Methodology for a Large Scale Building Internet of Things Retrofit

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Abstract

With the presence of sensing technologies today, buildings can be built fitted with various sensors and systems to encourage energy efficiency and sustainability. However, for legacy buildings that are still being actively used today, retrofitting is needed to improve the efficiency of the building because these technologies were not in place when the buildings were built. Retrofitting the buildings with sustainable capabilities can be very challenging. Therefore, a comprehensive methodology is needed for systematic deployment of the sensors and associated systems into the building, covering a complete cycle from identifying the needs and requirements of the system until its full operation. This study aims to devise and advocate a methodology for systematic retrofitting of sensors and hence enabling the collection of energy consumption data. To do that, a 20-year old six-storey academic building in one of the institutes of higher learning in Malaysia is used as a case study. This paper explains the first part of the progressive development of the proposed methodology, which is on the protocol for the placement of the sensors and devices. The outcome of this study details the operational planning that can be referred to for future buildings retrofitting work of similar scale.

CCS Concepts • **General and reference → Surveys and overviews**; **Reference works**.

Keywords internet-of-things, building retrofit, building energy management, testing protocol

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1 Introduction

On average, buildings worldwide consume 40 percent of overall energy resource and contributed to an average of 30 percent of global carbon emission. Building occupancy and ventilation system is one of the major contributors towards indoor carbon dioxide (CO_2) generation. Trapped CO_2 increases indoor temperature, leading to higher energy consumption to maintain ideal indoor temperature level [1]. Managing building energy consumption and sustaining indoor climate require extensive monitoring and sensing mechanisms within the building compound and outdoor. This is to ensure accurate perception on overall energy consumption and its indoor climate.

Enabling sustainable building practice involves both optimization of the overall building energy consumption and maintaining healthy indoor environment. Sustainable practices prior to building construction is effective, as whole building infrastructure can be planned and designed to adhere to sustainable building guidelines. The same cannot be said for existing buildings [2]. Enabling energy management in existing building requires certain sensing/monitoring retrofitting. Some buildings are old and building managers are not prone to the idea to have major building modifications just to install sensing/monitoring mechanisms [2]. This paper addresses the number of issues behind retrofitting sensing/monitoring mechanisms to optimise energy consumption and promote sustainable practice.

Studies on building sustainability and building energy efficiency refer to built-in building information modelling (BIM) to describe the mechanisms and characteristics involved in enabling building energy management [4]. BIM describes two crucial elements in building energy management, namely data acquisition and data management. Updating building information modelling works require collective process that includes data acquisition where the temperature and the humidity levels indoors are gathered and studied. This requires sensors placement connected to dedicated database that allow data management and analysis [3]. Following the idea, a full scale internet-of-things (IoT) living lab is initiated in one of the academic institutions in Malaysia. To the best of author knowledge, no such full scale project has been realised in Malaysia before.

The IoT living lab project is proposed by utilising academic building to enable sensors retrofit to observe energy consumption pattern for building. The idea was first established on November 2018 with the primary aim to become the point of reference for IoT implementation in existing building to observe the energy consumption pattern. The main challenge of this initiative is to retrofit sensors into existing building architecture. Wireless sensor installation is

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considered for this project to avoid any major structure modifications/renovations. Establishing wireless sensor networks require a number of preliminary tasks, namely, identifying the wireless coverage area, propagation loss and determining link quality. These tasks, in addition to identifying the type of sensing/monitoring needed will be elaborated in this paper. To the best of author's knowledge is the first work of its kind that propose testing protocol as a guideline for IoT building retrofit. The proposed guideline can contribute toward promoting more building retrofit works as a step forward towards sustainability practice and energy efficiency.

2 Building Profiles

The three 20-year old buildings are interconnected, with two buildings comprised of six floors while one building consists of three floors. The buildings area covers approximately 18,000 square meters. These buildings function as offices, classroom, laboratories, exam halls as well as student and resource centers. Due to varied buildings' functions, retrofitting sensor system is complicated if not managed properly. There is a number of known issues with the buildings under study namely changes in buildings' functions, internal renovations as well as temperature and humidity fluctuations.

Table 1. Profiles of the Buildings Under Study

ID	No. of floors	Total size (m^2)	Function
B1	6	approx. 6632	resource center, exam hall, auditorium, staff office, 24 hours area
B2	6	approx. 3160	classroom, laboratory, staff office
B3	3	approx. 2004	staff office, shop, cafe, classroom

There is no centralised automated control of electricity consumption in the buildings. Instead, timers are used to switch the system on or off. So far, electricity consumption of the buildings is captured based on the manual meter reading from the main switch board (MSB). There are no specific readings for separate electricity uses such as lighting, cooling and power socket in these buildings. In addition to this, information such as indoor climate and user's behaviour in the buildings is not captured. Such information is crucial in managing building energy efficiency while ensuring sustainability and improving indoor comforts. Due to the large floor areas involved in this study, there is need to establish the correct testing protocol that can be used as a guideline for similar tests on other floors. For this purpose, one of the floors in the first building under study, B1, which is the largest of the three buildings, will be used. It is planned that the methodology/protocol will be replicated for the other buildings.

3 Methodology/Protocol Development

The test protocol is initially established to systematically verify the proposed sensing mechanism positioning. The protocol is important for a large scale retrofit projects that involves multiple team members from multiple divisions. This study selects the largest floor area in B1 as a pilot trial-and-error test to form the correct test guideline/protocol. Figure 1 illustrates the overall project flow to establish the proposed testing protocol.

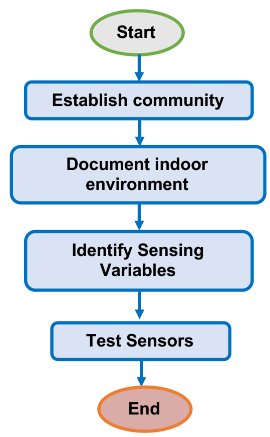

Figure 1. Overall project flow for initial stage of IoT retrofitting works

3.1 Establish Community

In any retrofit project, the buildings involved are already in use by the occupants and managed by the buildings' facilities management, i.e. the community. As the aim of the project is to promote sustainability and energy efficiency to the community, cooperation and involvement from the community is needed, especially when looking at long term deployment. Hence, in this study, the first step involves obtaining cooperation from the community. The community in our case are the students, academicians, researchers, office workers, shop owner, cooks and safety officers.

3.2 Observe Indoor Environment

It is imperative to observe and document the indoor environment because the sensing mechanism will be identified based on this observation. This is especially the case when dealing with old buildings that have undergone a number of major and minor renovations where not all renovations are properly documented. The available floor map may no longer correctly represent the current state of the buildings. Below are among the key questions to be asked are when making this observation.

1. Is there distinct temperature/humidity changes at each area of the floor? (Some cold and humid area can have molds or peeled paints. This can be determined from eye observation)
2. Based on building manager(s) experiences, which areas in the building are commonly crowded? At what time range?
3. How many AHU units are there at each floors? How large is the floor area?
4. What is the operation time of the said buildings?

Indoor observation and documentation is carried out by organising site visits with key experts in sensing such as project leader, engineers and researchers. Documentation includes acquiring indoor layout and confirming that the layout is correct based on the physical observation. Any mismatch needs to be corrected at this stage.

3.2.1 Label the Floor Map

The first step of the testing protocol is to label the key areas of the floor. This is done at the early stage to estimate the number and the types of sensor needed. Documentation needed is the internal layout of the building in study. Labelling is done on the layout as shown in Figure 2 to be used as a reference during the proximity, latency and positioning tests later. The numbers in the layout represent the areas while the numbers in the triangles represent the proposed gateway positioning. [Maybe need a sentence to describe what gateway is here]. Table 2 shows the sample of the legend for the floor map in Figure 2.

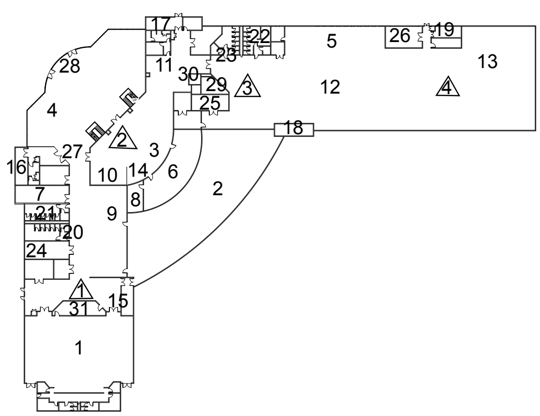

Figure 2. Labelled floor layout

3.3 Identify Sensing Variables

Malaysia's climate is typically hot and humid. Hence, buildings in Malaysia are equipped with HVAC system to enable indoor cooling. For B1, the HVAC system is based on district cooling system where water is chilled overnight away from the building. The chilled water is then piped into the building's pump room, which is then distributed to localised AHU units on each floor early in the morning. The system is old and has been operating for more than 20 years with complex system architecture.

Table 2. Legend Descriptions

Legend	Legend Details
1	Auditorium
2	24-hr Reading Area
3	Information & Service
4	Exhibition Area
:	:
31	Auditorium Control Room
Tri. 1 - 4	Gateway (Triangle)

Apart from this, the lighting system in the building is wired electrically and switched on from 8.30 a.m. to 10 p.m. on weekday and 9 a.m. to 4 p.m. during weekend. A section of the building operates 24-hour a day and from 10 p.m. to 8.30 a.m. the next day, the cooling system is based on two high volume low speed (HVLS) ceiling fan. From the observation of the indoor environment, it is clear that a number of indoor sensing variables is needed as below.

- Temperature
- Occupancy
- Humidity
- Carbon Dioxide
- Electricity Consumption

Understanding this, the project maps out the best strategy to identify data collection approach for sustainability and efficiency using an existing/old building ventilation and lighting system. For initial stage in this project, it is important to understand the indoor climate of the existing building as a whole. To achieve this, a number of preliminary steps need to be taken as below.

- The occupancy behavior within the building in study.
- Identify critical factors fluctuate the indoor climate.
- Specify the sensing system that does not require major modification/renovation on the existing building.
- Sensors positioning to get the most feasible data reflecting the indoor climate.

3.4 Test Sensors

Next is the sensor tests, which involve proximity, latency and positioning test to identify the correct placement of sensors and gateways in the building. Initiating sensor tests require understandings of the building under study. Indoor environments and propagation in each building could vary depending on the structure, user traffic and cooling mechanism. The test can be carried out from sensing samples obtained from vendors. The positioning of each sensing mechanism involved is verified from the test and recorded in the form of documentation. Once this is done, sensing equipment can be purchased and the project can move towards next stage.

3.4.1 Proximity and Latency Test

Proximity and latency tests are carried out to identify the signal coverage and the time taken for data from source to reach designated destination. In this study, the data source is the sensor, relayed using Zigbee wireless protocol, and the designated destination is the gateway. Proximity test is carried out to identify how far is the signal coverage for the sensors installed in the area. Common signal coverage for the particular gateway in this study is between 15 and 20 metres. This coverage is for an area that does not have propagation or obstacles issues. Building in this study has obstacles such as concrete walls and metal-based amenities. Apart from this, the building structure is such that some areas are open space with the height of the ceiling of more than 50 meters (e.g. legend 4 and 28 in Figure 2), while other areas have a lower ceiling ranging from two and half to three meters (e.g. legend 9 in Figure 2). The proposed testing protocol sequences are as follow.

1. Select the area to test. Refer to the floor map provided (as shown in figure 2). At least two assistants are needed to conduct the test.
2. Identify three important things based on the proposed gateway placement:
   - The closest power sockets (to power up the gateway). Take note of the distance from gateway position and power socket.
   - The closest LAN sockets for (to connect gateway to network). Take note of the distance from gateway and LAN socket (if any). If there is not LAN socket detected nearby, do take note as well.
   - Ideal gateway placement in the area. Note that it is preferable that the gateway is beyond people's reach.
3. Based on the labelled floor layout with proposed gateway placement as shown in Figure 2. Identify the sensors needed for the area and test the reception to the gateway based on received signal strength and measured latency (using counter).
4. Record the gateway coverage received signal strength and measured latency of each sensors involved.
5. Take note of areas where sensors experience high latency when relaying changes to gateway.

3.4.2 Positioning Test

Positioning test involves identifying the correct sensor and gateway point. This involves multiple trial-and-errors, as well as verification from the proximity and latency test. In this test, we need to identify the correct arrangement for sensor and gateway that would enable better coverage with lower delay. From the tests, we identify that some areas where sensor signals have high latency even when it is within gateway signal coverage. This is due to non-line-of-sight (NLOS), especially involving concrete wall or metal-based obstacles. Concluding from the test, the number of gateways proposed is increased and rearranged as shown in Figure 3.

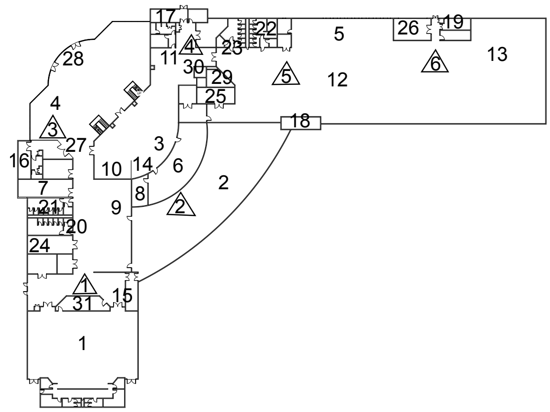

Figure 3. Floor layout with rearranged gateway

4 Future Work

This paper presents about the first phase of the development of a protocol for a large scale building retrofit. The protocol is important in ensuring proper execution of such a large scale project on existing buildings. It is evident from the sample of result presented that if testing protocol is neglected, there will be issues in gathering data once the sensors are installed. With the execution of the protocol, sensors' placement and required number can be more accurately determined. Hence, the next step would be to acquire the identified sensors for the floor and to proceed with the replication of the protocol on other floors and buildings.

Acknowledgement

To be included.

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