lamp, but it was still consumed an electrical power of 1.18 W for supplying the electronic devices. Thus, the LCTL could save an maximum power of 26.82 W, compared with 28 W T5 fluorescent lamp. The measured data and calculated saving results are shown in Table 3.

Table 3. Measured electrical power of the LCTL

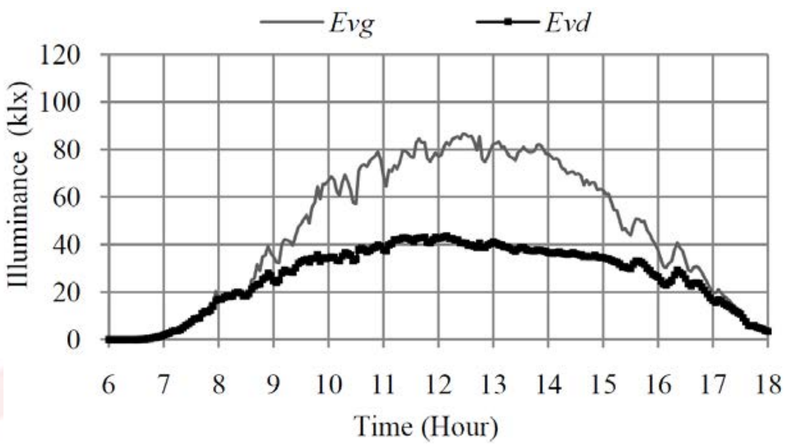
No.	Measured work plane illuminance (lx)		LCTL Current (A)	Electrical power (W)	
	Controlled illuminance[1]	Total illuminance[2]		LCTL	Saving[3]
1	0	182	1.60	18.83	9.17
2	50	236	1.59	18.71	9.29
3	100	283	1.54	18.13	9.87
4	150	329	1.53	18.01	9.99
5	200	374	1.46	17.18	10.82
6	250	407	1.31	15.42	12.58
7	300	402	0.85	10.00	18.00
8	350	350	0.10	1.18	26.82
9	400	400	0.10	1.18	26.82
10	450	450	0.10	1.18	26.82

Remarks

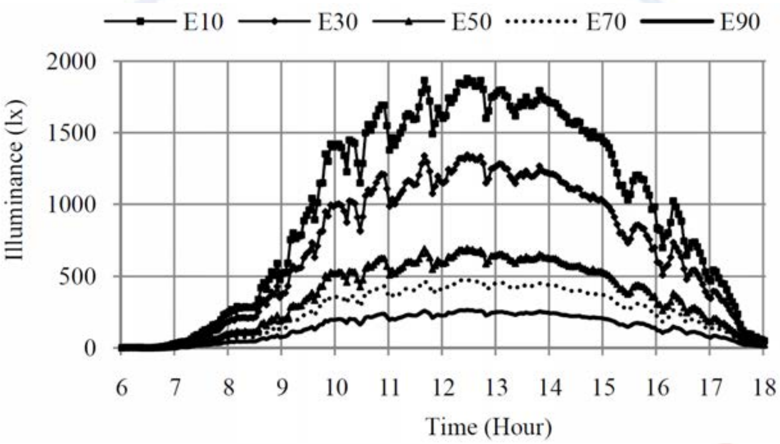
[1] illuminance from lighting with dimming device
[2] illuminance from LCTL and illuminance from Lighting with diming device
[3] compared with 28 W T5 fluorescent lamp

One day saving of LCTL.

The DWFS with the slat angle of 0° was experimented on 17th January 2011. Fig. 9a exhibited the variations of the global (*Evg*) and diffuse horizontal illuminance (*Evd*) obtained from the daylight station. Values of the global illuminance reached the peak at 83 klx during noon time with the corresponding peak of the diffuse illuminance at 41 klx. The sky was rather clear on that day.



a. Global and diffuse horizontal illuminances



b. Work plane illuminance

Figure 9. Showing results of measured illuminance on 17th January 2011.

Fig. 9b exhibited the variation of the interior daylight illuminance on the work plane at 10% to 90% of room depth from the window. At 10% and 30% of room depth, it was observed that the daylight sufficiently illuminated the room over 500 lx for most of the daytime (10:00-16:00 hrs). The calculation of electrical saving of LCTL, using the saving value from work plane illuminance in 6 levels, i.e., >338 lx, >300 lx, >250 lx, >200 lx, >150 lx, and >100 lx, respectively as shown in Table 3. When the LCTL was installed at 30% of room depth, its saved an electrical energy of 0.23 kWh/lamp/day, when compared with 28 W T5 fluorescent lamp.

Yearly saving of LCTL.

In this section, the calculation of work plane illuminance was conducted. A computer programming was used for this calculation with the room model identical to that of the experiment. As since 2003, Thailand's building regulation for safety has enforced that the glazed windows of buildings taller than 23 meters must be the laminated type only. In this study, two laminated glasses were used as the outer glass of the DWFS, i.e., heat reflective glass laminated with green glass (HG) that had widely been used for windows of the high-rise buildings in Thailand, and green glass laminated with clear glass (GC) that offers higher visible transmittance than the first one. For all of simulation cases, the inner glass of DWFS was 6 mm clear glass. Table 4 gives the properties of the glasses.

Table 4. Properties of the glasses for the DWFS simulation.

Glass	Thickness (mm)	Reflectance	Transmittance
Green-Clear	12.38	0.12	0.67
Heat reflective-Green	12.38	0.22	0.12
Clear	6	0.08	0.80

A series of calculation was conducted on the slat angle of 0° and changing the types of the DWFS outer glass, including the window orientations. The one-year hourly record of the daylight measured in Thailand was used for the simulation. The simulation results were analyzed from 08:00 to 17:00 hrs and for 5 working days (Monday-Friday).

The calculation of electrical saving of LCTL was performed using the saving value from work plane illuminance in 6 levels, which mentioned above. The tables were used to present the monthly averages of the interior daylight at 10%, 30%, 50%, 70%, and 90% depths of the room (D), percentage of time of the interior daylight exceeded 6 illuminance levels at 30%D and electrical energy saving.

In case of the high transmittance of laminated green-clear glass, Tables 5 to 8 showed that the interior daylight at 30%D exceeding 338 lx varied from 57-73% of time in a working day in a month. The LCTL could save the electrical energy of about 5.21-6.18 kWh/month. While the low transmittance of laminated heat reflective-green glass spread the interior daylight level, the LCTL would save the energy only 50% of the laminated green-clear glass, except the north. The total electrical energy saving is shown in Fig. 10.

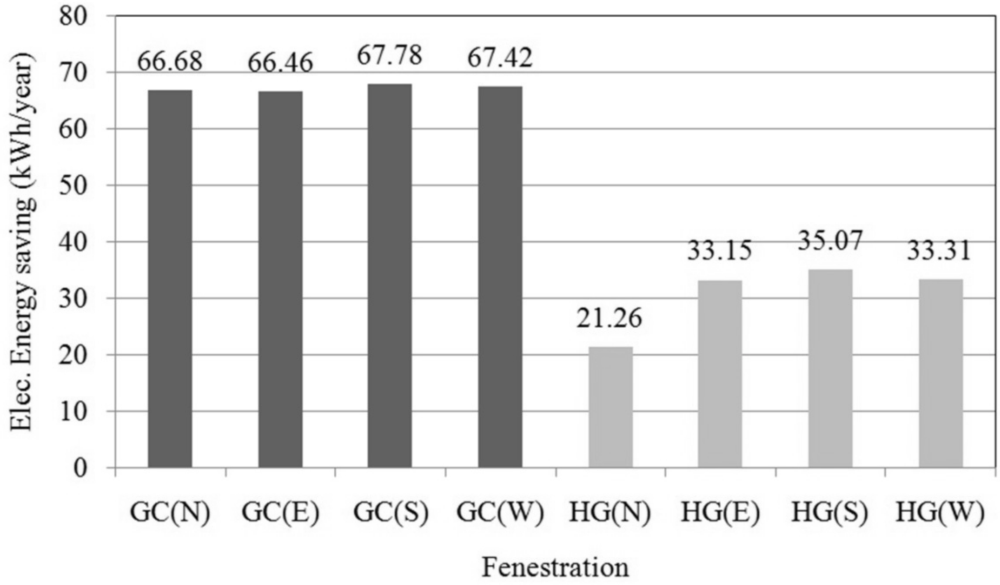


Figure 10. Showing results of electrical energy saving of LCTL with the DWFS at slat angle of 0°.

Table 5. The simulation results of the DWFS facing north and saving of LCTL

Month	Average of the interior daylight (lx)					The interior daylight at 30%D (Percentage of time)						Saving
	10%D	30%D	50%D	70%D	90%D	>338 lx	>300 lx	>250 lx	>200 lx	>150 lx	>100 lx	(kWh/month)
Laminated green-clear glass												
Jan	996	621	367	228	172	57	4	5	2	0	0	5.21
Feb	1038	646	382	237	178	67	3	1	1	1	1	5.42
Mar	1148	708	414	255	191	68	1	1	1	0	0	5.73
Apr	1337	816	466	284	210	62	1	2	1	2	1	5.25
May	1599	979	569	349	260	73	0	0	0	0	0	6.07
Jun	2005	1220	694	422	312	69	0	1	0	0	0	5.59
Jul	2039	1239	703	427	315	66	1	0	0	0	0	5.53
Aug	1699	1039	597	366	271	72	0	3	0	2	0	6.15
Sep	1520	929	532	325	241	65	1	1	1	1	0	5.34
Oct	1256	774	450	277	207	67	2	2	1	1	1	5.81
Nov	1007	633	380	238	180	63	1	3	2	0	1	5.31
Dec	949	599	360	226	172	59	2	2	4	1	0	5.26
Laminated heat reflective-green glass												
Jan	181	113	67	41	31	0	0	0	1	8	35	1.37
Feb	188	117	69	43	32	0	0	0	0	11	39	1.44
Mar	208	129	75	46	35	0	0	0	0	22	34	1.71
Apr	243	148	85	52	38	0	0	0	3	32	22	1.71
May	291	178	103	63	47	0	0	2	15	28	23	2.17
Jun	364	221	126	77	57	1	5	16	23	15	7	2.37
Jul	370	225	128	78	57	1	5	15	18	14	8	2.24
Aug	309	189	109	66	49	1	2	8	23	17	14	2.19
Sep	276	169	97	59	44	0	0	2	20	22	14	1.80
Oct	228	141	82	50	38	0	0	0	1	30	26	1.77
Nov	183	115	69	43	33	0	0	0	0	8	37	1.35
Dec	172	109	65	41	31	0	0	0	0	6	31	1.15

Table 6. The simulation results of the DWFS facing east and saving of LCTL

Month	Average of the interior daylight (lx)					The interior daylight at 30%D (Percentage of time)						Saving
	10%D	30%D	50%D	70%D	90%D	>338 lx	>300 lx	>250 lx	>200 lx	>150 lx	>100 lx	(kWh/month)
Laminated green-clear glass												
Jan	2327	1403	729	450	335	60	1	4	2	1	0	5.30
Feb	2515	1746	946	532	362	66	3	2	1	0	1	5.41
Mar	2294	1503	948	475	358	65	2	1	1	0	0	5.66
Apr	2097	1404	737	479	373	62	2	2	1	1	1	5.27
May	2851	2032	1052	639	411	70	1	2	0	0	0	5.98
Jun	2196	1426	770	436	322	69	0	1	0	0	0	5.58
Jul	2332	1502	808	496	345	66	1	0	0	0	0	5.53
Aug	2875	1980	1015	671	493	72	0	3	1	2	0	6.15
Sep	2392	1563	830	521	395	64	1	1	1	1	0	5.29
Oct	2487	1657	851	525	391	65	1	2	4	1	1	5.73
Nov	2777	1947	936	527	393	63	0	1	5	1	1	5.30
Dec	2797	1579	832	518	386	61	0	1	4	2	0	5.28
Laminated heat reflective-green glass												
Jan	422	254	133	82	61	14	7	6	7	8	10	2.62
Feb	456	316	172	97	66	22	3	3	4	10	13	2.79
Mar	417	272	172	86	65	21	4	1	5	8	15	2.86
Apr	381	254	134	87	68	16	2	2	5	9	18	2.41
May	518	368	191	116	75	21	1	4	3	9	20	2.97
Jun	399	259	140	79	59	14	4	4	7	14	17	2.66
Jul	424	273	147	90	63	14	2	6	10	13	13	2.63
Aug	522	359	184	122	90	24	2	3	8	14	14	3.29
Sep	434	283	151	95	72	19	2	4	8	11	13	2.77
Oct	452	300	155	95	71	19	4	5	7	10	14	2.91
Nov	504	353	170	96	71	19	1	4	6	6	19	2.60
Dec	508	287	151	94	70	19	1	4	6	8	13	2.63

Table 7. The simulation results of the DWFS facing south and saving of LCTL

Month	Average of the interior daylight (lx)					The interior daylight at 30%D (Percentage of time)						Saving
	10%D	30%D	50%D	70%D	90%D	>338 lx	>300 lx	>250 lx	>200 lx	>150 lx	>100 lx	(kWh/month)
Laminated green-clear glass												
Jan	3172	1943	1112	676	498	66	1	1	0	0	0	5.57
Feb	2607	1588	918	560	414	70	1	1	0	1	1	5.52
Mar	1848	1129	651	398	295	68	0	0	1	0	0	5.76
Apr	1471	896	510	310	229	62	1	2	1	2	1	5.25
May	1277	788	462	285	213	72	1	1	0	0	0	6.05
Jun	1465	895	514	314	233	69	0	1	0	0	0	5.59
Jul	1612	983	561	342	253	66	1	0	0	0	0	5.53
Aug	1677	1025	590	361	268	72	0	3	0	2	0	6.16
Sep	2049	1248	709	431	318	65	0	1	1	1	0	5.35
Oct	2627	1602	916	557	411	69	1	2	1	1	0	5.88
Nov	3411	2081	1223	749	552	69	0	0	0	0	1	5.58
Dec	3718	2270	1331	814	599	66	0	0	1	0	0	5.54
Laminated heat reflective-green glass												
Jan	578	354	203	123	91	38	4	7	4	3	7	4.06
Feb	475	289	167	102	75	31	5	11	7	4	11	3.70
Mar	337	205	119	72	54	3	5	16	15	9	14	2.42
Apr	267	163	93	56	42	0	0	2	12	28	17	1.80
May	232	143	84	52	39	0	0	0	3	24	32	1.79
Jun	266	163	93	57	42	0	0	0	11	28	24	1.92
Jul	293	178	102	62	46	0	0	3	19	21	18	1.94
Aug	305	186	107	66	49	0	2	11	19	15	19	2.24
Sep	373	227	129	78	58	5	11	16	11	11	7	2.49
Oct	479	292	167	102	75	29	6	10	6	5	8	3.74
Nov	624	380	224	137	101	47	2	6	4	2	6	4.47
Dec	680	414	243	149	110	46	2	8	2	3	4	4.51

Table 8. The simulation results of the DWFS facing west and saving of LCTL

Month	Average of the interior daylight (lx)					The interior daylight at 30%D (Percentage of time)						Saving
	10%D	30%D	50%D	70%D	90%D	>338 lx	>300 lx	>250 lx	>200 lx	>150 lx	>100 lx	(kWh/month)
Laminated green-clear glass												
Jan	2240	1340	716	440	327	62	0	4	1	1	0	5.35
Feb	2284	1573	866	485	342	65	2	4	0	1	0	5.34
Mar	2234	1520	952	461	350	67	2	0	1	0	0	5.74
Apr	1951	1230	761	403	303	63	1	2	1	2	0	5.29
May	2332	1488	963	461	333	73	0	0	0	0	0	6.10
Jun	2451	1584	1001	469	346	69	0	1	0	0	0	5.59
Jul	2503	1615	982	489	361	66	0	0	0	0	0	5.54
Aug	2311	1450	875	478	356	72	0	2	0	2	0	6.18
Sep	2258	1479	820	519	335	65	1	1	0	1	0	5.35
Oct	2408	1606	846	525	370	69	1	1	1	1	0	5.91
Nov	2751	1852	908	523	390	68	1	0	0	1	0	5.57
Dec	2445	1364	763	471	351	63	4	0	1	0	0	5.47
Laminated heat reflective-green glass												
Jan	406	243	130	80	60	19	4	5	7	7	10	2.74
Feb	415	285	157	88	62	20	4	2	6	11	14	2.71
Mar	406	275	172	84	64	17	2	5	5	8	19	2.71
Apr	354	223	138	73	55	12	2	6	4	7	22	2.33
May	424	270	175	84	61	18	3	4	5	9	21	2.89
Jun	445	287	182	85	63	20	2	4	6	15	14	2.96
Jul	455	293	178	89	66	15	1	6	7	12	16	2.71
Aug	420	263	159	87	65	19	1	5	5	15	15	2.98
Sep	410	268	149	94	61	14	5	4	10	13	13	2.64
Oct	437	291	154	95	67	17	5	3	10	13	14	2.91
Nov	499	336	165	95	71	24	2	5	4	7	16	2.99
Dec	444	248	139	86	64	20	2	5	4	8	12	2.75

Discussions and Conclusions

The lighting controller for LED lamps cooperated with daylighting is a simple design. The device is uses the pulse width modulation technique to adjust the LED light level, it could work appropriately. The devices will turn-off the LED lamps, if daylight excesses 338 lx. The LED lamps give the maximum illuminate of 182 lx, it consumes about 18.83 W. The measurement and calculation indicated that it could save about 0.23 kWh/lamp/day, when compared with 28 W T5 fluorescent lamp. Moreover, the calculations were conducted to investigate the electrical energy saving for a daylight application through the double pane window with internal fixed-angle slats in Thailand. The results from the calculations demonstrated that the LCTL installed near window could offer a potential energy saving in the tropics.

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