THE IMPACT OF USING INTERNET OF THINGS (IOT) TO IMPROVE THE OPERATIONAL PERFORMANCE OF A COMMERCIAL BUILDING

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ABSTRACT

The rapid growth and deployment of the Internet of Things (IoT) based technology have opened up new avenues for technical advances in various areas of life and building performance. The primary aim of IoT technologies is to simplify processes in various fields, improve system efficiency, and, ultimately, improve quality of life. Despite the remarkable efforts by standardization bodies, professional alliances, building industry, academia and others, there are still multiple challenges to be addressed before IoT can realize its full potential. The challenges can be addressed from a variety of perspectives, including smart buildings and energy conservation. The core scope is to deliver a comprehensive overview of how open issues and efficiencies could be tackled by future researches. Some insights are provided directed at specific emerging ideas to facilitate future research. Also, this paper brings order in the existing literature by classifying contributions according to different research topics. The outcome detailed contributed to a better understanding of current technological progress in IoT application areas. In addition, it overviews the environmental implications linked with the increased application of IoT products in general and mainly in commercial building energy management. Lastlty, it presents and discusses a case study on a representative building that was used to analyze the impact of IoT technology, and this resulted to a substantial saving of 41% as compared to the original building's energy use.

Key Words: Internet of Things, smart building control, Artificial intelligence, Energy management.

1. Introduction

The Internet of Things (IoT) is a modern invention that enhances a set of new platforms for the next wave of technological innovations. The implementation and rapid development of the IoT based technologies have allowed novel possibilities in technological advancements in numerous aspects of life. IoT simplifies processes in different fields, ensures a better efficiency of and improves overall quality of life. However, despite the great efforts of standardization bodies, alliances, industries and researchers, there are still challenges that halts IoT to reach its full potential. These challenges should be considered from different areas of application such as smart buildings and their energy management. Four main topical areas are discussed in this paper: fundamentals of IoT, the potential applications, benefits, and challenges. Furthermore, to reflect on the benefits of IoT towards a commercial building, a concise summary of how energy and money savings may be achieved in a commercial facility is on providing.

2. Fundamentals of IoT technology

Kevin Ashton the co-founder of the Auto-ID and his colleague David Brock used the term IoT for the first time in 1999. He gave not only the name but also, he defined IoT as a “Uniquely identifiable interoperable connected things with radio frequency identification (RFID)” [7].

In due course, even though there is no exact definition of IoT [2] it generally can be defined as; the interconnection of computing devices incorporated in everyday gadgets via the Internet, enabling them to send and receive data [2], [3] . IoT is seen as a digital system that monitors, sensors, records and adjusts the interaction between the connected physicl objects (things). This interaction is the great strength of IoT, where the physical world meets the digital world [4]. This cooperation of devices can be used not only in ordinary household objects but also in sophisticated industrial tools The technology has become the common paradigm of modern, new types of dynamic information system and better communication [1], [3]. Further, the global market for IoT end-user solutions is forecasted to grow. The technology reached 100 billion dollars in market revenue for the first time in 2017, and it is predicted that this figure will reach around 1.6 trillion by 2025 [5].

IoT Security Foundation, 2019 categorises IoT devices into three main categories:

I. Sensors
II. Actuators
III. Gateways

These building blocks of the IoT as shown in Figure 1 has different uses and applications. Sensors are used to collect data from the surrounding. These collected data are transferred to the processor by using actuators. Further, gateways act as a communication hub and may also implement some automation logic [6].

The information obtained from the sensors is collected at the cloud and is managed by different software. Next, the information is made available to the end-user by configuring an alert system (email, text, notification, etc). All these device types may stand alone or be embedded in a larger product. They may also be complemented by a web application, mobile device app and cloud-based service [3] [6].

This simplified diagram below is selected from many different models. It is a much-reduced version of the different models. Different companies can develop different ways of IoT assembly, depending on the devices associated.

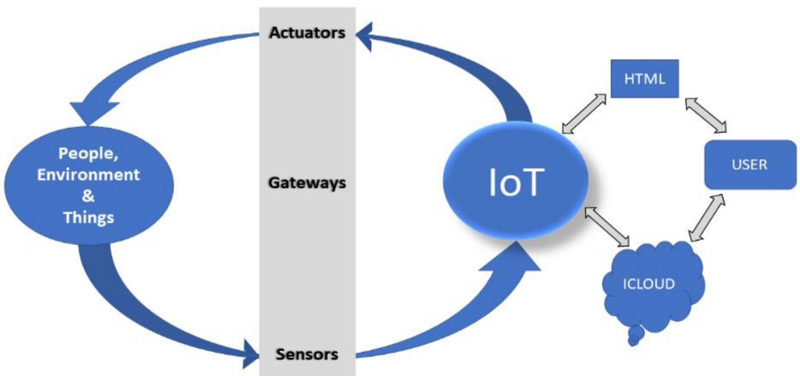

Figure 1: Simplified block diagram of the basic building blocks of the IoT

3. Potential applications of the IoT

The IoT applications are extremely diversified and are increasing every day in many areas. Currently, there are plenty of applications of IoT and is expected to develop drastically in the coming years (see Figure 2) [7].

An illustrative example of a an application include transport logistics; where weighty benefits could be brought to the worldwide supply chain. This could be realised through monitoring every detail such as commodity details, purchasing of raw materials, production, and sales of the product after-sale service [3]. Also, it could be used in smart factories and could benefit them by improving productivity and reducing their operating expenses [8]. In the retail sector, IoT could benefit both the business and the customers by Omni-channelling information and products [9]. Healthcare is another sector that could benefit from IoT by making the interaction between specialists and patients much more efficient [8]. The challenges of complex systems of infrastructure in technology, economy, social and political structure and human behaviour incorporated in the concept of the smart city can be addressed by utilising IoT [10], [11]. Smart parking sensors are attached in parking spots to identify the arrival and departure of vehiclescan give an efficient management solution that helps motorists to save time and fuel. It also offers drivers precise and real-time information about parking [12]. Further, IoT supported applications are smart grids, street lighting management, traffic light management, waste management and environmental monitoring [2], [7].

A related IoT application is the support of IoT enabled smart buildings [4]. Smart homes will be aware of the activities inside the building, for the most part affecting three viewpoints: consumption, security and comfort. Therefore, the IoT based system can fundamentally support these requirements. In residential and commercial buildings, IoT devices enable the possibilities that users can control and monitor, set schedules and get real-time feedback on energy usage remotely. These sensors will measure the outside temperature and even can determine the occupants inside the rooms and thereby establish an HVAC control strategy, flow of light etc. The goal is to achieve better levels of comfort while cutting overall energy expenditure [8] [10] [13] [14].

Additionally, smart buildings address the issue of security by using complex security frameworks for identifying fire, burglary or unapproved entry. The stakeholders associated with this situation establish a very heterogeneous group. Various parties will collaborate in the user's home, such as device manufacturers, internet organizations, security organizations, telecommunications operators, media specialist organizations, power service organizations, and so on [13] [14].

Detailing every potential application of IoT is beyond this paper. However, the abridged IoT applications are detailed below in Figure 2.

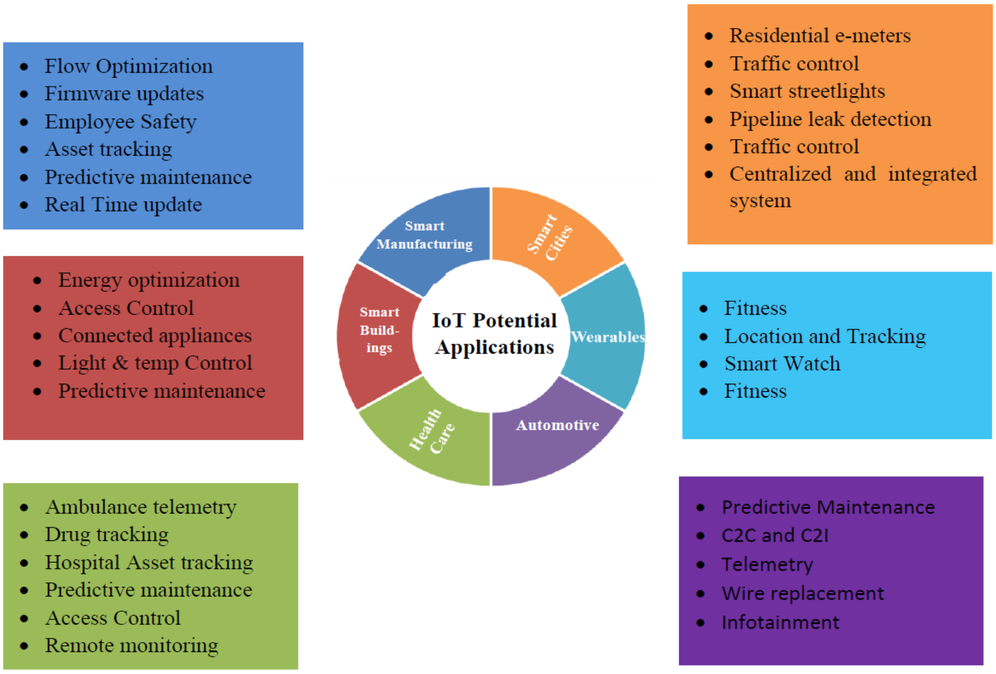

Figure 2: Potential Applications of IoT [8]

4. Benefits of IoT

The IoT technology promises noticeable benefits to all sectors [3]. The benefits are obtained through physical items, data analysis and services. However, the effect of IoT varies among organizations. The main benefits that an organization with an IoT system can have the following: [12].

1. Productivity improvement: IoT permits the monitoring and control of the various procedures, which optimises the different tasks that increase productivity and efficiency and as a result reduces running expenses [12] [15].
2. Predictive analysis: By utilizing the enormous amount of gathered data, IoT's new advancements make it conceivable to look at repeating examples and add to prescient analysis, which can be utilized fundamentally in maintenance. This exact data will be utilized to improve existing procedures and administrations [16].
3. Rapid response: The information makes it conceivable to monitor the frameworks set up in real-time and even distantly. They encourage the enhancement of maintenance interventions, but also give the organization a strategic advantage in monitoring market developments [15].
4. Reduction of human errors: credit to the complementarity of innovations, for example artificial intelligence, IoT makes it conceivable to diminish human errors because of unremarkable or tedious assignments [12] [15].

5. The current challenges

Each surge of innovation selection has its difficulties, and IoT is no special case [17]. IoT based solutions consist of several technologies, making an environment that is unpredictable and quickly evolving. When Forbes Insights 2017 conducted a global survey of 502 executives who distinguish themselves as responsible for, or acquainted with, the current or arranged IoT activities of their organization. The top five challenges identified with building out IoT capabilities are [18]

1. Lack of Investment
2. Keeping the IoT Secure
3. Cross- Department Cooperation
4. Integration of Disparate Data
5. Availability of Skilled Staff

Further, the IoT business statistics for 2020 predicts that nearly 75% of all the IoT business projects are likely to fail. This is mostly due to a lack of understanding of the data that the IoT provides. [19].

6. Data Collection and Analysis

The data has been collected from one of the office buildings based in east London with a total floor area: 2700 m^2. The data was collected from two sensors located in the 4^{th} floor south and 3^{rd} floor north. The data was obtained as a comma-separated values file which compromises data for May and June of the year of 2019. The sensors collect data of the indoor temperature, indoor CO_2 level, indoor relative humidity and occupancy level. The data collection was in a 10 minutes interval of a full day. Thus, a total of 144 points (24 x 6) a day worth of data has been collected. Occupancy is defined as the number of devices that enters the building. The grand assumption is one device is equal to one person; therefore, the occupancy level is the occupied status or number of occupants in the building.

The initial step for analysing the data was to average the number of devices out of the working hours (08:00am – 6:00pm) in a daily pattern. To avoid the many factors such as background noise which is the door to door communication over the time when the building is unoccupied affect the data collection. Also to show the technological advancements in building design and for predicting real energy usage.

Once the number of devices of working hours in a daily pattern was averaged, the data was expressed in a chart as shown in Figure 3 to see if the data in the dates correspond and how the occupancy level acts during working hours in daily patterns.

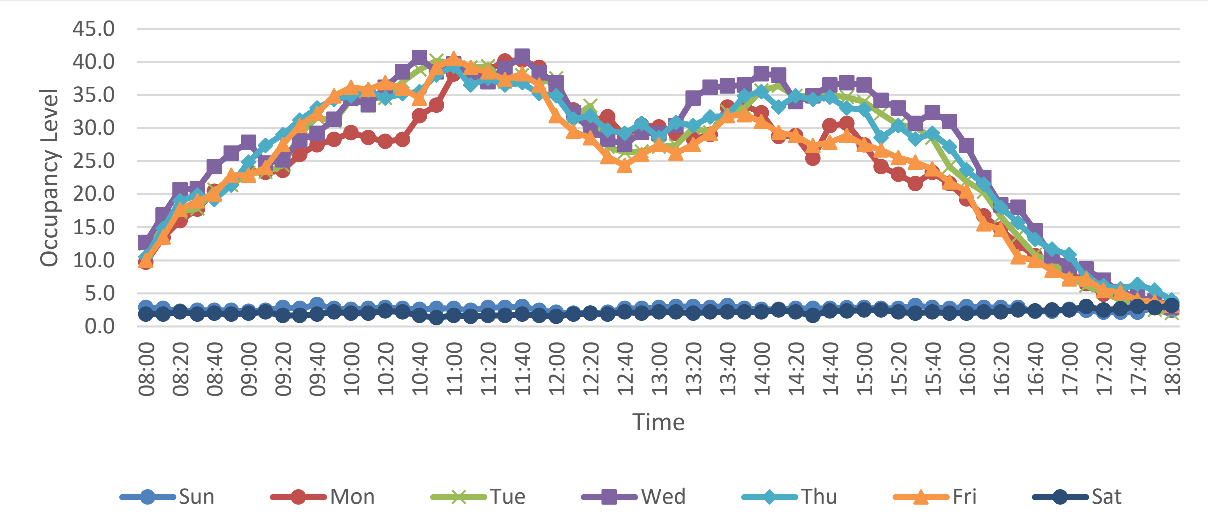

Figure 3: The distribution of the occupancy level across operational hours in daily patterns

Figure 3 depicts how the occupancy level changes over the course of a week and at different hours. It shows the number of devices indicating the occupancy level. It can be seen how begins at a low level , steadily grows throughout the shift, and then gradually declines toward the end of the shift. There are two clear peaks, one in the morning and the other in the afternoon, as shown in the diagram. The graph also shows a decline in the mid-day (lunch time) period. In addition, there were less than 5 devices on weekends.

Further, the information in Figure 3 may inspire a shift toward a more practical energy usage perspective. They can encourage a faster adoption of demand management and control. The greatest number of occupancies the building countered each interval time was then calculated from the average daily number of devices for the worst-case scenario of saving. However, to combat air pollution, 10% was set aside for fresh air. As a result, the whole saving estimate was based on the 90th percentile. The 90th percentile was discovered to be 55. See Table 1 for further information.

The trend may be seen in the percentages and occupancy levels. The data analysis is made easier by this connection.

Percentages	Occupancy Level
10%	5.5
20%	11
30%	16.5
40%	22
50%	27.5
60%	33
70%	38.5
80%	44
90%	49.5
100%	55

Table 1: Occupancy level expressed in percentage

By using Table 1, a graph of percentage of the occupancy level vs average hours have been constructed. The graph is shown below.

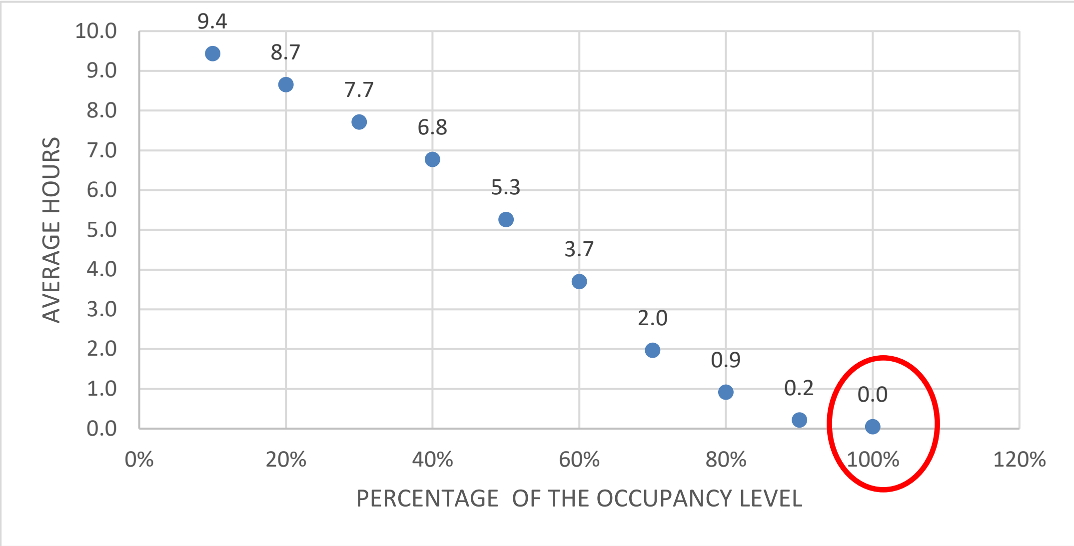

Figure 4: The percentage of the people for how long the space was occupied.

Figure 4 above represents the percentage for how long the space was occupied. The graph emphasises that the relationship between the percentage of the occupancy level and the amount of time they spent on the building are disproportionate. In contrast to what systems without the IoT technology assumes. A system without monitoring the link between real-time occupancy level (actual time spent inside the building) along with real energy monitoring predicts that the building is most of the time 100% occupied. This leads to excessive energy and money wastage. This analysis highlights that the building was fully occupied for less than an hour. This stresses the importance of the IoT technology or real-time occupancy-based energy management.

A graph have been plotted for variables time vs the percentage space used by people. The relationship and the pattern of the graph has been used for a better energy management strategy. The graph is shown below in Figure 5.

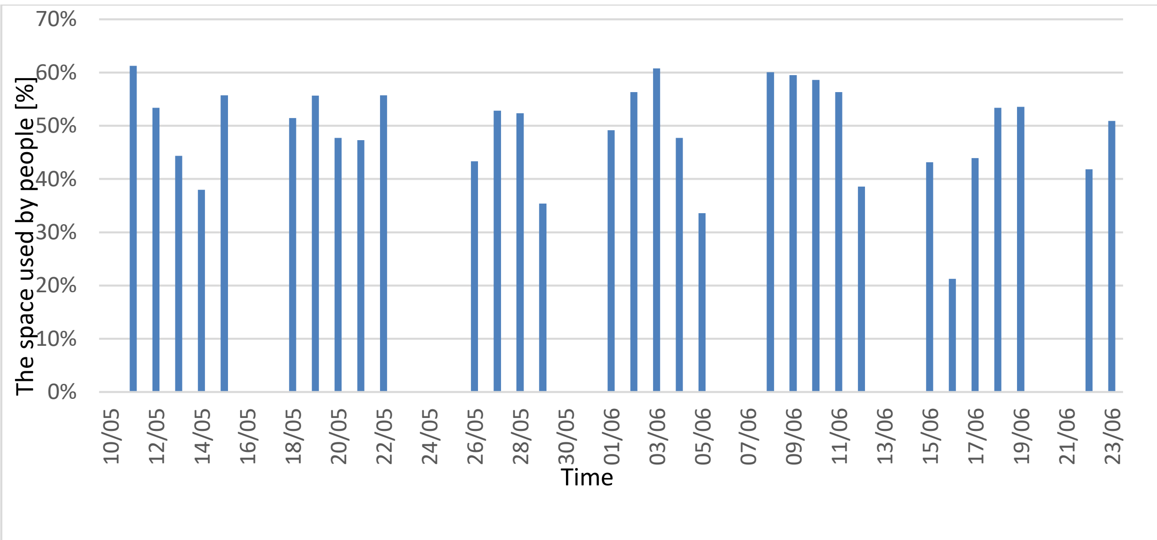

Figure 5: The relationship between the days and the occupancy level.

Figure 5 above clearly emphasizes that there are no consistencies between the dates and the occupancy level presented in percentage. This analysis is vital as it helps the facility manager not to make any wrong decisions by assuming a correlation between the dates and occupancy level.

By using the analysed data from Figure 6 see Table 1 and the analysed occupancy level raw data, the relationship between the average kWh/day and the speed of the fan in percentage was expressed in a graph as shown below.

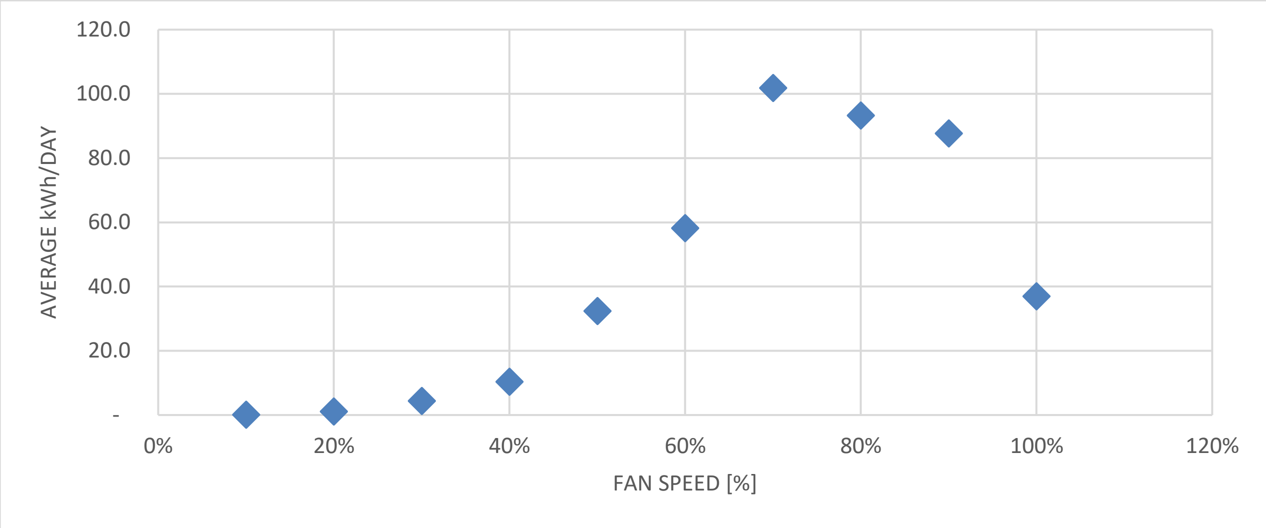

Figure 6 The Relationship of the average kWh/day and Fan Speed [%]

Figure 6 above shows the relationship of the average kWh/day vs fan speed expressed in percentage. As it displayed on the graph, the average kWh/day increased exponentially with the increase of fan speed up to 70%. After that, it started to drop gently up to 90%. At the latter stage, it dropped sharply. Since all the data is extrapolated from the number of people who have visited the building, the pattern showed inconsistency. There is no clear pattern on the overall graph. The inflexion point could have been better identified if our axes were extended to smaller gaps.

7. Results and Discussions

In Table 2 below, how the raw data and the analysis progressed to a saving in terms of energy and money will be discussed

Hours in bands		**% Accumulative**	**AVG-hours**	**Total hours**	**fan speed**	**AVG-kWh/day**	**Total-kWh**
POWER OF AHU / ORIGINAL	172 kW					1,720	53,320
up to	10%	6%	0.6	17.5	10%	0.1	3
from previous, up to	20%	8%	0.8	24.2	20%	1.1	33
from previous, up to	30%	9%	0.9	29.3	30%	4.4	136
from previous, up to	40%	9%	0.9	29.2	40%	10.4	321
from previous, up to	50%	15%	1.5	46.7	50%	32.4	1,003
from previous, up to	60%	16%	1.6	48.5	60%	58.1	1,802

from previous, up to	70%	17%	1.7	53.5	70%	101.8	3,156
from previous, up to	80%	11%	1.1	32.8	80%	93.3	2,891
from previous, up to	90%	7%	0.7	21.7	90%	87.6	2,717
above previous	100%	2%	0.2	6.7	100%	37.0	1,147
sum totals		100%	10.0	310.0		426.1	13,210

Table 2: The average daily and collective kWh saving by utilizing the IoT technology

The data presented in Table 2 above is derived from Table 1 and Figure 6. These are information obtained from the analysed collected raw data. Table 2 above shows a full range of the savings at each occupancy level for an average day and collective days which are 31 days eliminating weekends and bank holidays.

The table above also clarifies the relationship between the occupancy level and how that will affect the energy consumption. The energy difference within and without the IoT technology is described in the table in terms of a day and a year. This table also shows how big the saving margin is and also by utilising this table the energy saving could be predicted for the entire year. Further, the raw data used in this table are only two months' worth of data. Hence, by using the raw data of a year the same data analysing method could be implemented. In that way, the exact energy saved could be found.

SAVINGS	*% active*	*%*	*kWh/day*	*Total here*	*kWh/year*	*£/year*	*£/year/m2*
Ventilation	75%	75%	1,294	30,083	242,601	£ 31,538	£ 1.17
ORIGINAL CONSUMPTION (during working hours)	100%		1,720		430,000	£ 55,900	£ 2.07
Saving (%)						56%	
Chiller power	200kW						
Cooling	75%	45%	907		170,121	£ 22,116	£ 0.82
ORIGINAL CONSUMPTION	100%		2,000		500,000	£ 65,000	£ 2.41
Saving (%)						34%	
Heating power	200kW						
Heating	75%	45%	907		170,121	£ 22,116	£ 0.82
ORIGINAL CONSUMPTION (during working hours)	100%		2,000		500,000	£ 65,000	£ 2.41
Saving (%)						34%	
TOTAL saved					**582843.43**	**£ 75,770**	**£ 2.81**
TOTAL ORIGINAL					1430000.00	£ 185,900	£ 6.89
TOTAL SAVED					***41 %***		

Table 3: The saving from the IoT tech (LightFi) in terms of energy and money

Table 3 deconstructs the savings and displays them in terms of energy, cost and percentage. The yearly operating cost is computed using a 0.13 £/kWh for electric energy. Total operational costs are included in the total yearly energy consumption cost. Without the technology, the first yearly expenditures are estimated to be £ 185,900, with an annual energy usage of 1430000 kWh. Furthermore, the estimated yearly expenditures of utilizing IoT technology are £ 75,770, with an annual energy usage of 582843.43 kWh. This results in 41% savings in both energy and money. If the fresh air been completely regulated, the savings would have been even higher. However, as shown in Table 3 to keep air pollutants such as moisture, odours, gases, dust, away only 75% of it is controlled leaving 25% to run at all time.

The economic impact is assessed using the following criteria: original investment, annual operating cost, annual maintenance cost, and total investment. Formerly, the appropriateness of frameworks was anticipated and estimated without the use of technology, followed by the economic viability of using IoT technology. The comparison shown in table 3 reveals that the advantage cost percentage is extremely large, and the net present values are mostly positive. These findings indicate that the frameworks have a lot of room for improvement.

The tenant behavior, which will determine how the framework should operate, is a common aspect that must be addressed for successful energy use in buildings. Occupant behavior expectation is a difficult consideration in buildings performance analysis since it depends on how the tenant perceives and the building's function. As a result, advances like machine learning have shown to be useful in predicting occupant behavior since they rely on prior knowledge and anticipate future behaviour [20]. One of the characteristics of the data utilized in this research is that it was a very big dataset comprising indoor air quality and occupancy level data. Despite the size of the database, information on the inhabitants and energy usage was only available in aggregate form. As a result, there may be additional factors that impact the energy-saving effects that are not taken into account in this study. More study into the impact of other variables is needed to determine whether they also have a role.

Another limitation of the data utilized in this study is that it does not examine occupant interactions with building systems, which is crucial for forecasting energy use. Simulation models have a significant degree of uncertainty and inaccuracy without such an examination [21]. Another important aspect of building energy usage is the use of plug load energy, which is generated by small equipment such as PCs, toasters, ovens, fans, and restricted warmers that are directly powered by AC plugs. This element has a zonal dependency according to tenant requests in this way. In this case, the resident action that can help reduce plug load energy consumption is to turn off the gadgets when they are not in use [21]. After working hours, energy usage is reported through turned on lights, printers, and displays at offices. Similar building energy waste has been reported during non-occupied hours, according to another current investigation. [22]

In comparison to prior research [20], one of the features of the methodologies employed in this article is that it takes into account both real-time occupant level and real-time energy savings, as well as indoor air quality. Another strength of this research is that both the original and saved energy were studied, resulting in a better understanding of not only the real effect of thermal renovation, but also the parts of the energy calculation technique that require attention/improvement. When real-time occupancy level-based energy management is utilized, the findings show a substantial reduction in energy use. This may be accomplished with the use of IoT technologies such as LightFi. The fact that the structure is not entirely inhabited is one possible explanation. The fact that the facility was completely filled for less than 10% of the working hours was demonstrated in this article (see Figure 4).

Furthermore, we utilized the assumption that one device corresponds to one person. This carries an inherent uncertainty since a person may have many devices or none at all, such as a phone that is turned off. Despite its limitations, this study adds to and validates previous ideas that real-time occupancy level-based energy management leads to lower-than-expected energy savings.

8. Conclusions

This paper aimed to get a better insight in commercial buildings through evaluating the effectiveness of using the IoT approach in a representative case study which resulted a saving in energy and cost.

Based on this case study, it was estimated that by utilizing the IoT technology, quantity of energy saved was 582843.4 kWh per year, and the yearly cost saved was £ 75,770 which translates to a savings of 41%.

Apart from the yearly anticipated saving, it's difficult to establishwhich day of the week reflects the most efficient saving because the statistics show no trends.It was also discovered evidence that a high CO_2 occupancy combined with a low relative humidity will not be a cause of any discomfort to the occupants. The interior temperature, on the other hand, is more likely to induce discomfort. As a result, the facility manager and the LightFi technology teams must look into and resolve this issue. Based on these findings, the thermal comfort and indoor air quality should be considered while achieving energy and cost savings.Overall, this article has provided fresh insights on the impact of Internet of Things technology on energy and thermal comfort in commercial buildings. Raw data for the whole year is necessary for more accurate estimates of yearly energy savings.

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