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Power Management of LED Street Lighting System Based on FPGA

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ABSTRACT

Light Emitting Diode (LED) lamp is new lighting technology used over the world, its high efficiency, low power consumption, dimming capability, long lifetime, environmental friendly and much more advantages make it preferred source in new outdoor and indoor lighting systems. The method of time-control is used to manage the power consumption of an LED using Very high speed integrated circuit High level Description Language (VHDL) program and implement the design using Field Programmable Gate Array (FPGA) /Spartan 3A starter kit. Two dimming scenarios are implemented to reduce the power consumption of LED, Pulse Width Modulation (PWM) technique is used as dimming method and based on real time clock designed using (VHDL) program and was implemented on the same FPGA kit. 70% annual energy saving was achieved using first dimming scenario and 71.4% with second scenario compared to High Pressure Sodium (HPS) lamp and about 20.1% power saving using first scenario and 23.7% with second scenario compared to normal LED operation.

Keywords: LED, Pulse Width Modulation, FPGA (Field Programmable Gate Array), Dimming, Power Saving.

ادارة الطاقة لمصابيح الدايود الباعث للضوء في نظام انارة الشوارع المستند على البوابات المنطقية المبرمجة

الخلاصة

مصباح الدايود الباعث للضوء (LED) هو تكنولوجيا جديدة تستخدم في الإضاءة حول العالم، الكفاءة العالية وانخفاض استهلاك الطاقة وامكانتية العتم والعمر الطويل وكونها تقنية صديقة للبيئة و مزايا اخرى جعلت منها المصدر المفضل في نظام الإضاءة الخارجية والداخلية الجديد. تم استخدام أسلوب السيطرة الزمنية لإدارة استهلاك الطاقة لـ LED باسخدام برنامج (VHDL)، تم تنفيذ التصميم باستخدام (FPGA)/SPARTAN 3A. كما تم تنفيذ استراتيجيتين للعتم للحد من استهلاك الطاقة باستخدام تقنية (PWM) والذي يعتمد على توقيت حقيقي تم تصميمه باستخدام (VHDL)

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وتنفيذه على بطاقة FPGA ذاتها. تم تحقيق توفير في الطاقة يصل الى 70% باستخدام اسلوب العتم الاول والى 71.4% باستخدام الاسلوب الثاني مقارنة باستخدام مصابيح HPS المستخدمة حاليا وتوفير في الطاقة بنسبة 20.1% باستخدام الاسلوب الاول و23.7% باستخدام الاسلوب الثاني مقارنة مع مصابيح LED قبل استخدام تقنية العتم.

INTRODUCTION

In 2008 that governments around the world made a decision to speed up reductions in energy use and the associated CO_2 emissions. They also decided, more generally, to cut down on the use of resources. Lighting accounts for 19% of electrical consumption worldwide, which means that it presents a considerable potential for reductions over the next decade. Moreover, LEDs offer a way forward: they can already compete with incandescent lights, it is estimated that 30 billion light bulbs are in use on the planet, consuming each year a total of 2,650 TW.h[1].

Since 2003 Iraq suffering from lake in electricity due to subversive deeds and diminution in electricity production against massive loads growing, many kinds of products step inside Iraqi market and are consuming high power. Iraqi government now has a plan to reduce the use of electricity to decrease the gap between electricity generation and consumption. It is require using new technologies with low power consumption and higher efficiency also attaining higher efficiency from these technologies through smart power management.

The use of white LEDs in lighting systems will significantly save power and reduce CO_2 emission, and has numerous advantages compared to traditional lights:

- ***Higher energetic efficiency of the illumination systems.***
- ***Longer lifetime and therefore less maintenance.***
- ***Higher flexibility and control of the level of light and color variation.***
- ***Low power consumption (battery driven autonomous systems, consumer applications where security is important).***
- ***Environment friendly- no toxic material*** [1].

LEDs can have their light emission controlled. This control is known as dimming, the most used strategies of dimming are: the variation in the level dc, which controls the luminous flux emitted by varying the dc current LED amplitude applied, and Pulse Width Modulation (PWM), which uses a square wave power supply for these devices, thus the light flux is changed by varying the duty cycle of this signal [2].

PWM was adopted as standard by many LED manufacturers, and refer to PWM as a viable way to control the LED’s luminous flux. Changing the value of the current flowing through the LED affects the wave length of light emitted. Therefore, PWM dimming is more suitable because in this case rated current is applied to the LED in all times, changing only the fraction of time during which current flows in each period (duty cycle)[2].

Light dimming pave the way for massive energy savings in lighting applications. They enable us to reduce the output and therefore save energy as soon as full output is no longer needed. The options include simply reducing the output during the night and achieve maximum efficiency with variable dimming. Advantage can be taken of off-peak (no more light needed) times to reduce energy consumption significantly [3].

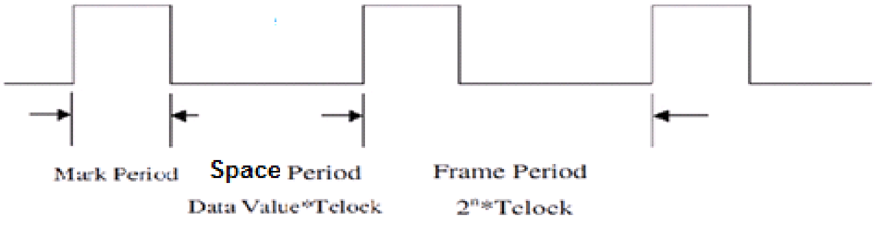
Wang Yongqing et al.[4] design an automatic control circuit of LED street lamp, It has three working modes : light control, delay quenching and delay plus low power. Under the delay plus low power mode, the LED street lamp is lit at night automatically and changed into pulsed lighting in low power after the setting time. It would be turned off in daytime. T.W. Ching [5] transition-mode(TM) dimmable high brightness light-emitting-diode (LED) driver for general and residential illumination applications is presented. An improved pulse-width modulation dimming technique utilizing a low cost micro-controller is studied and implemented with a current-regulated LED drive, in [6] they presents a comparative analysis of power LEDs dimming method, this study shows that PWM dimming has several advantages when compared to current variation dimming. [7] present the design, the synthesis, and the implementation of pulse width modulation (PWM) in Xilinx Field Programmable Gate Array (FPGA).

This work proposed two scenarios A and B to dim an LED during night by single step and multistep respectively as shown in Figure 1, to reduce the power consumption and hence increasing the lifespan of LED, PWM is adopted as dimming method. In scenario A, LED Street lamp is lit at sunset saved time and after midnight (no more traffic) it changed to operate at 60% of its rating power and as the sunrise saved time occurred it would be turned off.

During the last years, the number of hardware implementations based on Field Programmable Gate Arrays (FPGAs) is increasing because it satisfies the high speed of system and hardware cost constraints. FPGAs implementation allows the building of rapid prototypes reducing development times and board area [8]. Use VHDL language to implement the proposed hardware structure using Xilinx ISE Design Suite 13.3_3, downloaded on SPARTAN 3A starter kit and display the current time and dimming ratio using LCD display of the kit.

PULSE WIDTH MODULATION

Pulse Width Modulation (PWM) is used in many diverse areas such as controlling the speed of DC motors, The design shown in Figure 1 presented in this brief uses a register to store the desired "mark" value, which is automatically loaded into a down counter upon reaching its terminal count. The PWM Frame Period is the product of the counter’s clock period and the terminal count value, being the sum of the "mark" and "space" periods. The design is readily scaled up or down simply by changing the width of the register and counter [9].



$$Duty\ cycle = \frac{Mark\ period}{Frame\ period} \qquad \dots(1)$$

$$Duty\ cycle = \frac{(2^n - \ Data\ value) * Tclock}{2^n * Tclock} \quad ...(2)$$

$$Duty\ cycle = \frac{2^n - \ Data\ value}{2^n} \quad ...(3)$$

$$Duty\ cycle = 1 - \frac{Data\ value}{2^n} \quad ...(4)$$

PWM signal used to control the brightness of LED through controlling the duty cycle of the PWM signal as describe next:

According to [10] 200 Hz PWM signal generated to avoid noticeable flicker, Since we used SPARTAN 3A with 50 MHz clock source and all our registers and counters synchronized and operate at the same clock frequency so we need 18 bit counter.

$$Tclock = \frac{1}{fclock} = 20\,nsec \quad ...\ (5)$$

$$PWM\ period = 2^n * T\ clock \quad ...(6)$$

$$\frac{1}{200Hz} = 2^n * 20\,nsec \quad ...(7)$$

$$n = log_2 250000 \approx 18 \quad \ldots (8)$$

We have 2^{18} different duty cycle to control our LED; Table 1 shows some data values and their equivalent duty cycles.

REAL TIME CLOCK

In order to control the LED lamp through night time we need a real time clock (RTC) in order to get the real timing and since our FPGA starter kit have a great flexibility and precise 50 MHz clock source, RTC implemented using VHDL code and display the time digits on LCD. Figure (2) shows the real time counter flow chart.

EXAMPLE CLOCK DIVIDER CODE

Using 50 MHz clock of SPARTAN 3A to built 1 second delay, this delay will be used to enable the minute delay and so on.

```
INETIAL:PROCESS (clk)
BEGIN
IF  (rising_edge(clk)) THEN
            IF  scaler_int <49999999 THEN
                    scaler_int <= scaler_int +1;
                     sec_1 <='0'; --deactivate sec_1 signal
                       ELSIF  scaler_int = 49999999 THEN
                        Scaler_int <= 0;
                        sec_1<='1'; -- activate sec_1 signal
              END IF;
  END IF;
END PROCESS;
```

TWO DIMMING SCENARIOS

Because LEDs can be easily controlled, they can also be set to dim at certain parts of the day, enabling councils to react to peak or low-usage periods. Depending on the night time, when traffic is reduced we proposed to dim an LED to 60% of its rating power as shown in Figure 3.a, this was done by comparing the hour counter and minute counter values with the saved sunrise and sunset times, as the hour and minute counters reached the sunset time the PWM signal used to control the brightness of lamp activated with 100% duty cycle for full brightness, at 12 am PWM signal turned to 60% as the data value changed to specific duty cycle.

Figure (3.b) shows another dimming scenario started at sunrise with full brightness (100% duty cycle), at 10:00 pm the duty cycle changed to 80% and after 2 hours the duty cycle changed to 60%, and finally turned off as the sunrise time occurred.

EXPERIMENTAL RESULT

VHDL program was written using Integrated Software Environment ISE design suite 13.3 developed by Xilinx, program synthesized, simulate and implemented on target FPGA device (SPARTAN 3A). Our program was written to operate in real timing so simulation time is too long so we decide to scale down all our counters by 1000,000 to simulate the signals using ISim. Also the width of PWM register is scaled down to 12 instead of 18 to make the waveform noticeable, using equation 4 with n=12 to get the scaled down data values the results shown in Table (2) .

In scenario (B) PWM signals changed as the data value loaded to PWM register changed as listed below:

- Depending on the day and night time as shown in Figure (4) data value changed from $(FFF)_{HEX}$ which represent 0% duty cycle to $(000)_{HEX}$ represent 100% duty cycle to turn on the unit as the hour counter denoted as scaler_hr reaches $(10001)_2$ and minute counter denoted as scaler_min reaches $(1000)_2$ i.e at (5:08 pm) the sunset saved time,
- After that data value changed from $(000)_{HEX}$ 100% duty cycle to $(333)_{HEX}$ 80% duty sycle as scaler_hr reaches $(10110)_2$ i.e at (10:00 pm)as shown in Figure (5).
- Figure (6) shows that data value changed to $(666)_{HEX}$ for 60% duty cycle as scaler_hr reaches $(10)_2$ i.e at (02:00 am) .
- Finally as the scaler_hr reached the saved sunrise hour $(111)_2$ and scaler_min reaches $(101)_2$ the data value changed to $(111)_{HEX}$ for 0% duty cycle i.e at (07:05 am) to turn off the unit as shown in Figure (7).

Oscilloscope used to verify the real timing operation by noticing the PWM signal assigned to specific pin the results shown in Figure (8). also LCD used to display the current time and dimming ratio shown in Figure (9).

In scenario (A) we simply changed the VHDL code to fit the proposed dimming steps and downloaded it on SPARTAN 3A. Simulated the results using ISim and verified the PWM signal using oscilloscope.

RESULTS AND DISCUSSION

According to the proposed scenario A LED lamp with 150 w will operate at 60% of its power 90 w from 12 am until sunrise. This scenario will decrease the power consumption of the unit by about 20% compared to normal LED lamp operation and about 70% compared to High Pressure Sodium HPS lamp.

In scenario (B) power consumption decrease by 23.7% compared to normal LED lamp operation and about 71% compared to HPS lamp.

Calculations for power saving and CO_2 emission and electricity cost were taken for 100 pieces; Table (3) shows the results. Also annual power consumption of HPS, LED and LED with dimming is shown in Figure (10).

Since we used FPGA to implement proposed two dimming scenarios any change in dimming ratio could be done easily by changing VHDL code.

CONCLUSIONS

- Using 150 w LED lamp for street lighting instead of 400 w HPS:
  - Reduce power consumption about 164552.6 kwh annually, it is about 62.5 % power saving.
  - Reduce CO_2 emission about 44.9 ton annually.
  - Decrease electricity coast 12822.6 $ annually.
- Using an LED for street lighting with dimming scenario A :
  - Reduce power consumption about 119738.2 kwh annually it is about 70% power saving compared to HPS and about 20% compared to normal LED operation.
  - Reduce CO2 emission about 50.3 ton annually compared to HPS and 5.4 compared to normal LED operation.
  - Decrease electricity coast 14368.6 $ annually compared to to HPS and 1546.2 $ compared to normal LED operation.
- Using an LED for street lighting with dimming scenario B:
  - Reduce power consumption about 122024.5 kwh annually it is about 71.4% power saving compared to HPS and about 23.7% compared to normal LED operation.
  - Reduce CO2 emission about 51.3 ton annually compared to HPS and 6.4 compared to normal LED operation.
  - Decrease electricity coast 14643 $ annually compared to HPS and 1820 $ compared to normal LED operation.
- More power saving could be achieved for another application like tunnels and highways using smart controllers to dim an LED unit while there is no cars passing.
- Using FPGA to implement our design showed great flexibility and software program is easily changed to any desired dimming ratio.

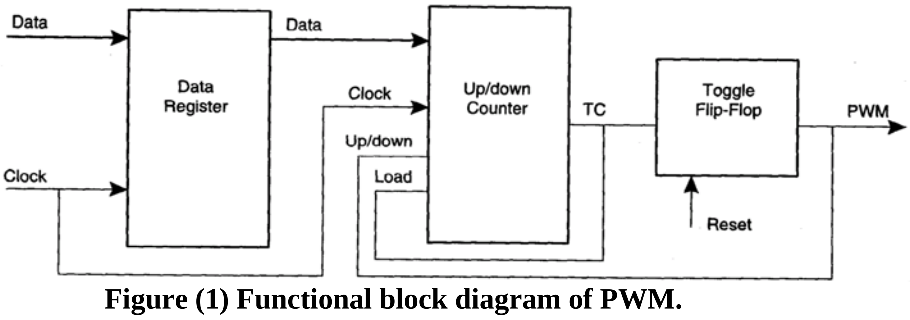


Figure (1) Functional block diagram of PWM.

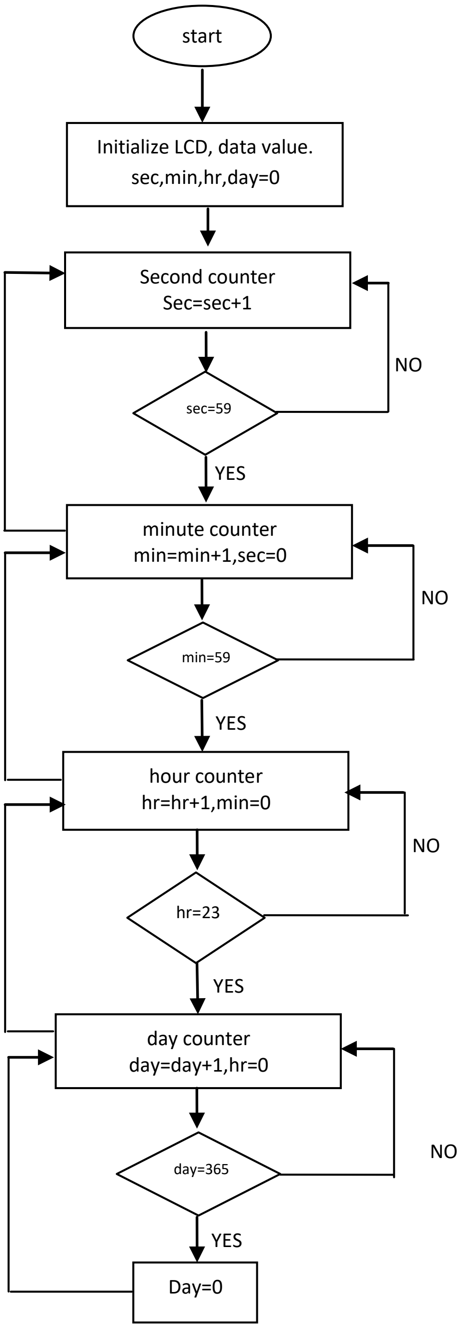
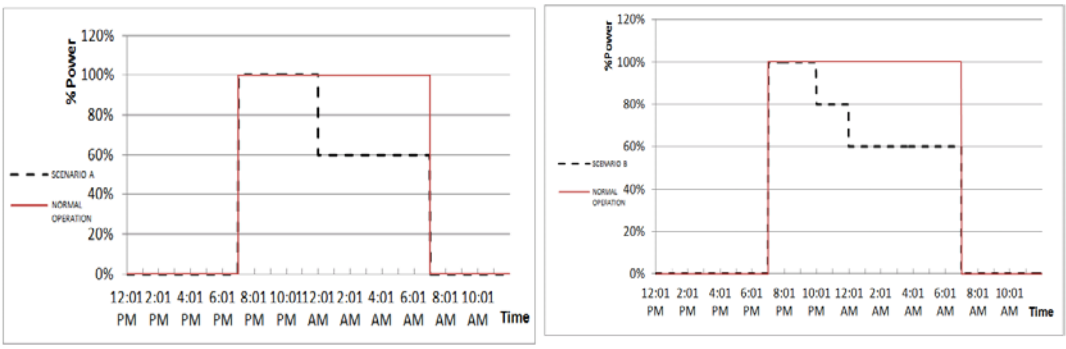


Figure (2) Real time counters flowchart.



3.a

3.b

Figure (3) a. First dimming scenario (A).
b. Second dimming scenario(B).

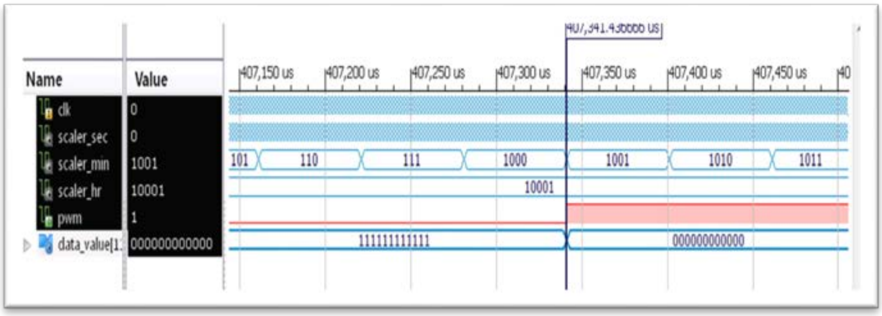


Figure (4) Simulation results.

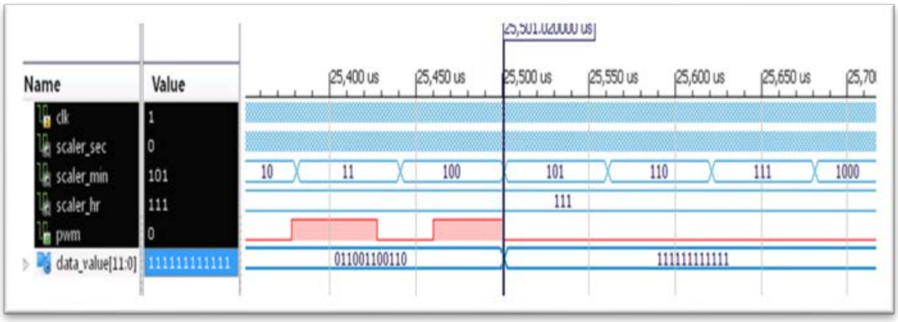


Figure (5) Simulation results.

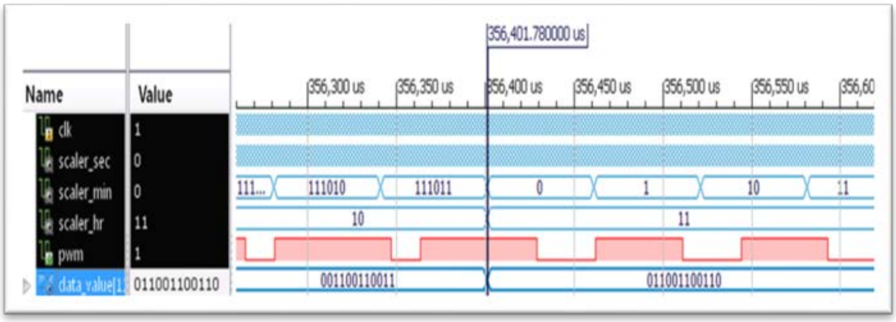


Figure 6 Simulation results.

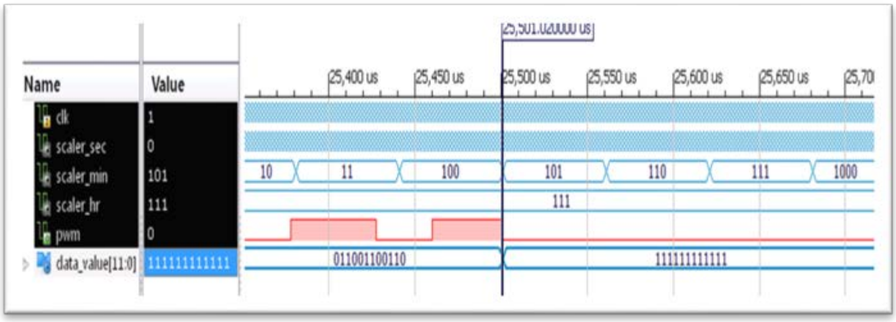


Figure 7 Simulation results.

Figure (8) PWM signals using oscilloscope.

Figure (9) LCD display of SPARTAN 3A.

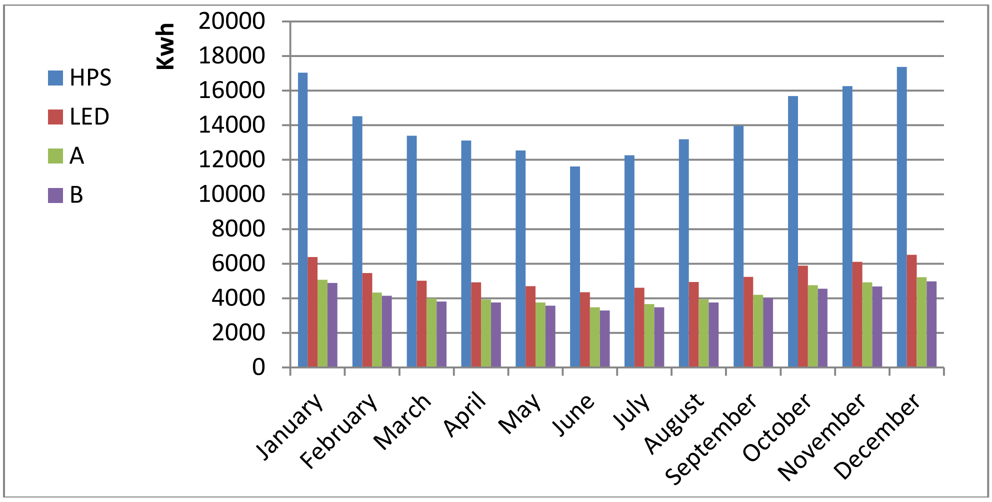


Figure (10) Annual power consumption for one year.

Table (1) Some of the data values for different duty cycles.

Data value (Hexadecimal)	**Duty cycle%**
00000	**100**
0CCC	**80**
19999	**60**
26666	**40**
33333	**20**
3FFFF	**0**

Table (2) scaled down data value and equivalent duty cycles.

Data value (Hexadecimal)	**Duty cycle%**
000	100
333	80
666	60
999	40
CCC	20
FFF	0

Table (3) calculations results for 100 pieces.

Technology	HPS (400W)	LED (150W)	LED with scenario A	LED with scenario B
Annual Power consumption(kw.h)	170964.32	64111.62	51226.0824	48939.7968
Annual reduction in Power consumption with respect to HPS (kw.h)	---	164552.68	119738.23	122024.5
Annual reduction in Power consumption with respect to normal LED operation (kw.h)	---	---	12885.53	15171.824
% Annual Power saving with respect to HPS	---	62.5%	70%	71.4%
%Power saving with respect to normal LED operation	---	---	20.1%	23.7%
Amount of CO2 emission (Ton)	71.8	26.9	21.5	20.5
Reduction amount of CO2 emission with respect to HPS (Ton)	--	44.9	50.3	51.3
Reduction amount of CO2 emission with respect to normal LED operation (Ton)	---	---	5.4	6.4
Annual Electricity cost US$*	20515.7	7693.3	6147.1	5872.7

*Electricity charge: US$ 0.12/Kw.h
* CO_2 emission is 0.42 kg/kw.h

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