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SUSTAINABILITY INITIATIVE AT RMIT UNIVERSITY

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ABSTRACT - *This study aims at giving a complete retrofit solution for existing lighting system including light fixtures, switchgear and lighting circuit with dimming option by successful interfacing among them. Positive outcome of this study will pave the way of replicating the same package retrofit solution to other similar systems around the world. As LED lamps are the latest and most energy efficient sustainable source for domestic and commercial application, it was chosen as a retrofit tool against existing CFL and T5 luminaires. The study primarily aimed at giving a platform for LED luminaires by using existing infrastructure including hardware and software. Major challenges involve a smooth transition from AC to DC system by retaining existing circuit and it should promise future cost savings in retrofit projects. Findings of this study indicate that 50% energy savings may be possible over present system.*

Keywords: LED, CFL, Dimming, T5, Sustainability, HVAC, DC, AC

1. INTRODUCTION

RMIT University is fostering a "think green" culture within the University community and beyond and encourages staff, students and the general public to make changes in their day-to-day lives, both at work and at home, to minimise their impact on the environment. To support RMIT's mission, in this research project probably for the first time all the light sources are proposed to be powered by solar panels in a Direct Current (DC) environment. The idea is to integrate LED lighting technology with solar system, low voltage DC application [1], intelligent dimming control and intelligent on/off control. A smooth transition from AC to DC system without changing the present infrastructure is a major challenge in this project.

This study aims some unique research and development in the following areas:

Retrofitting LED chips into existing five types of fixtures being used into the research lounge so that it could bring immediate benefit to million other domestic and commercial buildings in Australia by replicating the same.

Creating a common 48 Volt DC platform for all the equipment including all drivers of five type fixtures. Operating with a 48 volt system significantly reduces driving current of LED fixtures and minimizes cable size to give a big advantage of using existing cables. Advantage of using a common DC voltage level from the DC bus up to the drivers helps avoid presence of multichannel variable DC to DC converters and cables of different sizes.

To use corresponding drivers as DC to DC converters having 0-10 Volt DC pulse width modulation dimming capability [2].

Primary objectives are to achieve 100% energy saving with solar system, also 50% energy savings without solar system and reduction of carbon footprint.

2. DATA CAPTURE AND ANALYSIS

2.1 Metering device

The HIOKI 3196 POWER QUALITY ANALYZER (3196) was used as it can measure both single phase and three phase system parameters.

2.2 Steps involved

1) Identifying different modes of operation
2) Segregating day wise hourly operation in four modes
3) Determining Kilo Watt (KW) consumption in each mode ; it was done by two methods:
   A. Directly from the demand window
   B. Data logger sensors also monitored ampere consumption at the points of measurements. From voltage window, corresponding voltage was determined.
   KW consumption in each mode= Ampere*voltage
4) Finding out kilowatt-hour(KWH) consumption in each day's operation

KWH= $\sum_{i=1}^{4} kw\ in\ mode\ i * hours\ of\ operation\ in\ mode\ i$

5) After getting consumption of each day in 14 day's observation, total consumption and

average consumption were determined.

6) Linear extrapolation gives yearly consumption on the basis of average load
7) Next step involves finding out some important ratios for future reference to determine average load of retrofitted system.

2.3 Key Metering Program's Features

i. 14 Days continuous data capturing

ii. HIOKI 3196 POWER QUALITY ANALYZER has been used for data capturing

iii. Data has been captured from three different points in the distribution board of B-28 Research lounge by three CT sensors and three Channels

iv. Program was intended to find usage pattern of that particular area

Instrument set up was designed to successfully capture load variation in all the four modes of operation by the user

Figure 1 represents kilowatt-hour consumption for 14 days observation

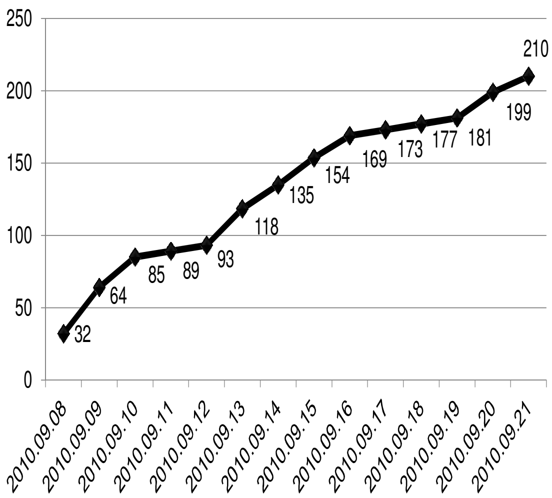

Fig.1: Cumulative energy consumption

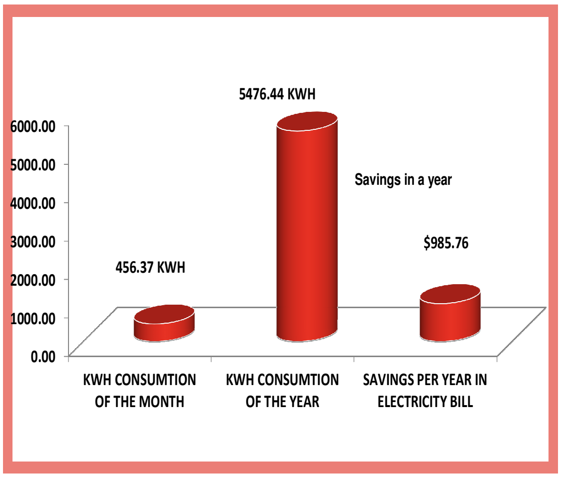

Fig.2: Load scenario and future cost savings

Based on the data found in Figure 1, Figure 2 has been drawn which shows monthly and yearly KWH consumption. Savings in a year has been calculated on the basis of 100% savings with solar system. But it will be half of the calculated savings if solar panel is eliminated from the system. Electricity tariff has been assumed 18 cents/KWh considering hike in price over the project lifetime.

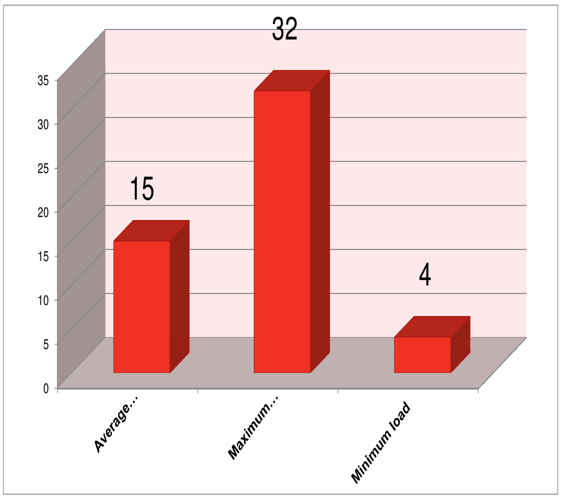

Fig.3: Maximum, average and minimum load

Figure 3 shows maximum, minimum and average load (KWH) in 14 day observation

3. DESIGN AND IMPLEMENTATION

3.1 Conceptual design

Fig.4. Conceptual model of LED retrofit

In Figure 4 Maximum power point tracker maximizes the output of the solar panel [3]. Input side of the MPPT [4] deals with 31.76 ampere at 89.5 volt DC and expected to produce 48-60 volt DC at the output .In the conventional operations, MPPT controls the charging of the battery but in our case Selectronic [5] device takes care of that. Programmable Selectronic device is expected to Control the charging and discharging of the battery [9], Feed additional power to the grid, Covert incoming DC from the battery to AC to serve the grid, Automatically changeover to bring the existing GRID to serve the load in case of the battery or Selectronic failure. Transmit DC directly from the battery to the load, Give AC input to the PHILIPS dynalite dimmer; [8] Charge the battery in case of the power outage from the panel.

A switch mode power supply has been proposed to produce AC to DC from the grid to supply load in case of the failure of Selectronic inverter charger. Four power supplies each having 48V DC, 10A capacity will be used as standby power supply [6] to feed DC BUS A (two SMPS in parallel) and DC BUS B (other two in parallel). [7]

The reason for going into a two bus system is two distribute the load for ease of routine and preventive maintenance and due to the constraint of using four SMPS in parallel to serve a single BUS.

3.2 The Battery

The battery sizing calculation has been undertaken based on parameters shown in Table 1

Table 1: Battery sizing calculation

Maximum load with LEDs(watt) according to design data	Hours of operation	Off peak load(watt)	Hours of operation	energy consumption of the day (Etot) watt-hour	number of days of autonomy (Taut)	Nominal system voltage (Vdc)	Depth of dischrage(DODmax)	Cx ,battery capacity(AMPERE-HOUR)	Recommended battery size(AH)
1267.94	6.00	12.00	18.00	7823.61	0.90	48.00	0.50	293.39	300.00

Battery sizing calculation [10]

Batteries for energy storage were sized according to the following equation:

Cx= Etot* Taut/ Vdc* DODm

Where,

Cx = battery capacity, specified for an appropriate discharge rate x, in ampere hours (Ah)

Etot = total design daily energy demand from the d.c. bus, in watt hours (Wh)

Taut = number of days of autonomy

Vdc = nominal voltage of the d.c. bus (i.e. battery voltage), in volts (V)

DODmax = design maximum depth of discharge

Sample calculation of the spread sheet:

Etot= 1267.94*8 + 12*16
=7823.61Watt-hour

Taut= .9 day

DODmax= 50%

Vdc= 48 Volt

Cx=7823.61 *0.9/(48*0.5)
= 293.39 Ampere-hour

Due to battery efficiency factor, recommended battery size= 300AH

3.3 The Cable

The cable sizing calculation has been undertaken based on parameters shown in Table 2.

Table 2: Cable sizing calculation **[10]**

CATEGORY	SYSTEM VOLTAGE	LOAD CURRENT(MAX)	DISTANCE(M)	ALLOWABLE VOLTAGE DROP(%)	ALLOWABLE VOLTAGE DROP(mV/A-M)	SELECTED CABLE SIZE mm^2	ACTUAL VOLTAGE DROP(mV/A-M) OF SELECTED CABLES ACCORDING TO AS4509.2
1.From solar panel to selectronic	89.5	33	100	5	1.356060606	35	1.3
2.selectronic to battery	48	35	5	1.5	4.114285714	16	2.8
3.AC grid to SMPS	230	20	5	4	92	2.5	18
4.SMPS TO DC BUS	48	20	5	1	4.8	16	2.8
5. DC BUS TO BRANCH	47.72	4.9	33	6.5	19.18243661	2.5	18

NOTE: TO SELECT A PARTICULAR CABLE SIZE, THE FOLLOWING CONDITION MUST BE MET
ALLOWABLE VOLTAGE DROP SHOULD BE GREATER THAN ACTUAL VOLTAGE DROP

Sample calculation:
Formula used: CALCULATION OF VOLTAGE DROP
Voltage drops in cables can be calculated as follows:
(a) Define mains and sub-circuits and measure/estimate the route length of each circuit
(including vertical and switch runs).
(b) Determine the maximum current requirements for each circuit (maximum demand).
(c) Allocate the maximum permissible voltage drop to each circuit section.
(d) Apply information from (a), (b) and (c) in the following voltage drop equation:
Vc = 1000 * Vd/ Imax* L
Vc = 1000 * Vnom * V%/ Imax* L
where
Vc = cable voltage drop, in mV/Am
Vd = allowed voltage drop, in volts (V)
L = route length, in metres (one way) (m)
Imax = maximum current loading, in amperes (A)
Vnom = nominal system voltage, in volts (V)
V% = percentage voltage drop
Sample calculation :
ALLOWABLE VOLTAGE DROP (mV/A-M), Vd= 1000*47.72*6.5/(4.9*33*100) =19.18
According to AS 4509.2, 2.5 mm2 cable has a drop of 18 mV/A-M. So 2.5 mm2 cable has been selected for this purpose

3.4 Retrofit at a Glance

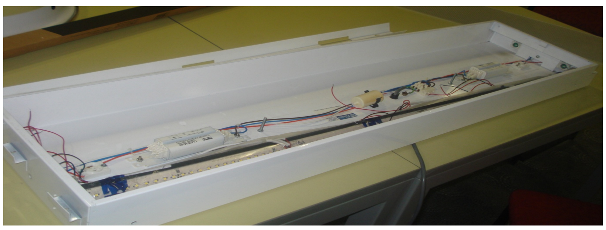

Fig.5: Previous T5 fixtures

Figure 5 shows previous T5 fixtures with two tubes and two ballasts. Dimming was controlled by DSI signal from the Philips dynalite dimming channels.

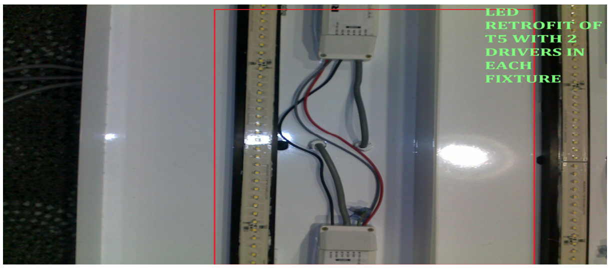

Fig.6: LED alternative of T5 fixtures

Figure 6 shows LED alternative of T5 fixtures with two drivers having pulse width modulation capability.

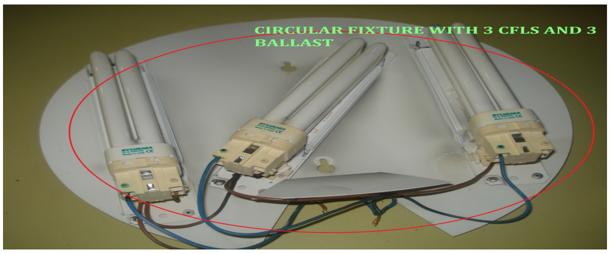

Fig.7: Previous Circular CFL fixtures

Figure 7 shows previous Circular CFL fixtures with three U shaped CFLs and three ballasts. Dimming was controlled by ON/OFF signal from the Philips dynalite dimming channels.

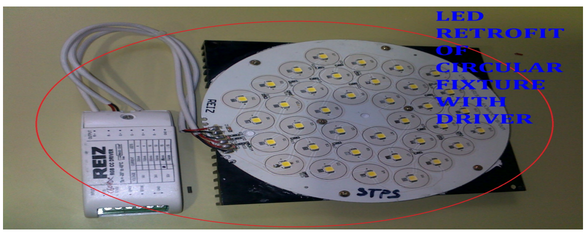

Fig.8. LED alternative of circular fixtures

Figure 8 shows LED alternative of circular fixtures with one driver replacing three ballasts and three CFLs.

Philips dynalite dimmer generates ON/OFF input signal and driver controls dimming level by generating ON/OFF mode. Driver is responsible for taking care of 36 LEDs for ON/OFF operation.

Fig.9: LED Drivers

Figure 9 shows LED Drivers replacing ballast with advanced feature of pulse width modulation dimming.

4. RESULTS

4.1 Cost Savings by Reducing Wattage

Cost savings calculation has been undertaken based on watt reduction parameters shown in Table 3

Table3: LED watt consumption and cost savings

KWH CONSUMTION OF THE MONTH	KWH CONSUMTION OF THE YEAR BY PREVIOUS SYSTEM	SAVINGS PER YEAR IN ELECTRICITY BILL WITH SOLAR SYSTEM	PEAK LOAD WITH LED (WATT)	AVERAGE LOAD WITH LED (WATT)	% OF ENERGY SAVINGS BY LED	KWH CONSUMTION OF THE YEAR BY LEDs	SAVINGS PER YEAR IN ELECTRICITY BILL WITHOUT SOLAR SYSTEM
456	5476	986	1268	665	50	2731	492

Energy consumption in KWH by lighting loads only and corresponding savings of $986/year considering 100% savings if the system is powered by solar energy.

4.2 Cost Savings by Reducing Heat

Cost savings calculation has been undertaken based on heat reduction parameters shown in Table 4

Table 4: Light and HVAC interaction [11]

CLF(am)cooling load factor	CLF (pm)	average CLF	ballast factor	Total Watts of CFL	AV. HR. OF hvac operation	Heat produced by CFLs per hour(KW)	Total Watts of LEDs	Heat produced by LEDs per hour (KW)	Reduction in heat generation(KW) PER YEAR	SEER	SAVINGS IN KWH/YR	COST SAVINGS IN 1YEAR($)	COST SAVINGS IN 15 YRS ($)
0.87	0.95	0.91	1.1	1333	8.00	1.33	664.93	0.61	1062	2.917	364	65	983

Generally, Cooling load factors are used to convert instantaneous heat gain from lighting to the sensible cooling load; Q = CLF*ballast allowance factor*Average load, CLF = Cooling Load Factor, by hour of occupancy.
Heat produced by previous system /hour
Q =.91*1.1*1333=1330
Heat to be produced by LED system /hour = .91*664.93 =605.1
Reduction in heat generation/year = (1333-605.1)*8*7*26/1000 =1062 KWH (heat energy)
Savings in electricity consumption due to reduced work by HVAC system=1062*SEER = 1062/2.917==364 KWH (Electrical energy)
Cost savings=364*.18=$65/Yr

4.3 Cost Savings by Reducing Maintenance Cost

The maintenance cost calculation has been undertaken based on parameters shown in Table 5

Table 5: Maintenance cost savings

Led life hours	Existing CFLs life hours	No. Of CFLs	Maintenance cost per CFL	Lifetime savings	Savings per year
50,000	6000	148	$50	$61,667	$2,857.31

Existing CFL life hours=6000, Led life hours =50000 No. of CFLs= 148, Maintenance cost per CFL= $50 Lifetime savings= 50000*148*50/600= $61,667 Savings per year= 61,667/15 (15 year is LEDs life span considering daily 8 hours of operation) =$2857/year

4.4 Benchmark

Benchmark has been undertaken based on parameters shown in Table 6

Table 6: comparison between previous and retrofitted system

Item	Before	After	Remarks
Connected load(Watt)	3662.8	1721	53% reduction in connected load
Peak load(Watt)	2542.8	954.48	62.51% reduction in peak load
Average load(Watt)	1333.5	664.9328781	50.13% reduction in average load
MODE 1 load(Watt)	2542.8	954.48	62.51% savings in MODE1
MODE 2 load(Watt)	1590.4	953.18	40% savings in MODE2
MODE 3 load(Watt)	1030.4	240.20	83% savings in MODE3
Dimming	Dimming by DSI	Dimming by PWM	
CFL circular fixtures	3 CFLs in one fixture with 3 ballast	LED stream with driver	
T5 fixtures	2, T5 in one fixture with 2 ballast	LED stream with 2 drivers	
Decorative	14 side wall cfl and 8 upper wall cfl fixtures	14 side wall LED and upper wall single strip LED fixture	
lighting circuit			
BUS	AC bus	DC bus	
Redundancy	No redundancy	Redundancy included	
carbon footprint (TON/Year)			2.2 TON reduction/Year, 33TON/15 Year
Maintenance cost Savings/Year			$2,857.31
Power cost savings/Year			$491.54
Maintenance method	Breadown maintenance policy	Age based group replacement policy	

Above comparison indicates significant reduction in energy consumption in terms of connected, peak, average load, mode 1, mode 2 and mode 3 loads. This table also shows transition from DSI to PWM dimming and form AC to DC environment. Reduction in carbon footprint is also remarkable.

4.5 Reduction in Carbon Footprint

With solar system:
Total energy savings by LED retrofit= (5476.44+1013.8) =6490.24 KWH/Year
Average CO2 emission (KG/KWH) = 0.62
Reduction in CO2 emission= 6490.24 *0.62/1000= 4.023 ton/year
Without solar system:
Total energy savings by LED retrofit= (2745.68+1013.8) =3759.48 KWH/Year
Average CO2 emission (KG/KWH)= 0.62
Reduction in CO2 emission= 3759.48 *0.62/1000 =2.33ton/year

5. CONCLUSIONS

This research project is successful in terms of creating a complete DC platform for the LEDs. Major user requirements, project Goals and KPIs have been maintained with success. Retrofitting idea has been implemented properly by keeping most of the system hardware intact including cables and dimming function with four modes of operation. Preliminary result based on the data taken at the commissioning phase shows a clear evidence of energy savings up to 50% without solar panel which fulfills the project goal.

This project can easily be a retrofit model for any future development and implementation of retrofit project and could experience success by replicating the same.

6. REFERENCES

[1] G. Mura, M. Vanzi, "The interpretation of the DC characteristics of LED and laser diodes to address their failure analysis", *Microelectronics Reliability,* vol. 50, no. 4, 471-478, 2010

[2] L. Svilainis, "LED PWM dimming linearity investigation", *Displays,* vol. 29, no. 3, pp. 243-249, 2008.

[3] LG Monocrystalline Solar Module (http://www.lg-solar.com/business-resources/download/Data%20Sheet-LG240%20235%20230M1C-ENG.pdf)_link accessed 03.09.2010.

[4] Flexmax-80 Outback power systems (http://www.solarsalesinc.com/downloads/Outback%20FlexMax%2060.pdf link accessed 05.09.2010..

[5] Selectronic SP Pro Series 48 Volt 4000 Watts Invertercharger

[6] http://www.energymatters.com.au/selectronic-sp-pro-series-48-volt-4000-watts-inverter-charger-p-2506.html link accessed 10.09.2010.

[7] ABB Power supply CP-E 48/10.0 Data sheet http://www05.abb.com/global/scot/scot209.nsf/veritydisplay/a794d8e0074cd4ddc125749c00360999/$file/2cdc114064d0201.pdf link accessed 15.09.2010.

[8] ABB low voltage devices, www.abb.com link accessed 16.09.2010.

[9] Philips Dynalite DMC805 leading edge dimmer http://pdf.archiexpo.com/pdf/philips-.dynalite/catalogue/53631-19489-_7.html link accessed 20.09.2010.

[10] Energel 300ah gel battery by battery energy .http://www.batteryenergy.com.au/downloads/3.2.6.00%20Energel%20Operation%20and%20Maintenance%20Manual.pdf link accessed 13.09.2010.

[11] AS 4509.2—2010, 2010, accessed-5/9/ 2010

[12] ASHRAE Fundamentals, "Light and HVAC interaction" 1997, Chapter 28, Table 38 accessed 03.09.2010.

7. NOMENCLATURE

Term	Meaning
HVAC	Heating, Ventilation and Air Conditioning
CFL	Compact Fluorescent Lamp
LED	Light Emitting Diode
MPPT	Maximum power point Tracker
AC	Alternating Current
DC	Direct current
T5	Fluorescent lamp
SMPS	Switch Mode power supply
BUS	Set of electrical conductors that make connection among several circuits
PWM	Pulse Width modulation