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Design of Cloud-Connected IoT System for Smart Buildings on Energy Management (Invited paper)

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Abstract

Building energy management (BEM) system can provide cost-effective energy management solutions for smart buildings. However, the success of BEM is contingent on identifying large energy consuming devices, monitoring energy usage, optimal scheduling of flexible appliances, and distinguishing and controlling energy wastage. To this end, this paper discusses the design of Internet of Things (IoT) for a flexible BEM with the backend analytic that performs analysis on energy usage pattern and the wastage. We present the experimental results of real-time monitoring of consumers' energy usage in a commercial space to identify the electricity wastage. The experiment is conducted at an office testbed using a comprehensive wireless sensor network. Extensive analysis is done to identify the energy wastage pattern of users for reducing the electricity cost. It is demonstrated that it is possible to reduce significant energy wastage when an office building is equipped with the proposed IoT system.

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1. Introduction

One of the most widely studied methods to reduce electricity cost is the use of demand response management scheme [1], in which consumers can shift their electricity consumption from a high price period to a low price period, e.g., response to the dynamic pricing signals sent from the grid (see the related references in [2]). Such shifting in electricity demand helps utility in reducing the peak demand and hence can greatly alleviate the energy generating cost.

However, shifting in electricity demand causes inconvenience to the end users, and it is not suitable for commercial buildings as the number of flexible load in such buildings are limited. Besides, the end consumers, other than the building manager, are not responsible for the payment of the utility bill of the building, which makes the consumers not very prudent in efficiently managing their electricity usage. Further, the peak demand period of commercial buildings coincides with the peak demand period of the grid. Therefore, if the consumers, i.e., building occupants[1], are uninterested in saving energy, it may give rise to significant energy wastage in commercial spaces [3], which subsequently increase the cost of electricity. Given this reality, building energy management (BEM) system has been received considerable attention recently as a potential solution to prevent such expensive electricity usage.

In particular, it is important to have low cost BEM solutions that can immediately detect the energy wastage from an office building and be flexible enough to install into retrofit buildings. In this regard, a number of recent studies investigate the issue of cost-effective energy management in office spaces. For instance, a simulation based study of an office building is conducted in [4] to investigate the uncertainties in energy consumption due to actual weather condition and the building's operational practices. To manage the energy for electrical, heating, and cooling energy zones of a building, a semi-centralized decision making process using multi-agent systems is proposed in [5] for joint heat and power optimization with a view to improve energy efficiency and reduce energy cost.

In [6], the authors present a multi-agent comfort and energy system by designing a meeting schedular with multi-objective Markov Decision Process. The designed energy system is further implemented in a testbed with inputs from a real-world building including actual

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[1]Please note that we have used consumer and occupant interchangeably to refer to the electricity consumers in commercial buildings throughout the manuscript.

thermal zones, temperatures, occupant preferences, and occupant schedules. User comfort is considered in [7], which demonstrates an intermediary communication platform to facilitate the communication between humans and buildings toward adaptive end user comfort management and to compensate for high rate of discomfort in office buildings. An optimal operating strategy of building energy system with storage is proposed in [8], which is shown to be effective for reducing energy cost of the building. It is shown that the type and capacity of storage devices have consequential effect on the cost.

Inefficient use of consumer electronics such as various lights and thermal control of office buildings also cause significant waste of electricity. To address this issue, an intelligent LED lighting system is presented in [9], which uses multiple sensors and wireless communication technology to control LED light according to user's state and the surrounding environment. Similar energy control for lighting system is also studied in [10]. For thermal control in office buildings, a model-based key performance indicator is proposed in [11] that can be applied to both at room and central office level. The objective of the scheme is to monitor and suggest useful counteractions to be undertaken whenever inefficient management of cooling systems is detected. Finally, an integrated classification method to determine office buildings' energy and thermal comfort class is developed in [12] applying different clustering techniques. The classification results are used for a parametric study of common buildings' characteristics in each rating class, in order to provide a tool for adopting improvement recommendations for buildings' energy efficiency.

As from above discussion, most existing BEM studies deal with the problems of energy efficiency and cost reduction in office buildings from theoretical perspectives. However, for a better understanding of energy consumption/wastage pattern in such environments and implementations, it is required to install a large number of sensors that can provide real-time monitoring and control facility. To this end, a system based on IoT is a natural solution for old existing buildings.

In this paper, we demonstrate a number of experiments and related analysis conducted in a smart office environment within a testbed located at the Singapore University of Technology and Design (SUTD). We give a detailed discussion on the setup of the sensor and wireless communications network at the SUTD office testbed and explain the related technologies used for the experiments. In the experiments, the energy usage pattern of lights and air conditions (ACs) and room occupancy are continuously monitored through the deployed sensor network. The main objective is to identify the total number of hours of energy wastage by the room occupants and thus determine the total energy wastage from the identified hours. It is shown that a significant portion of electricity is wasted by the office members due to their negligence to switch-off the lights and ACs when the respective rooms are empty. The cost of the wasted energy from the office building is determined, and thus the consequence of the energy wastage on the electricity bill is established. We further explain how the experimental results of the proposed work can be utilized to implement effective energy wastage control schemes.

The rest of the paper is organized as follows. The system architecture is demonstrated in Section 2 followed by related energy analysis in Section 3. Finally, some concluding remarks are drawn in Section 4.

2. System Architecture

In this section, we describe the overall system architecture that is considered for the proposed study.

2.1. Desired Properties

The desired properties of the proposed architecture are considered in terms of the system's scalability, quality of service (QoS), security, dynamic and interoperability.

Scalability. The system needs to be scalable. In particular, it should have the capability for easy installation of new nodes and efficient network management with newly added nodes without any degradation in the system performance. This would leverage the extension of the network beyond a specific geographic area and number of smart devices, and further avoid the constraint on the number of smart devices that can be installed within a system for desired outcomes.

QoS. The IoT, which is the backbone of the proposed system, is inherently a complex and shared system consisting of a plethora of applications, networked components, and resources. Many devices are constrained in terms of computation, communication, and energy, in addition the constraints are also dynamic and heterogeneous. Coupled with the critical nature of many IoT applications, this motivates the need to provide QoS across multiple dimensions. The first dimension is the nature of the stakeholders. These include the application, resource providers, and the network that connects them. The second is the nature of competing applications in the IoT, since multiple applications must coexist. Finally, the nature of the constraints must be considered, e.g., network characteristics like latency for control messages and bandwidth, device properties like battery power and memory, environment attributes like location and temperature, or application requirements like priorities, precision and responsiveness.

Security. Security attacks on IoT system can be significantly catastrophic as it takes the control of large critical infrastructure systems and even of small scale systems like household appliances. As a result of these security attacks, consumers might receive wrong pricing information on their energy usage or a malicious controller, other than the authorised grid, may take the control over their scheduled loads. Therefore, strong security measures need to be taken against such as playback attack, for example, for ensuring data confidentiality, data integrity, and user/device authenticity.

Dynamic. The IoT network needs to have the capability to dynamically adopt to the change of environment. For instance, it should have the ability to self organize with the change of sensor network set up and self-healing capability in case of of an disruption in the network. Further, the network needs to be flexible enough to be connected with other existing or new network with a view to work in a larger scope.

Interoperability. Interoperability is a vital concept of IoT, which connects the devices in a network through a common software or platform in order to let them work together. Since smart grid is composed of large number of smart nodes such as homes, where each home has a number of intelligent devices, that can operate, communicate and interact autonomously, users may want to purchase an off-the-shelf devices, e.g., a sensor like camera or an actuator like light controller, and integrate them to the system. Therefore, interoperability of IoT is critical in making these smart devices work together.

2.2. Network Architecture

We surveyed and discussed some typical network architectures of IoT network for smart building management.

Cloud-based vs non cloud-based architecture. Generally, the cloud-based IoT architecture consists of users, which seek services from the system, distributed sensor nodes, and a number of intra-connected servers as a cloud platform. Specifically, a physical sensor is virtualized as a virtual sensor on the cloud computing. The nodes upload data to the servers with no concerns about the locations of the servers or their detailed specifications. Therefore, the cloud-based architecture supports the IoT services that can satisfy the requirement of scalability. Data collected from the sensors is transmitted to a data processing unit in the cloud [13]. The unit creates a storage format that is used to process the data and then send the data to database. Moreover, the authorized user is able to access or control the sensor via the user interface on web browser. In [14], an uID-CoAP architecture based on cloud computing is proposed to combine constrained application protocol (CoAP) with the ubiquitous ID (uID) architecture. The uID-CoAP keeps the knowledge and data required for practical complex IoT services. In addition, a software framework for embedded system is developed to enable IoT service to support application-layer API. Furthermore, the cloud-based IoT is developed for intelligent home automation system [15]. Systems with cloud computing capabilities analyze the assimilated data to recognize the activities of inhabitants or events. These can automate the domestic utilizations effectively and also can support the inhabitant by reducing the costs and improving the standard of living.

Single hop vs multi-hop IoT network. In single hop IoT architecture, sensor nodes are directly connected to a data sink/gateway that assembles the data. The data transmission delay can be minimised and large data volume applications such as multimedia sensor network can be supported [16]. However, the network size and coverage of single hop IoT network are limited by the 1-hop range of the sink, which does not support large-scale IoT networks.

Therefore, multi-hop IoT architecture is developed to cover urban scenarios. In [17], a multi-hop IoT network is proposed to integrate MANET and WSNs, which enables cross-network impromptu communications to boost urban data collection in smart city. It is shown that multi-hop IoT architecture improves ubiquitous and collaborative urban sensing by enabling a fine-grained adaptive control for more scalable management of urban environments. Data routing attracts lots of research attentions in multi-hop IoT network. A secure routing protocol is proposed to enable the IoT devices to authenticate before forming a new network or joining an existing network [18]. The proposed routing protocol embeds the multi-layer parameters into the routing algorithm, thus combining the authentication and routing processes without incurring significant overheads. A scalable smart city testbed is developed for large-scale IoT experimentation [19]. Specifically, all the nodes deployed are part of the same physical network as long as it is possible to find a set of IEEE 802.15.4 links connecting, on a multi-hop manner, any pair of the deployed nodes.

IP-based vs non-IP based network protocol. The two-way communications between the sensors and the server are motivated by the type of network architecture. In particular, we use IP-based and non-IP based communication protocols in the system. In an IP-based communication protocol, as shown in Fig. 1, to communicate with the server the sensors install in each room first communicates with a respective Wi-Fi access point. Then, the information is passed from the Wi-Fi access point to the server through Wi-Fi. For

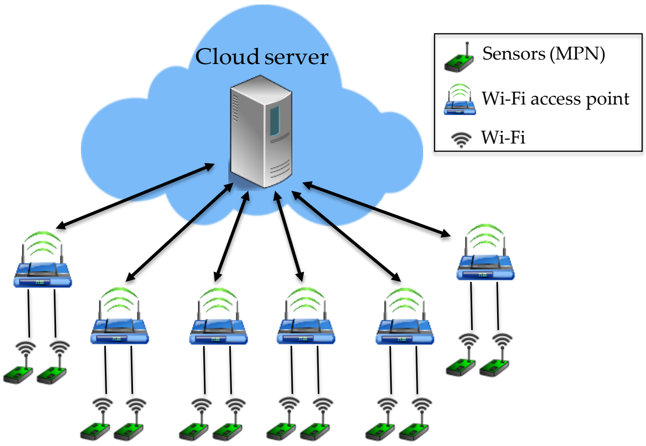


Figure 1. Single-hop IP based wireless sensor network based on Wi-Fi.

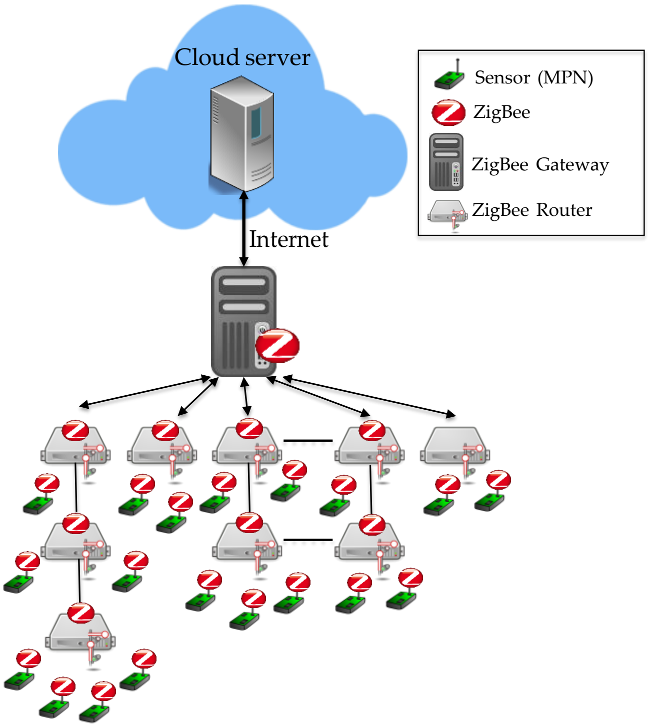


Figure 2. Multi-hop star topology Non-IP based wireless sensor network based on ZigBee.

communication from server to the sensors, the control signal from the server is first transmitted towards the Wi-Fi access point, which is further send to the respective controller via Wi-Fi [20]. However, if we want to extend the coverage using WiFi, installation of additional access point may not be easy. Further as the number of devices increases in the network the MAC protocol may not be in favour. Nonetheless, there is a new standard 802.11AH to support machine-type devices.

For non-IP based communication protocol, we show the network architecture in Fig. 2, where sensor nodes send their respective signals through ZigBee to a router from where the signals are retransmitted towards a gateway. The ZigBee Alliance has developed a specification for a reliable, cost-effective, low-power, low-data-rate wireless networking protocol, which is built on the top of the IEEE 802.15.4 standard [21]. ZigBee uses multi-hop support for communication, and hence if one router is down, the node can reconnect to another router. Thus additional coverage can be added easily through ZigBee. However, the transmission of control message could be more difficult in such failure. The ZigBee standard defines the network layer specifications for star, tree, and peer-to-peer network topologies, and also provides frameworks for the application programming in the application layer. In ZigBee, the network layer is in charge of organizing and providing routing over a multi-hop network (built on the top of the IEEE 802.15.4 functionalities). On the contrary, the purpose of the application layer is to provide a framework for distributed application development and communication. To transfer the data using ZigBee, we use a XBee Pro-S2B module, which has a RF data rate of 250,000 bits per seconds (bps) [22]. Now, the gateway, upon receiving the signals from all the routers transmit them over internet towards the cloud server. Similarly, for server to sensor communication, the control signal first sent from the cloud to the gateway, and then the gateway sends the control signal towards the intended controller node.

2.3. Sensing and Control

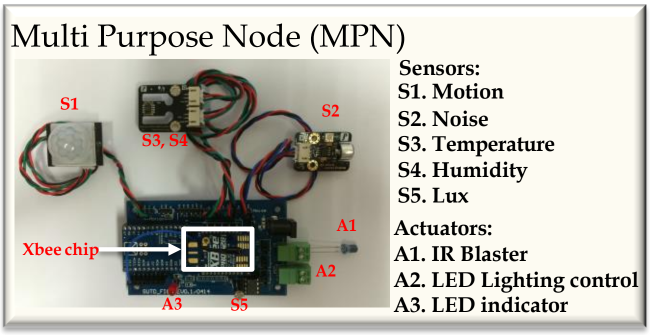


Figure 3. Demonstration of the MPN used in each office room for sensing and controlling purposes.

The sensing of different environmental parameters are accomplished by installing a multi-purpose node (MPN) in each of the room that we wish to sense the wastage of energy and control. An MPN, as shown in Fig. 3, is a combination of a number of sensors and actuators. On the one hand, an MPN is equipped with sensors like motion detector, noise detector, a temperature and humidity sensor, and a lux sensor. All the environmental data collected by the sensors are stored and analysed in the cloud server.

Specifications	Xbee Pro S2B
Indoor/Urban range	Up to 300 ft, up to 200 ft for international variant
Outdoor line-of-sight	Up to 2 miles, up to 5000 ft for international variant
Transmit power	63 mW (+18 dBm), 10 mW (+10 dBm) for international variant
Receiver sensitivity	-102 dBm
RF data rate	250,000 bps
Number of channels	15 direct sequence channels
Supported network & topologies	Point-to-point, point-to-multipoint, peer-to-peer and mesh

On the other hand, a set of actuators consisting of a IR bluster, a LED lighting control and a LED indicator are also installed inside the MPN. The control signals are instructed from the cloud server to the actuators of the MPN, if requires, in order to control energy consumption of some of the office equipments, e.g., the AC of an office room may switched off if there is no one inside the room for a particular period of time.

2.4. SUTD Office Testbed

In the SUTD office testbed, each selected faculty office room is equipped with an MPN. The MPN is configured in a cloud-connected multihop non-IP based architecture as shown in Fig. 3. All the environmental data collected by the sensors are stored and analysed in the cloud server. The control signals, however, are instructed from the cloud server to the actuators of the MPN, if requires, in order to control energy consumption of some of the office equipments, e.g., the AC of an office room may switched off if there is no one inside the room for a particular period of time.

3. Energy Analysis

In this section, we show the energy analysis of the experiments that are conducted at the faculty offices. We present the results of eight selected rooms from the testbed, where each room has an MPN. The lux, temperature, humidity, motion, and noise sensors of the MPN are used to measure the light intensity, room temperature, humidity level, room occupancy, and operating condition of the ACs of the office rooms. The measurement is conducted periodically for every five minutes for a duration of two months. To this end, what follows are the analysis that we conducted for different aspects of the office rooms.

3.1. Occupancy Analysis

To conduct the occupancy analysis of the office rooms, we mainly focus on the values obtained from two types of sensor. In particular, an office room is considered to be occupied if the reading from the motion sensor is 1. In addition, if the noise sensor measures a noise reading o from a range of $[2, 3]$, the room is also assumed to be occupied. For other readings from the sensors, the server considers the room is empty. That is,

$$\text{Room} = \begin{cases} \text{fill} & \text{if, motion}= 1 \text{ or noise} \approx \sigma \\ \text{empty} & \text{otherwise} \end{cases} . \quad (1)$$

3.2. Light Analysis

To analyze the status of lights in a room, i.e., whether the lights are switched on or off, we measure the light intensity of a room through a lux sensor installed within the MPN. Particularly, if the measurement from lux sensor is less than 500, the lights are assumed to be off. Otherwise, the lights are assumed to be switched on. In summary,

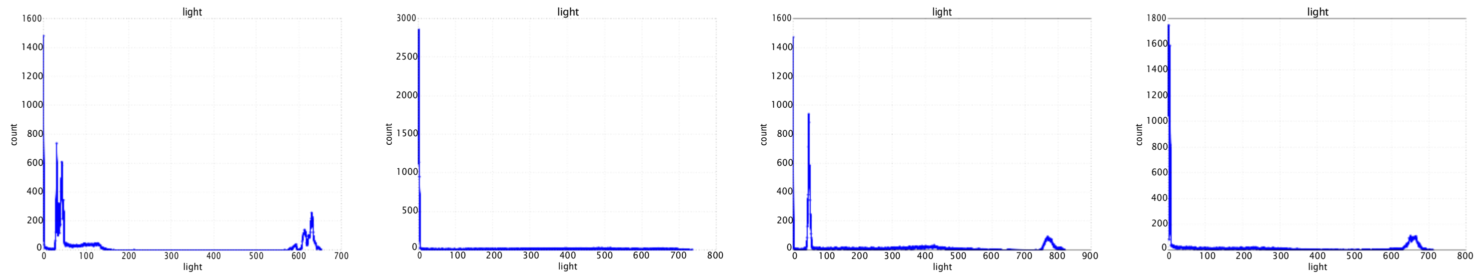
$$\text{Status of lights} = \begin{cases} \text{on} & \text{if lux} \geq 500 \\ \text{off} & \text{otherwise} \end{cases} . \quad (2)$$

It is important to note that the placement of sensors in the room affects the lux reading and may cause some error on the detection of the status of lights. For example, if the sensor is placed close to the window, some outdoor light sources such as natural light, corridor light, etc, can be captured, which causes a high lux value.

Fig. 4 indicates whether or not the lights in a room are switched on and also if there are other sources of light in the room. We demonstrate four histograms in Fig. 4, where we show how the cloud server can identify whether the lights of a particular office room are switched on or switched off. In particular, the histograms give us the count of the lux intensity inside four office rooms for the considered duration of time. For instance, consider Room-002[2] in Fig. 4a, where the lights are switched on for multiple time instants as well as the room gets some lights from the corridor even when the room lights are switched off. This can be interpreted according to the observed phenomenon from Fig. 4a where the cloud server receives a measurement of a lux intensity of 600 due to the lights within the room. Furthermore, due to the lights from the corridor, the histogram shows spikes at around the intensity of 40 for a large number of time. In a similar fashion, we can analyse the light usage behavior of other rooms as follows:

- In Room-007 (in Fig. 4b), the blind of windows is always open and hence natural light is captured in the room, which is demonstrated by the presence of lux from 200 to 600. The corridor light whose lux value is generally lower than 100 is not captured. Additionally, the occupant of the room

[2]Each room is assigned a different number for identification.



(a) Room-002 **(b)** Room-007 **(c)** Room-019 **(d)** Room-009

Figure 4. Light histogram for four office rooms, where each room has a different unique id.

hardly switched on the lights of the room within the experimental period since high lux values ($\geq$ 500) are not observed.

- In Room-019 (in Fig. 4c), the occupant's behavior is similar to the occupant of Room-007. The blind of the window is kept open so the natural light is detected in the room. However, the room lights are sometimes switched on and corridor lights are also captured in this room.

- As for the Room-009 (in Fig. 4d), the blind of the window is closed normally. And we do not observe any low intensity lux count in the histogram for Room-009 in Fig. 4d since the sensor is placed far from the corridor, hence, the corridor lights are not captured in this room. Moreover, the lights of the room are sometime switched on, which shows the light intensity around 650 for Room-009.

From these examples, it can be demonstrated that it is not an easy task to just understand the lighting profile in a room, as it greatly depends on the location of the sensors, the setup of the room (e.g., is it close to the corridor light or is the blind open always), etc. Some learning for each individual room is required in order to interpret the sensor readings correctly.

3.3. AC Analysis

The analysis of the status of ACs with the office rooms are performed based on the measurement and analysis of the humidity and temperature of the respective rooms. In this context, we first show how the humidity and temperature of office rooms are performed in the experiment.

Temperature. To analyse the temperature status in an office room, we assume that the temperature of a room is high if the room temperature is measured one degree more than the AC set point of the room. The temperature is considered low in other cases. That is

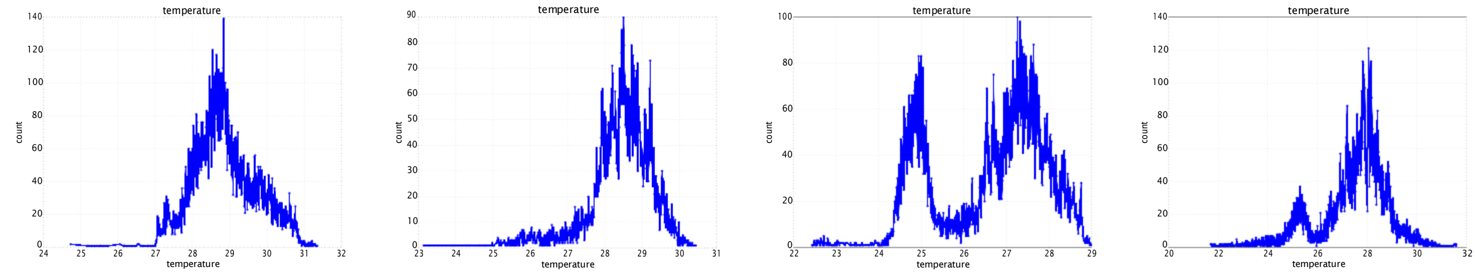
$$\text{Temp.} = \begin{cases} \text{high} & \text{if, temp.} > \text{AC set point} + 1 \\ \text{low} & \text{otherwise} \end{cases} . \quad (3)$$

Humidity. The humidity of an office room is assumed to be varied if the difference between the maximum and minimum humidity $H_{\max}$ and $H_{\min}$ respectively of the room remains greater than 3.0 for consecutive two measurements (i.e., for consecutive 10 seconds), and otherwise the humidity is considered stable. Therefore,

$$\text{Humidity} = \begin{cases} \text{varies} & \text{if, } H_{\max} - H_{\min} > 3.0 \\ \text{stable} & \text{otherwise} \end{cases} . \quad (4)$$

Now, depending on the users preferences on using their ACs on different days the temperature characteristics can vary significantly in different room, which can provide some idea on whether the AC is on or off. To show this, we plot the temperature histogram of four faculty rooms in Fig. 5. According to Fig. 5, we can determine if the AC of a room is switched on or off. For instance, for a temperature set point of 25 for room-011, there are two peaks of temperature count. Here, the temperature count peak around 24.5 indicates that the AC is on whereby the other peak around 28 refers to the case when the AC is off. Similar phenomenon is observed from Room-020. In case of Room-007 and Room-010, the set points are considered to be 25 degree celsius. However, according to the given histogram the temperature counts are around 28 and 29. Hence, from the observed data, the server can consider that the ACs within Room 007 and 010 are never turned on during the experimental period.

The measured temperature together with the variation of humidity is used in our experiments to determine the status of AC inside an office room. In Fig. 6, we indicate four different instances of AC status including on, off, starting on and starting off. As can be seen from the figure, when the humidity of a room varies and the temperature remains low, then the MPN considers that the AC of the room is turned on. The AC is assumed to be switched off if the temperature is high and also the humidity remains stable. For starting on and starting off, we measure the sample the measured temperature and humidity for every 25 minutes. In particular, if the temperature decreases from high to low within a



(a) Room-007 **(b)** Room-010 **(c)** Room-011 **(d)** Room-020

Figure 5. Temperature histogram for four office rooms where each room has a different unique id.

Humidity	Temperature	Status of AC
Varied	Low	On
Stable	High	Off
Varied	High	Starting on, if temperature decreases within a duration ≤ 25 minutes
		Off, otherwise
Stable	Low	Starting off, if temperature increases within a duration ≤ 25 minutes
		On, otherwise

duration of 25 minutes with varying humidity, the condition refers to starting on. However, if the temperature does not decrease within the specified duration (while humidity is varying) then the AC is considered to be off. Similarly, if the humidity is stable, then increase of temperature from low to high within 25 minutes indicates starting off state, which is otherwise considered as on. The decision making process of the AC status based on the measured temperature and humidity is briefly shown in Table 2.

Based on Fig. 4 and 5, the analysis is performed offline with the site information (e.g., sensor location and aircon set point) through site visit and user survey. As a future research direction, an online learning algorithm is needed to estimate the light and temperature readings, and hence to provide a real-time data collection and analysis.

3.4. Wastage of energy

Wastage in terms of time. After successfully measure the status of lights and AC in office rooms, the measured data is analyzed according to (1), (2), (3), (4) and Table 2 to determine the energy wastage in the office building. In particular, based on the measured data, we study the total number of hours when the office rooms are empty but the lights or ACs or both remain switched on. The key findings of the study are presented in Table 3. As can be seen from this table, a significant number of times the appliances in office rooms are

Table 3. Demonstration of the total duration of energy wastage in the office

Room Number	Dura,on of data collec,on	AC set point (ºCelsius)	Room empty, lights on (Hours)	Room empty, AC on (Hours)	Room empty (Days)
002	54 days	24	322	272	53
007	54 days	25	104	7	50
009	54 days	25	149	96	48
011	54 days	24	133	138	46
014	54 days	24	202	2	50
017	54 days	24	150	26	43
019	54 days	25	129	216	49
020	54 days	25	88	66	49

remained switched on even when the rooms are empty. For instance, consider No. room-1. In a measurement duration of 1296 hours, i.e., 54 days, the energy wastage for lights and ACs are 322 and 272 hours respectively. Since, lights and ACs consume a significant portion of electricity [10, 12], the study in Table 3 clearly emphasizes the volume of energy wastage that may occur in a commercial office space if the employees do not switch off their room appliances while leaving the office.

Wastage in terms of energy and money. Now to quantify the amount of energy wastage within office room, we map the total duration of wastage from Table 3 into the total energy wastage and the total cost for this wastage energy during these periods of time. We consider that each office room is equipped with a 40 W fluorescent light and an AC with system 3/4 (2260 W). Now, for the considered system and duration of wastage demonstrated in Table 3, the total energy wastage for both per day and the considered experimental duration are calculated by using HOME ELECTRICITY AUDIT form[3] provided by SP Service, Singapore. The same

[3]The form is available online for public use in https://services.spservices.sg/elect_audit_frameset.asp.

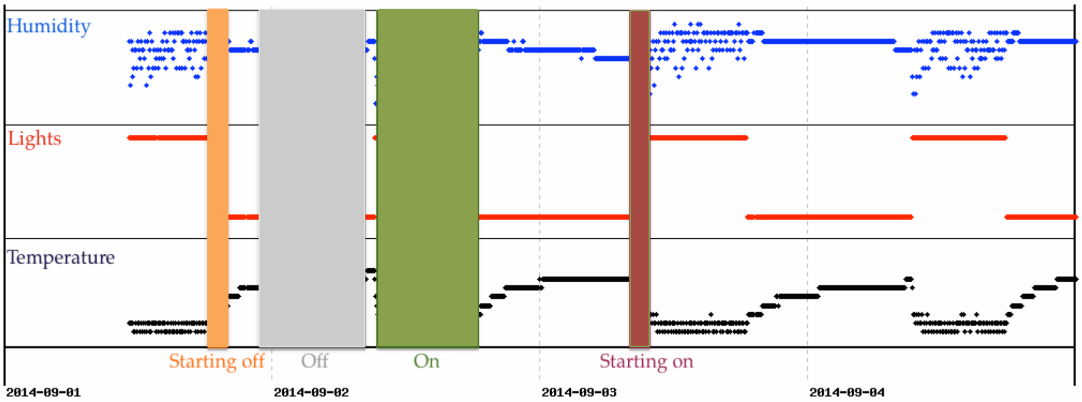


Figure 6. Measurement of humidity and temperature from an office room at SUTD office testbed.

Table 4. Demonstration of total wastage in terms of energy and money (in Singapore dollar (SGD)) from the SUTD office testbed.

Room Number	Total number of day	Energy wastage from lights (kWh)		Energy wastage from AC (kWh)		Cost of energy wastage from lights (SGD)		Cost of energy wastage from lights (SGD)		Total wastage (SGD)
		Average wastage per day	Total wastage in the considered time	Average wastage per day	Total wastage in the considered time	Average wastage per day	Total wastage in the considered time	Average wastage per day	Total wastage in the considered time	
002	54	0.2384	12.87	11.39	615.08	0.055	3.006	2.65	143.24	146.25
007	54	0.0772	4.16	0.27	14.64	0.018	0.972	0.063	3.402	4.374
009	54	0.11	5.94	4.02	217.23	0.025	1.386	0.937	50.60	51.984
011	54	0.0984	5.32	5.78	312.42	0.023	1.242	1.34	72.75	73.998
014	54	0.1496	8.07	0.02	1.22	0.035	1.89	0.005	0.288	2.178
017	54	0.1112	6.00	1.08	58.57	0.026	1.404	0.252	13.644	15.048
019	54	0.0956	5.16	9.04	488.16	0.022	1.206	2.105	113.68	114.894
020	54	0.0648	3.49	2.75	148.88	0.015	0.81	0.642	34.668	35.478
Total cost of energy wastage from the SUTD office testbed in the considered time										**444.204**

form is also used to calculate the cost of total wasted energy and the results are shown in Table 4.

As can be seen from Table 4, significant amount of energy and cost savings are possible if the proposed monitoring scheme is adopted in office environments to control the AC and lights when the occupants are not in their respected rooms. For example, over a 54 days duration, 627.95 kWh of energy worth of 146.25 dollar can be saved from only room-002 if room's AC and lights are switched off when the room is empty. If we consider the total cost of energy from the eight rooms, the energy and related cost savings from the wastage is significantly high. As can be seen from Table 4, the experimental result from the eight rooms demonstrated a savings of total 1856.2 kWh of energy that leads to a total savings of 444.204 dollar over a 54 days duration. Imagine an office building with 90 rooms, the saving could be easily 4500 dollar over two-month period.

4. Conclusion

There are several plans to explore the work in some other direction. One potential plan is to include the real-time analysis of data after learning from the users' behavior of energy usage. We are also interested to use the result, after learning, to do real-time energy management incorporating user comfort such as pre-cooling of aircons of office rooms through movement prediction. Moreover, an application on the user's mobile phone will be implemented to track and predict the movement, and trigger the pre-cooling of aircon before the the user arrives the office.

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