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# Wireless Sensor Actuator Network Architecture and Energy Model of a Camera Based Lighting Management System

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**ABSTRACT** Communication protocols and wireless networking technique is a cohesive part of any light management system. IEEE 802.15.4 standard based networking techniques for the climate-adaptive light management system and its energy model for sensor actuator node is the focus of this paper. This light integrated scheme with adaptive controls provides the desired illuminance at appropriate times with uniformity, by reducing the discomfort glare and energy use. The first part of this paper investigates the architecture and energy consumption of camera-based wireless sensor-actuator nodes with the help of energy models, including a control unit for the Light Management System. Then focused on the energy savings and techno-economic analysis of this wireless networked lighting system in a test room with automated control of Light Emitting Diode luminaire and Venetian blinds. The wireless sensor actuator networked lighting system performance is analyzed by evaluating the node energy consumption in idle and active mode with real time measurements. The energy consumption evaluation of the nodes allows users to improve node life time and think about power management schemes. The climate-adaptive control scheme shows improved uniformity and significant energy savings.

**INDEX TERMS** Energy, wireless sensor and actuator network, architecture, camera, lighting management system.

## I. INTRODUCTION

The application of Wireless Sensor Actuator Network (WSAN) is gaining momentum in residential and commercial buildings control applications. Aiming to solve the problem of developing a communication architecture for control strategies, there has been an emergent interest in the use of wireless sensor actuator networking technology to introduce improvement in the battery lifetime and flexibility in sensor placement [1]. Energy consumption is the most important factor to determine the life of a sensor network because sensor nodes are driven by battery. The energy optimization can be done by having energy awareness in every aspect of design and operation. This ensures that energy awareness is also incorporated into groups of communicating sensor nodes, actuator nodes, coordinator, control technologies, luminaires and drivers, communication and implementation

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platforms [2]. For a battery powered network scheme, the important sources of energy consumption are transmit power, receive power, power consumed for idle listening of sensor nodes.

This paper presents the network framework architecture of the design and implementation associated with a camera-based Daylight-Artificial Light Integrated Scheme (DALIS) [3]. The energy model of the wireless nodes could help the users to get the awareness on battery life of the nodes. Energy monitoring by appliance level information can provide awareness on energy saving [4]. The performance analysis of the WSAN is in terms of its Quality of service parameter [5]: the energy consumption of the sensors, network nodes and actuators are carried out.

## II. LITERATURE SURVEY

The application of communication protocols and wireless networking techniques are recent advancements for energy efficient implementation of automatic adaptive lighting

control system. ZigBee is one of the wireless protocols used for building automation, lighting control etc. [6]. According to [7], since the connection of multiple sensor nodes are tedious, ZigBee based wireless network technology can be used for organized sensor networks. Light control is one of the classic examples of using ZigBee in a house or commercial building [8]. Gloria *et al.* [9] suggests that IEEE 802.15.4 based ZigBee protocol is the best choice for an indoor building automation application. The current researches of lighting control focus on networking [10] and intellectualization of lighting control. Autonomous light control system with wireless sensor actuator networks controlled by binary and continuous satisfaction model simulation and prototyping is discussed by Yeh *et al.* [11]. The limitation of the system is the user must carry light sensors to measure the light intensities at each instant. To improve upon the wiring complexity and costly installations in smart building, wireless networking has been considered as a best solution [12]. According to authors [13], incorporation of emerging wireless sensor and actuator network technology with individual addressability, enhances the performance of the lighting communication network. It is reported that they achieved 60% energy savings with workstation based wireless photosensors to measure task illuminance.

The authors [14] assess wireless lighting control for daylight and occupancy adaptation and analyze control performance with open office lighting model and ZigBee wireless mesh. The system developed was a light harvesting wireless sensor module with photo sensor & motion sensor. Wireless sensor and actuators network application in lighting control is also addressed by Peruffo *et al.* [1], Labeodan *et al.* [15]. Peruffo *et al.* [1] addressed photosensor equipped luminaires simulation model with mesh scheme. Occupancy based and sensor equipped luminaires, light harvesting sensors are considered in these literatures for the adaptation. Connected lighting driven by data and controls, integrated into building management system is the latest technology development smart lighting [16]. A WSN used for building energy monitoring and control can reduce the energy budget needed to condition the space [17]. Jesus *et al.* [18] developed a WSAN providing support to an intelligent system for energy management and control that decides when devices should connect within a given range of time to optimize costs. ZigBee-based energy measurement modules are suggested by Han *et al.* [19] to monitor the energy consumption of home appliances and lights. In their research, Han *et al.* [20] demonstrated that with a remote-controllable and energy-saving room architecture a user can control the power outlets and the dimming light with an infrared remote control of any home appliance and save the total power consumption of a room. Different methods available to evaluate the energy consumption of WSAN nodes are finite state machine, stochastic analysis, petri net and analytical model [2]. A stochastic model-based energy evaluation of general sensor node is captured for sleep and active mode by Agarwal *et al.* [21]. An energy model for wireless sensor

node is designed to observe locally and globally the energy of the nodes in a network under any routing protocol [22]. It compares the performance with different routing protocols. Based on the literature review the research gap identified are, more research is needed in the area of energy consumption analysis of wireless nodes while integrating daylight and artificial light and in the reduction of number of nodes. For lighting control application with camera as sensor more research need to be addressed. Final energy analysis of the actuators has to be researched upon based on the energy model. Creating real testbed experiments for energy transfer is still ongoing research with a little breakthrough [23]. The multiple collocated sensors like photosensors and occupancy sensors mentioned in the literature [16], are replaced in this work using a single camera. Thus, the number of nodes is less compared to conventional light sensor-based Lighting Management System (LMS).

To implement daylight linked and occupancy adaptive lighting control, a Wi-Fi based wireless image sensor and ZigBee based wireless networked actuation system are used in conjunction with a centralized controller. The hardware architecture of wireless networked adaptive lighting scheme, component correlations in the networking scheme and the wireless nodes, and test set up in the research test room are deliberated in section 4. The experimental scenarios considered are: i) camera as occupancy sensor, ii) camera as photosensor, the energy consumed by the sensor and actuator nodes with a finite state machine energy model is analyzed and discussed in section 5. The energy savings for the lighting management system with respect to the analysis of seasonal variation and occupancy diverse factor are presented. The significant contribution of this paper is i) a WSAN architecture of camera-based test bed for luminaire and Venetian blind control for smart building ii) Energy model and Evaluation of energy consumption of the individual network nodes for operating task with finite state machine concept for a wireless networked camera-based lighting and venetian blind control scheme, iii) Evaluation of the energy consumption of luminaires and venetian blinds for a year. Authors [2] demonstrated the control algorithm development of the camera-based scheme. The paper addresses the camera based wireless sensor actuator network architecture with component correlations, state machine-based energy modeling and energy consumption analysis of the lighting automation scheme.

### III. SYSTEM DESCRIPTION

System level architecture of WSAN based lighting control scheme with camera as the sensor, balancing daylight, glare and energy efficiency goals is shown in Fig. 1. The system consists of dark room calibrated camera sensor, two luminaires and the driver modules, one controller (coordinator node), one motor and driver to control the blind. In the light integrated scheme as shown in the Fig. 1, the window and work plane low dynamic range images are captured by the digital camera.

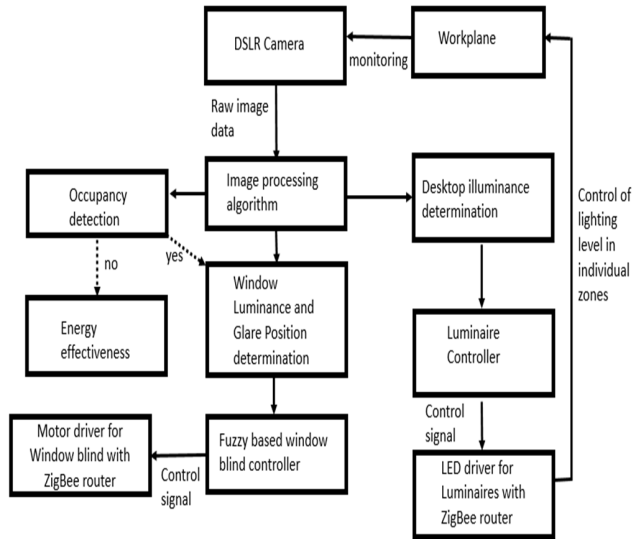


FIGURE 1. System level structure of image based daylight artificial light integrated scheme.

Varghese et al. [3] discussed, the image processing algorithm to detect occupancy, daylight information at the window, illuminance at the workplane. As the initial event, the camera act as occupancy sensor, and the information about occupant is present or not is sent to the controller. If occupant is present, the coordinator sent a message to activate the camera sensor to capture the window images and the window luminance is derived using the algorithm. The luminance and occupancy information obtained from the workplane images are used in the rule-based window blind controller and activates the motor of the window blind. After fixing the blind position based on the daylight availability, the gain scheduling- based luminaire dimming controller, controls the actuator nodes through ZigBee based networking scheme of the lighting control system. The networking and energy consumption evaluation method are discussed based on the window blind control signals generated in [3]. The blind operation is defined in two states, CW and ACW, for closing and opening of the blind respectively.

In CW and ACW states, the present direction (DIR) and past direction (PAST\_DIR) of movement of the blind are compared to provide the extra delay for the blind to flip. Once the motor operation is completed, the  $i$  value is updated with  $\alpha$  value according to Fig. 2.

The state diagram for the linear dimming is shown in Fig. 3. The luminance value at the luminance sensor is modeled as a linear combination of the artificial light and daylight contribution, which is written as

$$y(k + 1) = G_l u(k) + d(k + 1) \quad (1)$$

where  $y(k)$  is the task light measurement,  $d(k)$  is the daylight contribution,  $G_l$  is the luminance gain and  $u(k)$  is the dimming factor. Considering the luminaire gain with respect to previous state, the dimming factor ( $d_i$ ) after the initial condition is

defined as

$$d_{(k+1)} = \frac{d_k E_{set}}{E_{task}} \quad (2)$$

The nodes in the process flow diagram given in Fig. 3, are init, sensor, PWM generation, Light DIM, maintain set point and Light OFF. The control signals generated by the blind and luminaire controller is communicated wirelessly through ZigBee added nodes. The message data for luminaire and blind control transmission and reception is achieved and the packet loss is checked with the status message. A test room-based lighting automation with motorized blinds using wireless sensor control system and wireless actuator network nodes is the test scenario.

For the purpose of daylight integrated control, the test room is considered as primary side lit zone – working zone adjacent to the window and secondary side lit zone – working zone away from the window or extension of primary zone as shown in Fig. 4. Venetian blind of dimension 1.3m X 1.3m are mounted in interiors. The workplane height is considered is 0.85m from the floor.

#### IV. WIRELESS SENSOR AND ACTUATOR NETWORK ARCHITECTURE

Fig. 5 shows the WSAN scenario used for DALIS with Zig-Bee based star topology for the actuator nodes. The camera, temperature sensor, blind, luminaire and controller nodes are numbered from node 1 to 6 respectively. The real-time test workbench has the process flow: occupancy-based light switching, daylight linked light controls and integration of shadowing systems to daylight linked controls respectively. The system gets activated on an hourly basis. The DALIS acquires the occupancy data initially and the camera sensor node is in transmit mode. If occupancy is detected the output from the sensor node is processed by the fuzzy controller algorithm considering visual and thermal comfort to control the movement of the blind else the output is processed by fuzzy controller considering the energy effectiveness. The control signal ( $\alpha$ ), as mentioned in Fig. 2, controls the motor. The actuator is in the receiving mode during this time. The ZigBee [8] devices are working in the API mode. The direction and speed of the motor are appended in the data frame as RFs data Attention (AT) command and parameter. Next data frame incorporates the dim level of the luminaire and send to the driver part of actuator nodes 4 and 5 according to Fig. 3.

##### A. COMPONENT CORRELATIONS AND STATE MODELING

The component correlations and the state flow of the wireless network is shown in Fig. 6. It indicates the operation modes of the nodes used and the tasks each node does. SU, CU, PS, AU represents Sensor Unit, Communication Unit, Processor, and Actuation Unit respectively in Fig. 6. Finite state machine model is used to define the nodes and to evaluate the energy consumption of the nodes. The sensor node is defined in the state event transitions as follows. SU <ON, OFF>, CU <IDLE,

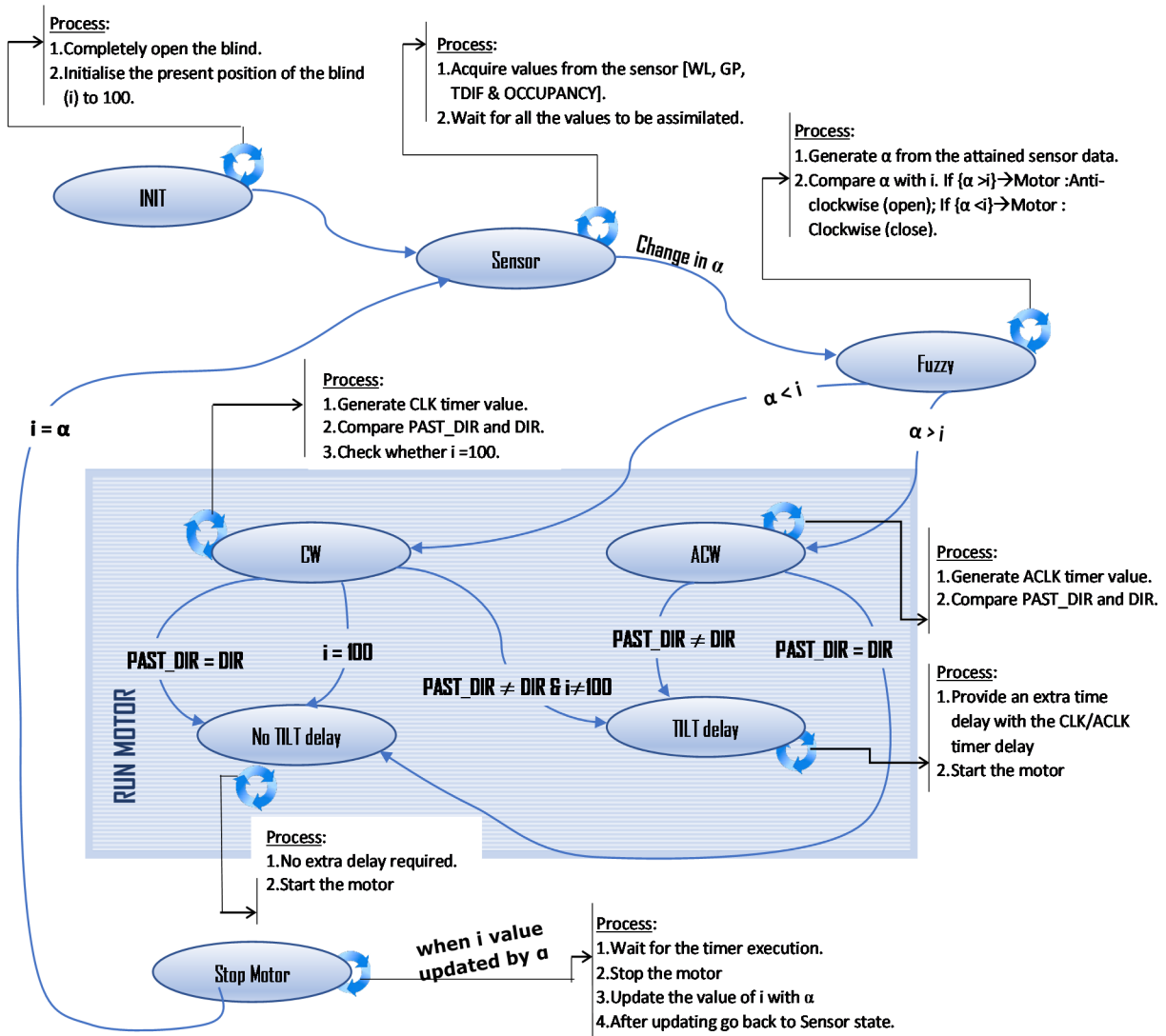


FIGURE 2. State diagram for venetian blind control.

TX, RX}, PS {OFF, IDLE, ACTIVE}, AU {CW, ACW, ON, OFF, DIM}. State transitions reveals the relation between the components and the network nodes. The beacon, data, acknowledgement frame are the messages which specify the correlation of the event. The Sensor, actuator devices implement task sensing or actuation, report to controller or receive data from the controller.

### B. NETWORK ESTABLISHMENT

The controller implemented on myRIO determines the appropriate control signals (data) for the actuators. The concepts defined in the IEEE 802.15.4 standard [9] with 2.4GHz frequency and data rate 250Kbps is considered [3] for blind control ( $\alpha$ ), speed and dimming signal transmission and reception. In the process flow, the process initiates with a radio frequency checking. Then start the network configuration and further actions including  $\alpha$ , dimming signal transmission, and reception, which take place in parallel.

The Xbee coordinator initiates and configures network formation. Before the coordinator initiates the IEEE 802.15.4 network, it performs one device check by sending out a beacon request to the end devices within the coordinator's operating area. Then the coordinator saves the received responses, containing the network description. By matching the result with the received response from the end devices, the coordinator decides whether to start the network or not in this frequency range. During network initialization, the network identifier, network address allocation and IEEE 802.15.4 network beacon is specified. For the wireless actuator node network, after the network establishment joining request is initiated by the coordinator to node 3 as shown in Fig. 3. The end device node 3 listens for the joining request. The next step is network command transmission/reception for node 3 from coordinator and then the user data transmission takes place. After this the similar procedure is repeated for establishing the connection for node 4, 5.



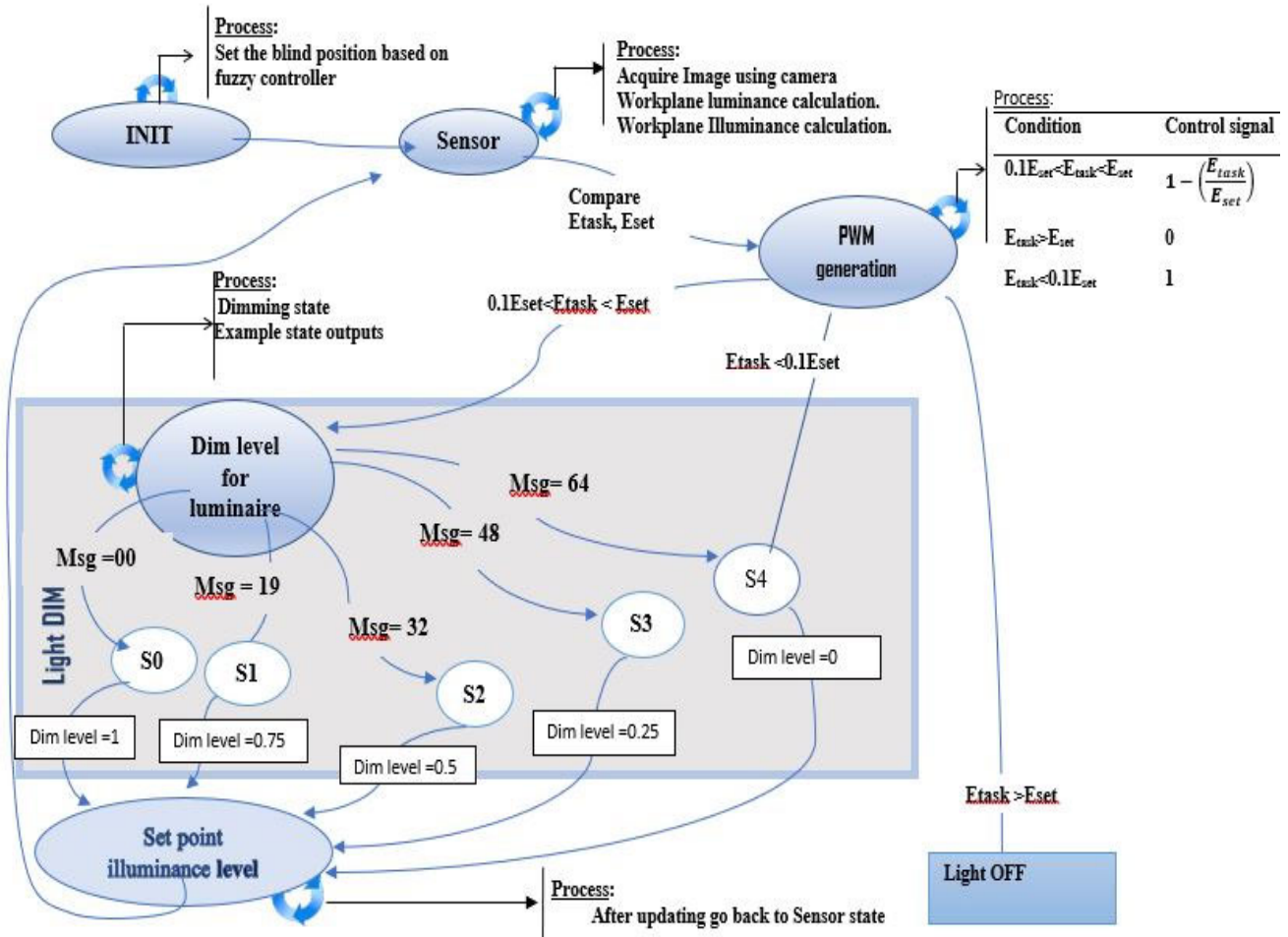


FIGURE 3. State diagram for luminaire control.

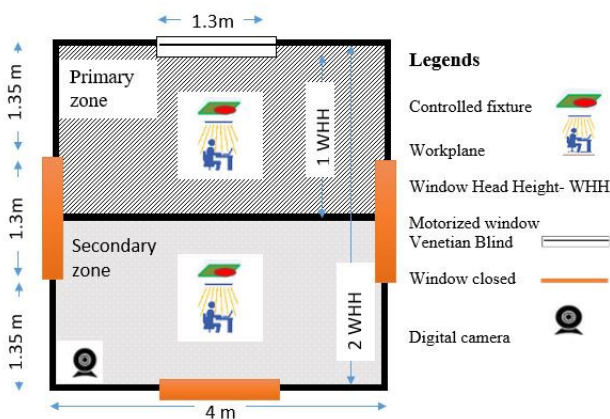


FIGURE 4. Details of the test room measurements.

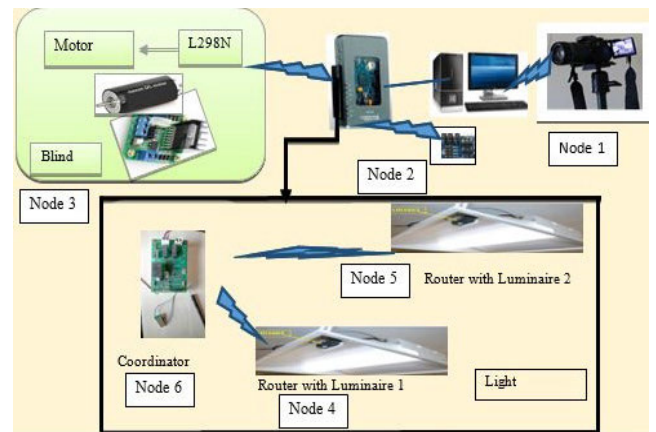
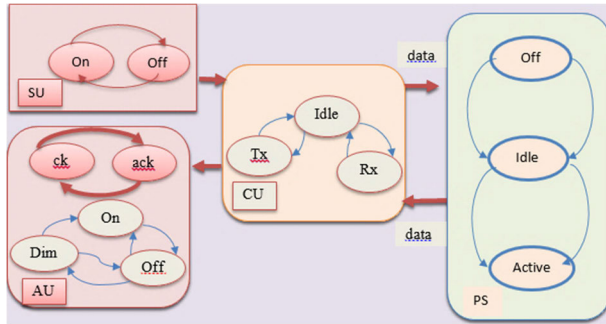


FIGURE 5. Hardware architecture of the WSN nodes for lighting control system.

**V. ENERGY MODEL OF WSN NODES**

The analysis of energy consumption with star topology for the hardware architecture nodes in idle, transmit and receive modes are discussed here. Through the preliminary investigations on wireless networked nodes, the authors already proved

that the ZigBee star topology offers the best performance in terms of end to end delay, throughput, and jitter [3]. In the networked lighting systems and building automation projects with multiple luminaires with collocated conventional sensors, where the emphasis is on saving energy especially in



**FIGURE 6. Component correlations and state relationship in the networking architecture for defining the energy model.**

idle mode, it is found that the mesh protocol is more sustainable [4]. But since the multiple collocated sensors are replaced by a single camera and the primary and secondary light zoning is considered the number of nodes has reduced in this work. The preliminary study showed that when the number of nodes is less star networking topology is feasible with respect to energy saving also. According to the generic energy model in the task-based energy evaluation is performed.

#### Generic Energy Model

%Total energy consumed by the system per cycle:

$$E_{cycle} = E_{transceiver} + E_{processingunit} \quad (3)$$

% Energy consumption at individual stages:

$$E_{sen} = E_{sensor} + E_{tu} \quad (4)$$

$$E_{processingunit} = E_{tu} + E_{controller} + E_{ru} \quad (5)$$

$$E_{act} = E_{driver} + E_{ru} \quad (6)$$

$E_{transceiver}$  is the energy consumed by the transceivers and  $E_{processingunit}$  is the energy consumption by the processing unit in (3).  $E_{sensor}$  is the energy consumption of sensor and  $E_{tu}$  is the energy consumption of transmission unit in (4).  $E_{controller}$  is the energy consumption of coordinator and  $E_{ru}$  is the energy consumption of the receiver unit in (5).  $E_{act}$  is the energy consumption of actuator node and  $E_{driver}$  is the energy consumption of the driver node.

#### A. ENERGY MODEL FOR DIFFERENT SCENARIOS OF LIGHTING MANAGEMENT SCHEME

This section discusses about the proposed energy model in different scenarios of the process flow.

*Scenario 1:* Camera as occupancy sensor is considered as the scenario 1 for the energy analysis. The total energy consumption  $E_{Active}$  for this scenario is given according to (7), where  $E_{sensor}$ ,  $E_{wakeup}$ ,  $E_{transmit}$  and  $E_{proc}$  are, respectively, the consumed energies in the system sensor, wake-up of the Wi-Fi transmitter, data transmission and processing.

% Camera as occupancy sensor

$$E_{Activescenario1} = E_{sensor} + E_{wakeup} + E_{transmit} + E_{proc} \quad (7)$$

$$E_{wakeup} = P_{on} * T_{wakeup} \quad (8)$$

$$E_{proc} = P_{on} * T_{proc} \quad (9)$$

$$E_{transmit} = P_{transmit} * T_{transmit} \quad (10)$$

The consumed energy  $E_{wakeup}$  is during the wake-up duration  $T_{wakeup}$  according to (7) and (8).  $P_{on}$  is the consumed power by the processor in (9). The consumed energy  $E_{Transmit}$  by the transmit mode is expressed as: (10), where  $P_{Transmit}$  is the dissipated power by the transmit mode and  $T_{Transmit}$  is its time duration.

*Scenario 2:* Camera as light sensor is considered as the scenario 2 for the energy analysis. The total energy consumption  $E_{Activescenario2}$  for this scenario is calculated as mentioned in (11), where  $E_{sensor}$ ,  $E_{transmit}$  and  $E_{proc}$  are, respectively, the consumed energies in the system sensor, data transmission and processing. Wi-Fi is already in the transmission mode in scenario 2, so the energy is not considered for wakeup mode.

% Camera as light sensor

$$E_{Activescenario2} = E_{sensor} + E_{transmit} + E_{proc} \quad (11)$$

*Scenario 3:* Energy consumption of the actuator transceivers is evaluated in this section. During the reception of the data, the consumed power by the actuator node is given by the (12), where  $P_{receive}$  denotes the power dissipation during the receive mode and  $T_{receive}$  denotes the time duration.

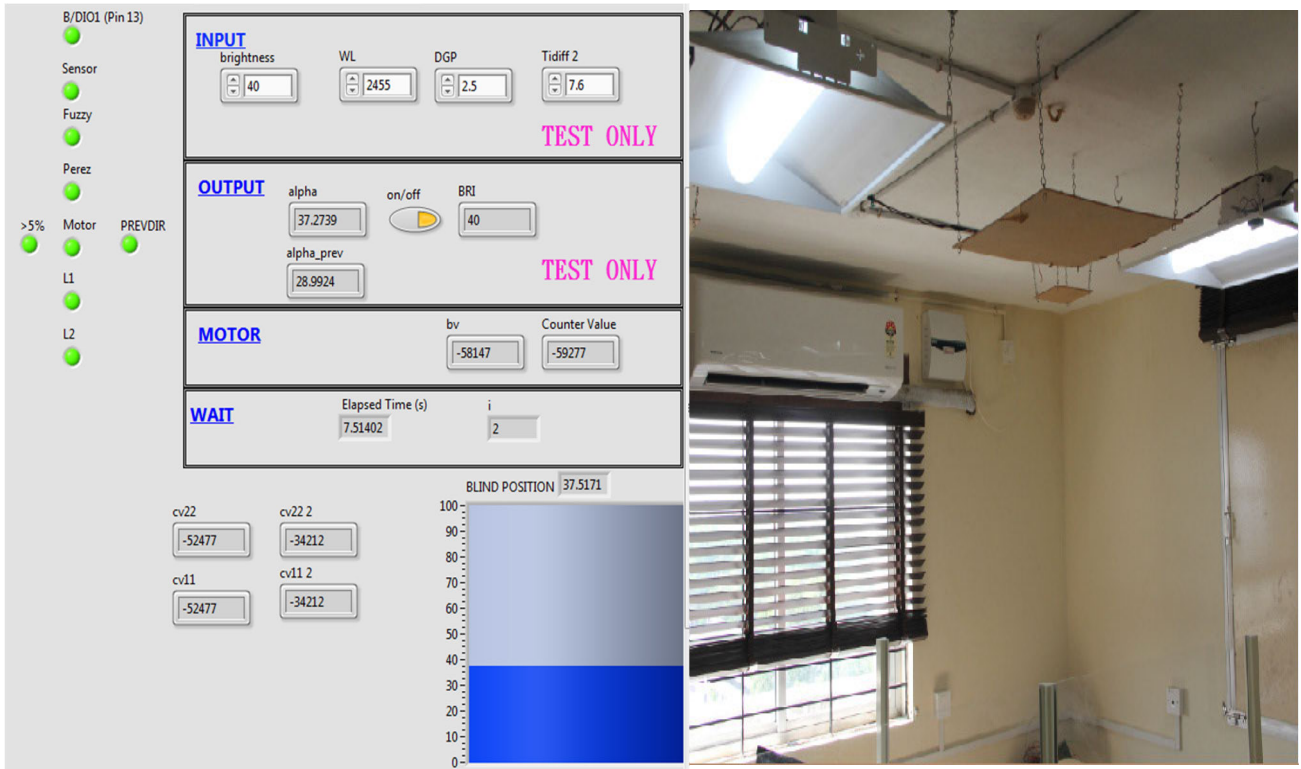
% Actuator transceiver

$$E_{receive} = P_{receive} * T_{receive} \quad (12)$$

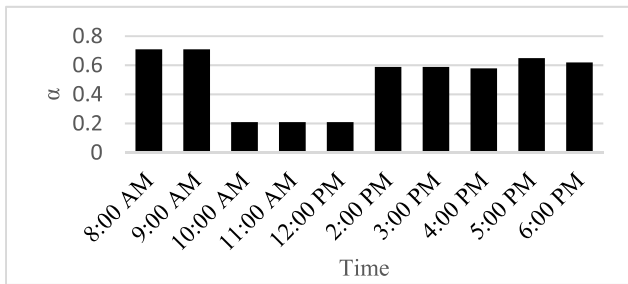
*Scenario 4:-* The physical test result performed per hour to measure the power consumption of the actuators are the scenario 4 consideration. For the realistic occupancy schedule of NLH classroom, the occupancy diverse factor is obtained according to ASHRAE 90.1 2004 standards.

## VI. RESULTS AND DISCUSSIONS

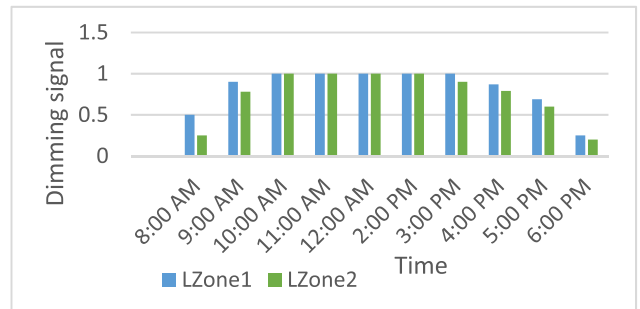
In this section the dimming level of the luminaires and control signals for the blind, the energy consumption evaluation of the wireless networked nodes, climate adaptive performance analysis of the wireless networked LMS, are discussed. The front panel of the LabVIEW program developed for wireless networked camera-based lighting control system and the blind positions and artificial light variation and the real time validation of the LMS are shown in figure 7. Both images represent the case with dimming level of 40% and blind opening of 37%. The blind positions are same according to the real time position and simulation. The LabVIEW model consists of 1) A fuzzy controller for automated window blind system provides visual comfort, thermal comfort. The system gives a blind position according to the occupancy of the room, daylight on the window(WL), glare(DGP), difference in the actual temperature and set point temperature( $T_{diff}$ ) (as shown in Fig. 7). 2) Motor rotation direction: The motor rotation direction either clockwise or anticlockwise is decided based on the present and required blind position( $\alpha$ ). 3) Blind actuation: This part determines the duration of time required to operate the motor to reach the set value. 4) Light actuation: This section send the serial frame to the luminaire master



**FIGURE 7.** Front panel view of the LabVIEW program developed for wireless networked camera-based lighting control system and the blind positions and artificial light variation and the Real time actuator position according to myRIO based controller.



**FIGURE 8.** Control signal for the venetian blind - a sample reading for one day.



**FIGURE 9.** Dimming signal for luminaires at zone 1 and zone 2- sample reading for one day.

controller unit to set the dimming level. Etask is received from the ceiling sensor attached to master controller unit. This checks the brightness level(BRI) at the luminaire for validation.

**A. CONTROL SIGNALS OF THE ACTUATORS**

Fig. 8 shows the venetian blind control signal, signals generated from the LabVIEW based program implemented in myRIO, which ranges from 0 to 1. The value represents the closing and opening of the blind respectively.

Fig. 9 represents the dimming levels of the luminaires located at zone 1 and zone 2. The setpoint illuminance considered was 500 lux, under the local zone occupancy case, according to the recommended norms for office lighting [17]. For the energy evaluation, a yearly measurement of the

control signals for venetian blinds and luminaire data is collected from the testbed. Based on the values given in the Table 1 the energy consumption of the nodes in transmit, receive modes are calculated. In this test, all ZigBee peripherals are powered at the same voltage level equal to 3.3 V.

**B. FRAME FORMAT**

The Serial frame format in the AT command request shown in Fig. 10 is used to send the direction of the blind movement and speed and Fig. 11 is used to adjust brightness of the luminaire. The frame specific data consists of the destination nodes address and RF data. RF data in Fig. 10 represents the direction of movement of blind and speed of the motor and in Fig. 11 represents the luminaire dimming level.

Set Motor Control Message																					
Frame field		Length				Frame specific data															
Start				Frame type	Frame ID	DA								NA	RF data		Checksum				
Value	7E	00	10	17	01	00	00	00	00	00	00	00	00	00	FF	FD	FF	FE	04 05	01 5C	6F

FIGURE 10. Frame format of the motor control data.

Set Dim Level Message																				
Frame field		Length				Frame specific data														
Start				Frame type	Frame ID	DA								NA	RF data		Checksum			
Value	7E	00	10	17	01	00	00	00	00	00	00	00	00	FF	FF	FF	FE	0X32		6F

FIGURE 11. Frame format of the dim level message of the luminaire.

TABLE 1. Tasks of the network elements and the consumed power.

Element	Task	Power
Controller	Idle	2.6W
Controller	Active(max)	14W
Sensor(Camera)	On	957mW
Wi-Fi	Transmit	1255mW
Wi-Fi	Receive	1240mW
Motor Control-Xbee	Transmit	108mW
Motor Control-Xbee	Receive	92.4mW
Motor Control -Xbee	Idle	92.4mW
Luminaire Control - Xbee	Transmit	50.49mW
Luminaire Control - Xbee	Receive	56.1mW
Xbee Coordinator	Transmit	577.5mW
Xbee Coordinator	Receive	74.6 mW

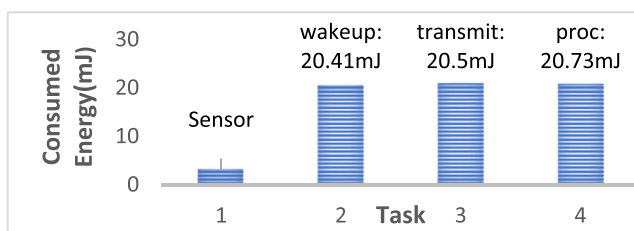


FIGURE 12. Energy consumption of the wireless sensor node for scenario 1.

C. ENERGY CONSUMPTION EVALUATION OF WSAN NODES

This section discusses about the energy consumption evaluation of WSAN nodes with the proposed energy model. The tests performed to evaluate the energy consumption of the nodes in different workload models is termed as scenario.

Scenario 1: In this scenario, the camera acquires image shown as task 1, the transmission of image considered as task 3 and the processor energy consumption for occupancy detection from the image is considered as task 2 in Fig. 12.

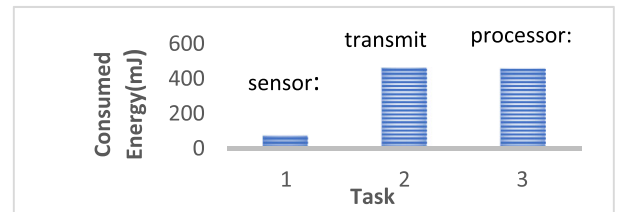


FIGURE 13. Energy consumption of the wireless sensor node for scenario 2.

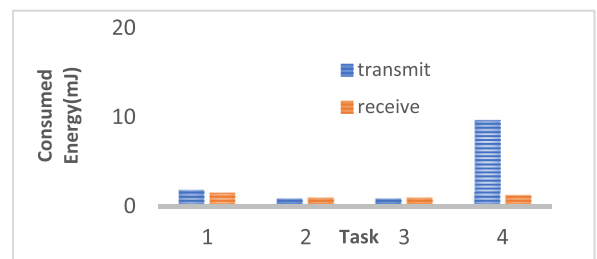


FIGURE 14. Energy consumption of the wireless actuator communication unit.

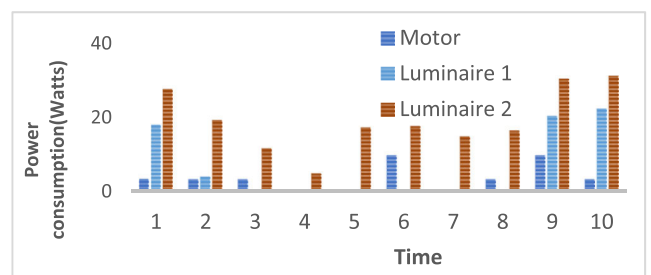


FIGURE 15. Power consumption of the wireless networked actuators with control signals of the venetian blind and dimming level.

The current usage for wakeup mode and transmit mode of Wi- Fi for Camera sensor is 245mA and 251 mA respectively, and the supply voltage is 5 V. Hence the energy



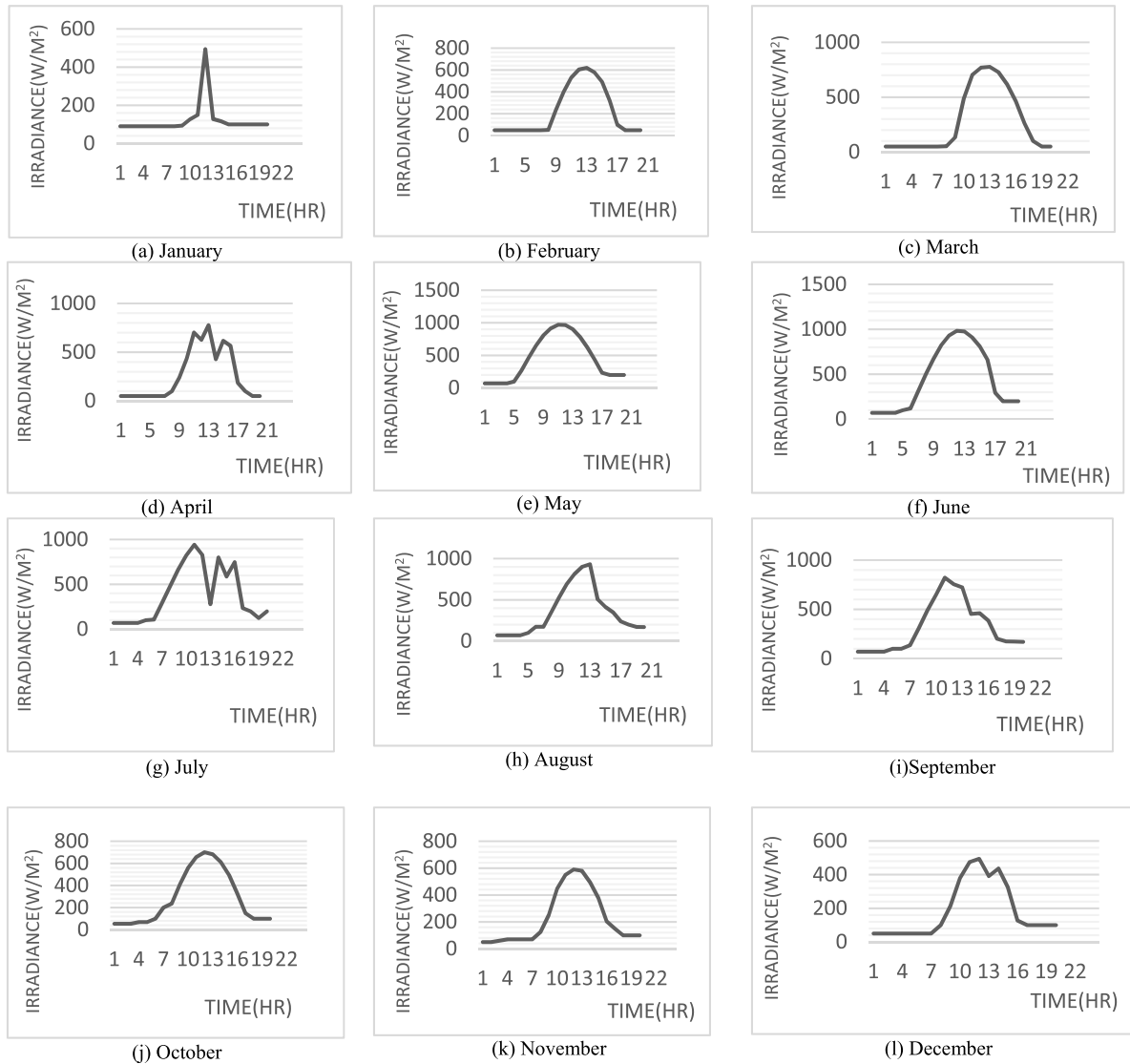


FIGURE 16. Monthly average irradiance data.

consumption is 20.41mJ and 20.91 mJ respectively for wakeup and transmit mode.

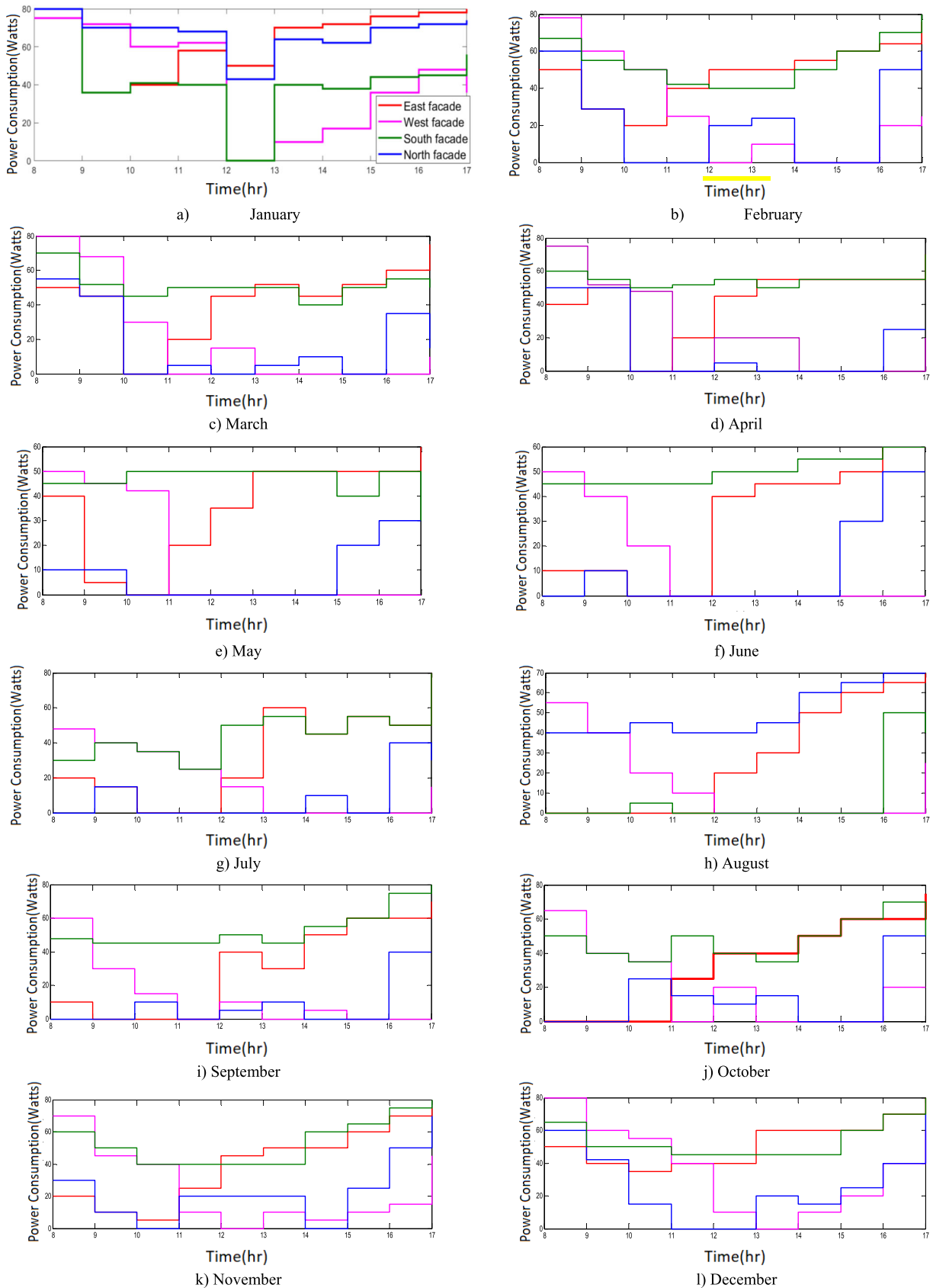
*Scenario 2:* In this scenario, task 1 is the camera acquires images of window and desktop to evaluate the window luminance and the workplane illuminance. The transmission of image is considered as task 2 and the processor energy consumption for reception and evaluation of information from the image is considered as task 3 in Fig. 13. In the process, temperature sensing is considered in all the tasks for thermal comfort achievement.

*Scenario 3:* MyRIO is the platform used to implement the blind and luminaire control which consumes 2.6W while in idle mode. The task 1, 2, 3 shows the energy consumption of the communication unit for blind control, luminaire for zone 1, luminaire for zone 2 routers respectively in Fig. 41. For the coordinator, task 4 is mentioned.

*Scenario 4:-* The physical test result performed per hour to measure the power consumption of the actuators are shown in Fig. 15.

**D. CLIMATE ADAPTIVE PERFORMANCE OF WIRELESS NETWORKED LMS**

The climate data is logged in from the pyranometer for the validation of the lighting system power consumption with respect to the seasonal variation. Variation in the average power consumption for east, west, and south and north facade window orientation is discussed in this section. The monthly average of the logged climate data is shown in Fig.16 and monthly average power consumption obtained as a function of irradiance is shown in Fig. 17. Fig. 16 and Fig. 17 comparison shows that the lighting power consumption varies inversely with respect to the irradiance.



**FIGURE 17.** Monthly average power consumption of wireless networked LMS, obtained as a function of irradiance.

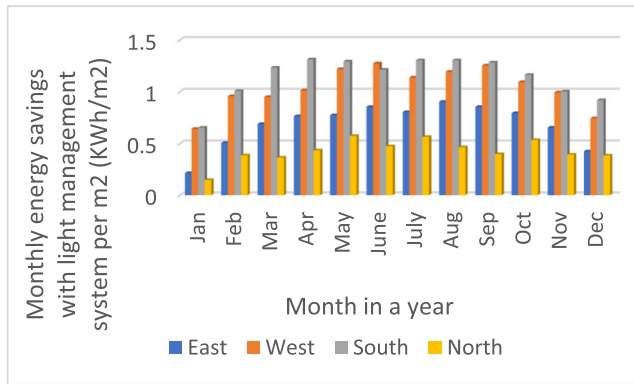


FIGURE 18. Monthly energy savings with LMS.

### E. MONTHLY AVERAGE POWER CONSUMPTION

Based on the window luminance and the work plane illuminance for 12 months in a year, the control signals for the luminaires are generated, using the test workbench integrated with the test room. The total power consumption of the actuators for every month is calculated according to (13).

$$P_a = \alpha \cdot P_m + \sum_{k=1}^2 d_k \cdot L_k \quad (13)$$

where  $P_m$  is the power consumption by the motor,  $d_k$  is the dimming factor of  $k^{\text{th}}$  luminaire,  $L_k$  is  $k^{\text{th}}$  luminaire.

According to Fig. 18 the seasonal energy savings obtained, in comparison with uncontrolled lighting scheme by considering the opening of window façade are: East: 0.25-0.9 kWh/m<sup>2</sup>, West: 0.65- 1.3 kWh/ m<sup>2</sup>, South: 0.64-1.3 kWh/ m<sup>2</sup>, North: 0.15- 0.57 kWh/ m<sup>2</sup>.

### F. TECHNO ECONOMIC ANALYSIS

In the techno-economic analysis (TEA), the Cumulative Annual Growth Rating (CAGR) is estimated as 16.4% (in line with the Global intelligent control market, 14.93 to 17.4 % CAGR growth by 2027), with a payback period of 2.6 years. The Net Present Value (NPV) estimated also shows that it is beneficial if worked for more than three years. The NPV is estimated positive for four years indicates the justification for going ahead (even the discount rate is 8% -10%). The NPV estimated positive for three years and above has justified going ahead (at 5% discount rate).

### VII. CONCLUSION

A camera based WSAN architecture is developed for an LMS and defined a finite state machine-based energy model description for the energy behaviors of wireless nodes. Networked lighting systems and building automation with multiple luminaires with collocated conventional sensors are replaced in this work using a single camera. Thus, the number of nodes has reduced in the primary and secondary light zone area. The study showed that when the number of nodes is less the star networking topology is feasible with respect to energy saving. The DALIS could maintain workplane illuminance with a uniformity of 0.94. Energy saving is demonstrated

as function of irradiance data. The future work of this test workbench is to import the WSAN based data into cloud and enhancing it as an IoT based lighting management system.

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