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Energy Monitoring Solution for SMEs

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Abstact
The complexity and high cost of building retrofitting for improved energy performance can be overwhelming for many SMEs. Tailor-made frameworks, are therefore, required to deliver long term energy reduction benefits, for relatively small commercial buildings. This paper presents a low cost energy monitoring and reporting solution for SMEs, which includes a system architecture, a baseline data generation strategy that significantly reduces the retrofitting timeline and a sensor network strategy that incorporates existing ICT infrastructure and minimises the number of IoT sensors. The system reports the energy monitoring data to building users in real time in an easy to understand format allowing building users to quickly analyse the affect of changes in their energy behaviour, encouraging them to try different low cost energy reduction strategies, before choosing more expensive solutions.

IoT, data fusion, sensor, sensor node, energy consumption, energy reduction, buildings, energy monitoring

1 Introduction

This work proposes an energy monitoring solution for micro, small or medium sized enterprises (SMEs), developed to help such organisations overcome barriers faced when trying to reduce building energy consumption. According to the Department for Business, Energy and Industrial Strategy (BEIS), in 2018, the UK's energy consumption was 143MTOE, where 28.9% was consumed by the domestic sector, 39.9% by the transport sector and 31.2% by the industry and service sector [1]. Buildings consumed 40.3%, with commercial buildings responsible for 49.4%, of which, 62% was for lighting and heating. Due to the significant cost of operating commercial buildings, there is a clear link between the size of an enterprise and the size of building they occupy. This is illustrated by a correlation in the energy consumed by small commercial buildings and by SMEs. In 2015, there were 5.38M UK businesses, 99% were

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SMEs [2], responsible for consuming 48.4% of commercial energy. Simultaneously, the commercial building stock included 1.57M buildings, of which 92% were classified as small buildings; 1000m^2 or less [2], and consumed 35.6% of all commercial energy.

Generally, SMEs are defined as enterprises with 0-249 employees. The energy consumption of enterprises based on employee numbers and building size are shown in Figure 1, created with data from [1]. The graph shows that for retail, office and hospitality, there is a clear correlation between energy consumption, enterprise size and building size. For the industrial sector, building size and energy consumption is instead dependant upon industrial equipment and processes. Similarly within the leisure sector some public buildings, including theatres and art galleries, the building size and energy consumption are more dependant upon size of audience or community served.

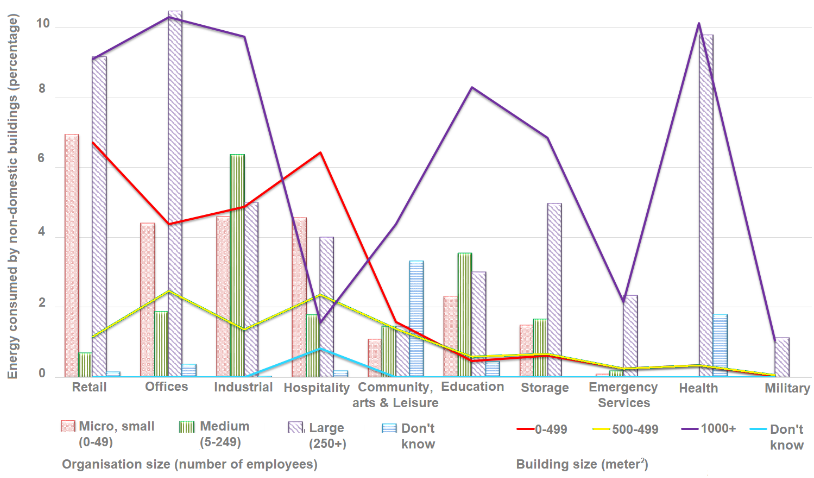

Figure 1: Energy consumption based organisation size and building size

2 Related Work

The Health & Safety Executive's (HSE) 1992 Workplace Regulations [3] defines a minimum floor space of 3.67 - 4.58m^2 per employee. So, a micro enterprise with 1-9 employees, could occupy a building 3.67 - 33m^2, plus toilets. The Total Office Cost Survey 2019 [4] values an individual work area at $£5,408 - £18,988$ annually (based on Norwich and London) using an individual area 2.5 times larger than HSE requirements. Using HSE regulations, the surveyed buildings would cost $£2,130 - £7,478$ per person. SMEs are sensitive to overhead costs, so will tend towards supplying employees with the minimal working area and occupy commercial spaces which are as small and low cost as possible.

Worldwide, building energy consumption is rising, but research shows that energy saving initiatives that include monitoring consumption and giving feedback to users can achieve long term energy reductions [5]. Feedback from surveyed SMEs [6, 7, 8] shows that barriers to the uptake of energy reduction initiatives include high upfront or lifetime costs, significant time commitments and expertise. Many commercial building energy monitoring and reporting systems do exist, but these systems are inaccessible to SMEs because they generally fit into three categories, being complex and expensive, affordable but requiring expertise to fit and manage, or affordable but overly simple and ineffective.

Previous research carried out in this area includes a number of surveys, such as [6] which audited 280 SMEs, [7] used data from energy audits to propose solutions to overcome SME energy reduction barriers, and [8] studied the gap between energy reduction measures and their implementation. Developmental work includes management of energy demand [9] using energy disaggregation techniques to turn off appliances, [10] developed an SME monitoring and targeting plan based on utility bill analysis, and [11] a monitoring system specifically for SMEs within manufacturing. These works highlight the barriers that SMEs face and offer a number of specific solutions but a solution suitable for a wide range of SMEs has not be offered.

Based on lesson learned, this paper presents a building monitoring and reporting solution designed specifically for SMEs based in small commercial buildings, to accurately monitor and report real-time energy usage. The system measures energy consumption and additional features including weather, occupant presence and occupant comfort levels. The data is analysed and fed back to the building users in an understandable format with the aim of encouraging users to test small changes to quickly and significantly reduce energy consumption, with no cost, or low costs to the SME.

3 Proposed System Specifications

Energy consumption is dependent upon many conditions and to create a complete picture for building users the system needs to measure energy usage, referred to as ‘metering’, and the additional conditions referred to as ‘monitoring’.

3.1 Baseline Generation Strategy

For a monitoring and reporting system to indicate a reduction in energy consumption, a baseline is required, this is the measurement of normal energy consumption before energy saving initiatives are applied. Traditionally, this comprises 18 months of metering and monitoring data. The advantage of this method is data completeness since it is generated using the same method as the data that it will be compared against. The disadvantage, particularly for SMEs, is the long lead time before implementing ESMs. Recent research from a study carried out in Manchester on behalf of the 'Boosting access for SMEs to energy efficiency' (BASEE) competition, this significant lead time can cause SMEs to disengage, resulting in a loss of company interest or finances. Instead, the proposed baseline generation strategy reduces the lead time to 3 months. The strategy is to create baseline data using metering/monitoring data collected for a period of 3 months, and combine it with building model data. Research shows building models can be inaccurate [12] due to significant differences between the building model and the real building. To improve the model, indirect building data will be added:

- pre-existing building energy performance specifications e.g. post occupancy evaluation (POE) and display energy certification (DEC),
- 12+ months' historical billing data,
- normal building usage information e.g. operating hours, occupancy levels,
- energy performance data collected from similar smart buildings,
- data collected from pre-installed sensors, security systems or BMS

This improved model can deliver consumption predictions within 3% of actual [12]. Additionally, during the baseline monitoring period, energy consumption profiling can be completed to determine where energy is consumed to inform the SME which additional ESMs may be most effective.

3.2 Proposed System Architecture

As discussed in the introduction, the cost of monitoring systems and their complexity can be prohibitive to SMEs, some lower cost solutions are available such as the Beringar IoT building resource and occupancy tracking module [13] costing £450 per module for the hardware, with an annual subscription of £350 for software-as-a-service data reporting. The Pressac smart monitoring hardware [14] costs £750 each and the Smart Citizen starter hardware [15] costs £100 each and both solutions offer a range of IoT sensors but require additional expertise to install, configure and manage. The Pressac kits include a Wi-Fi, Ethernet and LTE gateway but do not include software for reporting, instead they are compatible with commercial cloud platforms. The Smart Citizen kits are open source and connect to a range of open source reporting tools.

Alternate low cost solutions typically include installation of motion detectors to automate lights and other services but this is generally overly simple and ineffective.

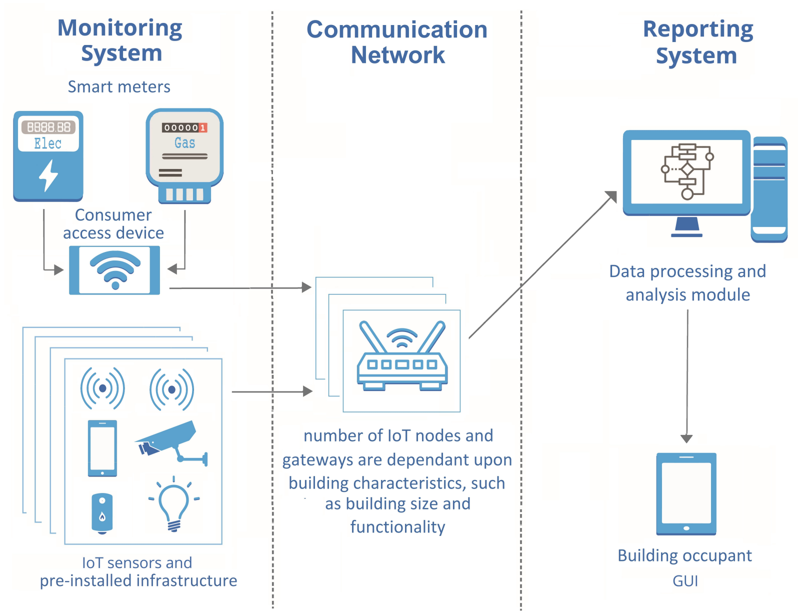

Figure 2: Proposed System Architecture

Learning from previous work [6, 7] and existing systems [13, 15], the proposed solution is simple enough that a user can set the system up straight out of the box, connecting pre-installed smart meters and other pre-installed systems using the existing WiFi network. Additional IoT sensor nodes can then be fitted around the building and connected, also using the WiFi network. The objectives of the proposed architecture are to:

1. accurately measure energy consumption,
2. accurately and reliably monitor the building,
3. use pre-installed ICT infrastructures such as WiFi, smart meters, BMS etc,
4. use minimal additional communication / metering / monitoring equipment,
5. feedback real-time understandable information to building users to enable changes in energy usage behaviour,
6. keep system simple for easy installation, set-up and maintenance,
7. keep system costs to a minimum.

The proposed architecture is shown in Figure 2 and is split into 3 sections; the monitoring system, communication network and reporting system. The monitoring system is comprised of the energy metering and the building monitoring. The energy metering will be completed by the smart metering equipment technical specifications version 2 (SMET2) gas and electricity smart meters. These meters are available without charge for SMEs from their utility company. The metering data from the SMET2 meters will be collected by a consumer access device (CAD) and transmitted to the processing and analysis module.

As discussed in the introduction, traditional building monitoring systems are expensive mainly due to high specification hardware. Inline with the low cost objective of the proposed solution, it has been designed to incorporate any previously installed building monitoring systems for example camera, heat imaging or RFID based security systems, clocking-in systems or BMS etc. The proposed system will combine data from these pre-installed systems with data collected by additional low-cost IoT sensor nodes. All of the data will be transmitted using the existing building WiFi network to the data processing and analysis module. Next the data will be processed and combined using data fusion techniques and analysed to determine if occupants are within specific building zones and if occupant comfort levels are being achieved, such as room temperature and light levels. The number of WiFi gateways will be kept to a minimum, dependant upon the size and layout of the building. In order to keep system costs to a minimum, data processing and analysis will carried out locally and isolated from the internet. Where users want a cloud-based solution, this will be available for an additional cost, the cloud-based solution will have the necessary security module embedded. The building monitoring results will be delivered to the building users in real time in the form of a reporting application which users can view on a computer, tablet or smartphone.

3.3 Sensor Network Strategy

Sensors are required to adequately monitor the features affecting energy consumption. Traditionally, building monitoring is achieved by installing a large number of IoT sensors around a building, where each IoT sensor includes a sensor, communication unit and power supply. This work proposes an alternative sensor network strategy which reduces installation time, installation complexity, the amount of repeated hardware, operating power and system costs. The strategy is implemented using accurate low cost sensors which have a large sensor range. Multiple heterogeneous sensors will be combined into a single sensor node which will also include a WiFi communication unit and power supply, resulting in a single sensor node which can monitor multiple features across a wide area.

The proposed sensor nodes have a combined circular coverage area, shown as the blue circle in Figure 3. The coverage range of the node is the coverage radius labelled c in the figure. If a square, of maximum dimensions, is drawn inside the circular coverage area, shown in black, an equilateral triangle can also be drawn, shown in green in Figure 3. Using Pythagoras' Theorem, the size of the node coverage square can be determined. Labels a, b, c denote the equilateral triangle:

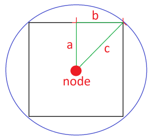

Figure 3: IoT node coverage area

$$c^2 = a^2 + b^2 = 2a^2 \quad (1)$$

$$a = \frac{c}{\sqrt{2}} \quad (2)$$

$$L_{\text{square}} = 2a = \frac{2c}{\sqrt{2}} = c\sqrt{2} \quad (3)$$

$$A_{\text{square}} = (L_{\text{square}})^2 = 2c^2 \quad (4)$$

To create reliable monitoring data, the sensor network strategy must offer complete coverage of the building. As such, the strategy defines the sensor coverage square, shown in black in Figure 3, as its coverage area. Additionally, the strategy stipulates that the sensor nodes should be positioned such that each node coverage square should either meet a building wall or a neighbouring node coverage square. Where two neighbouring node coverage squares meet, overlap should be kept to a minimum to reduce the number of nodes required. The proposed nodes have been designed with a coverage range of 7m, and the length of the node coverage square can be calculated as 9.9m.

Using the sensor network strategy, building size and layout, the required number of sensor nodes can be calculated. Typically, for an open plan building, less nodes will be required since the functionality of the sensor nodes is inhibited by building walls. If a small open-plan commercial building 10m x 10m is considered, based on the HSE regulations [3], the building can accommodate up to 20 employees. Using the sensor network strategy, each node can cover an area up to 98m^2, so just 2 sensor nodes achieve full coverage of the building, one in the open plan area and a second for the toilet area, as shown in Figure 4a. A similar sized building, 9m x 13m, configured with multiple internal spaces would require 5 sensors nodes to achieve full building coverage, as shown in 4b.

4 Conclusion

This paper proposes a energy monitoring and reporting solution, which is specifically designed to overcome barriers SMEs face when trying to reduce energy consumption. Though monitoring and reporting systems

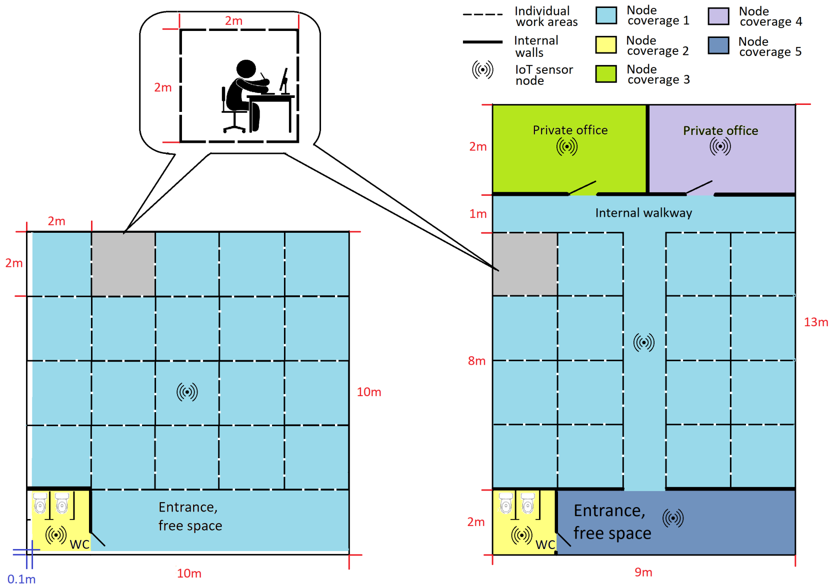

Figure 4: A: 10m x 10m open plan building, B: 9m x 13m building with multiple areas

do exist, research has shown that existing systems fit into three categories, either being too complex and expensive, affordable but requiring additional expertise to fit and manage, or affordable but overly simple and ineffective. The design of this energy monitoring and reporting solution makes it accessible to SMEs because it is low-cost, requires no expertise to install and operate and has a short lead time before reporting on improvements in energy behaviour, enabling SMEs to develop and test energy reduction strategies and quickly see the effects.

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