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A Taxonomy and Survey of Occupancy Detection Methods for Efficient Space and Energy Utilisation of Buildings

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ABSTRACT

Human factor has a significant influence in space and energy utilisation in buildings. Space utilisation refers to a measure of whether space of a building is being used and how it is being used. While energy utilisation refers to the amount of energy being used. As space and energy of buildings are mostly dominated by the occupancy and related activities, occupancy information is vital in managing space and energy use. By detecting the presence of an occupant in a building or occupancy detection, space and energy can be utilised efficiently by corresponding to the occupant's dimension and activities, thus avoiding wastage. Accordingly, through various methods, occupancy detection employs various sensors available in term of spatial temporal properties depending on the area to be deployed. Majority of past studies were focused on the aspect of energy utilisation and occupancy and there is lack of review paper which gathers information on occupancy detection inrelation to both space and energy utilisation.Therefore, this paper aims to develop a taxonomy of occupancy detection technologies for efficient space and energy utilisation of buildings. A survey of past studies on space and energy utilisation of buildings in relation to occupancy level are done to understand the relationship between occupancy and space and energy utilisation, respectively. A taxonomy is then built to identify the technologies which are currently available for occupancy detection.

Key words: Energy utilisation, Occupancy detection, Occupancy sensors, Space utilisation.

1. INTRODUCTION

Management of space and energy are crucial towards achieving sustainable development. The efficient use of space and energy of a building is dependent on the human factor. In this context, the information of the occupant's dimension in a building environment is a key component to be assessed and studied. For this purpose, occupancy detection is devised as barometer to attain optimal use of space and energy.

Occupancy detection refers to detecting the presence of an occupant person in a building. Occupancy information comprises of six features of spatial–temporal properties which include presence, location, number of occupants, activity, identity and tracking movement. The current approach to occupancy detection is by using occupancy sensors, which are further classified into terminal and non-terminal sensors. By utilising occupancy detectors, energy can be used efficiently by reducing or possibly eliminating wastage of energy due to lighting system and heating or cooling cycles.

Notwithstanding the ideal function of occupancy detection, research challenges arise as to the design of occupancy detection techniques. One of the challenges is how to avoid privacy or intrusiveness issues. An ideal design should preserve occupant's privacy by avoid identifying the occupant's identity or their activities.

The optimal control of building's environmental variables such as temperature, humidity and light have significant impact on energy consumption as well as indoor environmental quality. Such control is executed by a variety of sensors connected to the heating, ventilation and air-conditioning (HVAC) and lighting systems of the building.

Considering the impact of occupancy factor on space and energy utilisation of buildings, this paper reviews past studies on space and energy utilisation of buildings in relation to occupancy level. This paper is also motivated by lack of paper which gathers information on occupancy detection in relation to both space and energy utilisation. Hence, the objectives of this paper are twofold. First, to understand the relationship between occupancy and space and energy utilisation in buildings, respectively. Second, to develop a taxonomy to classify various current technologies identified to be used in occupancy detection methods.

For the purpose of this study, data on space utilisation and energy utilisation were identified using Science Direct and IEEE databases. The search was narrowed to occupancy detection methods. The papers extracted and reviewed were constricted to papers published from 2015-2020 to ensure current methods and technologies on occupancy detection were obtained. The papers were analysed manually for data on occupancy detection methods which relates to space utilisation and energy utilisation, and the devices used. The results were categorised and tabled(Table 2 and Table 3) as well as taxonomy was built for type of sensors used for occupancy detection(Table 1).

2. SPACE UTILISATION AND OCCUPANCY

Space utilisation refers to a measure of whether space of a building is being used and how it is being used. The utilisation rate is a function of a frequency rate and an occupancy rate. The frequency rate measures the proportion of time a space is used compared to its availability. Whilst the occupancy rate measures how full the space is filled compared to the capacity of the area. The utilisation rate can be assessed in terms of both actual use and predicted use [1].

Space utilisation should be particularly prioritised in a building design. An aspect which also ought to be taken into consideration is understanding the purpose of building being used or building characteristics. Various factors come into play when considering the importance of space utilisation which include money, energy, occupant's satisfaction and eco-friendly goal. Basically, workspace is expensive. This is particularly true for buildings in urban areas where property value continuous to rise. Information on space utilisation can avoid over budgeting or loss due to cost spent on buying unneeded space or renovating a building. Furthermore, under-utilised workspace may cost a company unnecessary expenditure on maintenance, utilities and electricity bills.

Space decisions may also affect the wellness, performance and satisfaction of employees, clients and visitors that walk through the door.In this sense, occupancy information could provide data to systematically manage a space. Past researches have shown that for commercial buildings, the average occupancy level only consist of one-third of its highest design for occupancy [2][3]. This implies that space of commercial buildings is not used efficiently to its maximum capacity. To this effect, occupancy detection method can be employed to strategically manage the space.

The following six features are the spatial–temporal properties that provide insight into comprehensive occupancy information that should be examined when designing and deciding the suitable occupancy detection method, to evaluate both space and energy utilisation in building [4][5]:

1. Presence:

Presence refers to recording the existence of an occupant - when does the occupant enters a particular building or area. A presence is indicated as long as the occupant stays inside. It may as well show when the occupant leaves the area.

2. Location:

Location refers to finding out where or which area the occupant enters. It would be beneficent to coordinate and divide the property into certain areas or zones. For example, information on occupant's location would help coordinate lighting system to save electrical usage. By identifying the occupant's location, lighting can operate when occupant's presence is detected in a designated area and turn off when he is absent.

3. Count:

Counting feature refers to the information on the number of occupant present in a particular area or zone. It also refers to recording the changes of occupancy level throughout the working hours. For instance, the heating and cooling level in the HVAC system can be adjusted depending on the total number of people present in a room. Overall, this information can also be used to analyse the occupancy pattern and behaviour.

4. Activity:

Activity refers to identifying what kind of activity the occupant is doing. Occupant's activity can be classified according to a variety of factors. First, by specifying the purpose of the room used for, for example meeting room, conference room or fitness centre. Second, by installing sensor at the desk of the employee to identify whether the occupant is present at the desk or not. Third, by categorising light activity from heavy activity, for instance, measuring the production of carbon dioxide level inside an indoor area [6].

5. Identity:

Identification refers to finding out who is present in the particular area. Although it is commonly used for security, it has been customised in smart environment for indoor surrounding comfort (temperature) according to personal preferences.

6. Tracking:

Tracking feature provides information on occupants' movement history across different areas in the building space. Tracking information is essential in the design of proactive comfort systems with the understanding of occupancy behaviour.

3. SPACE UTILISATION AND A TAXONOMY OF SENSOR TYPES

Multi-dimension analytics of built infrastructure can provide a robust and resilient tool for space use management. The emerging technologies in sensor-based data collection and data management can be explored to facilitate smarter decision making based on gathered information for built environments. Ultimately, this can help increase efficient use of space and reduce costs. A taxonomy of type of sensors that can be used for occupancy detections is provided in Table 1.

3.1Terminal and non-terminal methods

The approach to occupancy detection methods can be classified according to the use of terminal to keep track of the occupants. As such, occupancy detection systems are categorised into terminal-based method and non-terminal-based method [7]. For terminal-based methods, the occupants are required to carry a sensor or device. Technologies such as Radio Frequency Identification (RFID), Wireless fidelity (WiFi) and Bluetooth Low Energy (BLE) technology identify the occupants' presence by detecting the carried devices.

Table 1: A Taxonomy of Sensor Type and their Spatial-Temporal Properties[5][8]

Type	Sensors	Spatial–temporal properties					
		Presence	Location	Count	Activity	Identity	Tracking
Terminal	RFID	Yes	Yes	Yes	Yes	Yes	Yes
	WiFi	Yes	Yes	Yes	No	Partially Yes	Yes
	BLE	Yes	Yes	Yes	No	No	Yes
Non-Terminal	CO_2 sensors	Yes	Yes	Yes	Yes	No	No
	PIR sensors	Yes	Yes	No	No	No	No
	Ultrasonic sensors	Yes	Yes	No	No	No	No
	Image sensors	Yes	Yes	Yes	Yes	Yes	Yes
	Sound sensors	Yes	Yes	No	No	No	No
	Power meters	Yes	Yes	No	Yes	No	No
	Computer App.	Yes	Yes	Yes	Yes	Yes	No
Terminal and Non-Terminal	Sensor fusion	Yes	Yes	Yes	Yes	Yes	Yes

On the contrary, non-terminal-based methods adopts a passive approach to occupancy information without the need for the occupants to wear or carry any sensing devices. Such detection technologies include carbon dioxide (CO_2), Passive Infrared (PIR), Ultrasonic, sound detection, image detection, and power meters.

Table 1 lists the existing sensors available in the market according to the methods used in occupancy detection system; terminal-based and non-terminal based methods. The characteristics of the sensors are briefly described as follows:

3.1.1 Terminal-based methods

These methods use terminals such as Radio Frequency Identification (RFID), Wireless fidelity (WiFi) and Bluetooth Low Energy (BLE) technology carried by occupants to obtain occupancy information.

i. Radio frequency identification tags (RFID)

RFID-based system mainly comprises of the transmitter, receiver, transponder and antenna. There are two different methods which can be applied, known as active and passive modes. For active mode, an active RFID tag equipped with antenna, battery and unique identification is carried by the occupant. The RFID tag will be sensed by location sensors and information about occupant's presence and location are transmitted to the central server every interval time [9]. In addition, occupancy density and profiling can also be recorded.

On the contrary, RFID tag in passive RFID is not equipped with any power source. Hence, it cannot send data information to location sensors continuously[10]. Passive RFID, combined with PIR sensor, are commonly used in lighting control system [11]. RFID systems, however, raise privacy issues as occupants have to carry the RFID tags [12].

ii. Wireless fidelity (WiFi)

The wide availability of existing WiFi infrastructure in indoor environments makes it a good candidate for occupancy estimation and detection. Moreover, smartphones are widely accessible and mostly owned by occupants. The number of smartphones can indicate the number of occupants in a given space. The devices which are wirelessly connected to the access point in the building will be detected and provide occupancy information [13][14].

iii. Bluetooth Low Energy (BLE)

BLE technology is recently preferred by researchers for terminal-based occupancy detection. Among the merits of using this method are high resolution output in obtaining occupancy information, reduced probability of getting false-positive rates and the wide availability of Bluetooth enabled smartphone. BLE technology comprises of BLE beacon and Bluetooth device. BLE beacon acts like access point which is able to identify the Bluetooth enabled smartphone with precise localisation especially in densely populated area where a lot of WiFi enabled devices are present. The beacons will then send the information to the central server [8].

3.1.2 Non-terminal-based methods

These methodsutilisediverse detection technologies such as carbon dioxide (CO_2), Passive Infrared (PIR), Ultrasonic, sound detection, image detection, and power meters to obtain occupancy information.

i. CO_2 sensors

Using CO_2 sensors, measurement of CO_2 level can be utilised in detecting occupancy level in buildings. In this case, CO_2 level is used as an indicator of occupant's presence. CO_2 has been found to have a direct correlation with occupancy because human continuously exhale CO_2[15][5]. In essence, a large group of people in an area will have higher reading of CO_2 than a small group. This can be used for estimation of occupancy. Nevertheless, the limitation of this method is its inability to count the occupancy accurately.

ii. Passive Infrared (PIR) sensors

PIR sensors can detect occupants' presence and location. They do so by detecting the heat emitted by the occupants within its view range. Any human movement will create a change of infrared energy in the view field area and detected as presence as well as his location. However, PIR sensors have a number of limitations: i) it cannot count the number of occupant because the output is binary and ii) it cannot detect a still occupant because it requires continuous movement of heat energy [5].

iii. Ultrasonic sensors

Ultrasonic is an active device which consist of a transmitter and a receiver. The transmitter emits ultrasonic wave which bounces back when it hits an object. The time taken for bounce back represents distance of the object from the sensor. Occupancy is detected when the distance is lower than the threshold value. Through this method, occupants' presence and location can be determined.

iv. Image sensors

The merit of using image sensors is that it can provide wide range of occupancy information on presence, location, count, identity and activity. Subject to the image information intended, image sensors can be classified into two types: i) non-depth cameras and ii) depth cameras. Non-depth cameras such as surveillance camera provide occupancy information either with RGB frames or infrared images. On the other hand, the depth cameras such as time of flight (TOF) cameras provide both RGB frames and depth information. Depth information is obtained by calculating the distance of object from camera which is represented by depth image pixel value [16][17].

v. Sound sensors

Sound detection systems has been experimented as one of the methods to detect occupancy. By using microphone, audible sound waves captured can be measured to indicate occupancy presence. The concept is built on the fact that an array of sound waves is produced by the occupants, hence, it provides information on the presence and location of the occupants.

vi. Power meters

Power meter are used in occupancy detection based on the principle of direct correlation between energy consumption and occupancy [18][15]. High energy consumption may indicate high occupancy level and vice versa. However, the downside of this method is its inability to measure occupancy accurately because the energy consumption may be contributed by other factors such as energy emitted from other sources, for instance from the use of HVAC system without surveillance and monitoring.

vii. Computer application or activity

Computer usage and activity can be used to obtain occupancy information with respect to occupants' presence, location, count, activity and identity. This method takes advantage of the significant time occupants spent on them in buildings (e.g. office). By monitoring the Internet Protocol (IP) and Media Access Control (MAC) addresses in Wi-Fi access points and in the routers, we are able to gather information on occupant presence and location [19][5]. On the same note, occupants activity and presence can be detected through sound by installing acoustic sensor near keyboard and mouse[20].

3.1.3 Sensor fusion

This method adopts combination of either terminal and non-terminal-based methods, or terminal and terminal based methods, or non-terminal and non-terminal based methods. Fusion of multiple sensors offers a solution to overcome limitation of individual detection method. The combination works in a way that each individual detection method benefits from the strength of other detection method in the fused system and at the same time trivialises each other's drawback. Some study suggest that fusion of detection method may influence the costs involved in installation and operation [8].

4. ENERGY UTILISATION AND OCCUPANCY

Energy utilisation refers to the amount of energy being used in a building. Studies have found that energy performance of a building is significantly impacted by the human factor. The energy usage of buildings is mostly dominated by the occupancy and related activities [21]. Accordingly, information on human dimension and activities are central in managing energy use [22]. Past studies have shown that there is a significant correlation between energy usage and occupancy level [18][15]. In a study conducted by Martani et al.[18] in a university environment, it was found that the occupancy rate has a significant correlation with the overall amount of electricity used. The occupancy accounted for 63% and 69% of variation in electricity consumption for two buildings respectively.

Similarly, findings by Assimakopoulous et al. [15] also show that occupancy is significantly correlated with energy utilisation. In the study, three rooms with different purposes; a lecture theatre, a computer room and an executive office were chosen to identify whether the number of occupants affects the examined variables. In the lecture theatre, it was found that energy consumption increases with the increase number of occupants. In another room (the computer room), it was found that energy consumption rises at the same time as the CO_2 concentration increases. In this case, the concentration of CO_2 was used as an indicator of occupancy level inside the room. Occupancy rate influences energy values mainly due to the electric load produced by the computers.

The strong correlation between energy consumption and occupancy level implies the importance of occupancy detection as one of the solutions to control energy usage and achieving efficient use of energy.In 2017, the Malaysia Energy Commission [23] reported that the commercial sector recorded an electricity consumption of 43,724 GWh (30%) while the residential sectors recorded an electricity consumption of 30,340 GWh (21%) out of the total electricity consumption of 146,524 GWh. Commercial buildings usually consume more electricity than residential buildings due to having many floors, office space, high occupancies, and long hours of occupancy usage. Energy is used for a variety of purpose which include space heating, air conditioning, lighting, refrigeration, electronics, cooking, and water heating [24]. Out of these, lighting system and heat, ventilation and air conditioning (HVAC) system are considered the primary usage with estimated of 70% from the total usage [5].

Taking in light the human factor, occupancy information is therefore crucial to assess energy consumption. Studies in the past have suggested that occupancy information helps save approximately 10% to 40% of energy consumption. For instance, the information on the number of occupant can be utilised to reduce the electricity use, either by turning off the lighting system during non-occupied hours or by adjusting the opening rate of HVAC according to the temperature in the building [16]. The electricity consumption in the commercial sector is expected to increase in the upcoming years due to the increase of world population, expanding economy, urban migration and improved quality of life. In this regard, occupancy detection provides a solution to sustainability issue by saving energy, environment and cost.

4.1 Heating, Ventilating and Air-Conditioning (HVAC) and Occupancy

The total energy consumption of a building is mainly contributed by Heating, Ventilating and Air-Conditioning (HVAC) and lighting systems [25]. Generally, HVAC system operates in a fixed schedule and based on maximum occupancy assumption. Fixed schedule is typically from 7 am to 7 pm or 12 hours of operation with operation performance is set to maximum occupancy mode. Regardless of whether the building is fully occupied or partially occupied. In addition, a study made on an actual building occupancy shows that average occupancy only represents one third of the design occupancy, even at peak time.

In an environment where the occupancy information is gathered in real-time, the HVAC systems would be able to operate with flexibility and adjustability, in response to any changes that occur within the space building. The HVAC would operate in shorter period throughout the day as to operate 12 hours continuously. As a result, the energy consumption would be lower in theory. An accurate occupancy-sensing data would provide crucial input for a real time adaptive HVAC control scheme correlating to the exact number of occupants in a building over a time period [21].

As HVAC accounts for the majority of the total energy consumption, utilising occupancy-based controls would help achieve significant energy savings by temporally matching the building energy consumption and building usage. This has the potential to reduce up to a third of HVAC energy consumption. Moreover, accurate and reliable occupancy detection is becoming a key enabler for demand-response HVAC control, which requires the capturing of occupancy changes in real time [26].In addition to management of energy use, good indoor air quality is necessary to maintain employees' health and productivity at an optimum level. According to different climate regions and seasons, the comfort needs may differ and changes throughout the year. The occupancy numbers may change within hours in a day depending on the working schedule or events conducted.

The following are some suggestions on demand-driven HVAC operation techniques which could be implemented to optimize the HVAC system after the occupancy information have been obtained, thus achieving energy savings [27]:

i. Setting a higher temperature in any unoccupied area.
ii. Setting a lower ventilation rates in any unoccupied area.
iii. Supplying the airflow based on occupancy detection.
iv. Adjusting outside air volume based on occupancy level.
v. Capable to quickly respond to the fast-changing heat loads with acceptable time taken.
vi. Able to operate the HVAC system in according to the occupant desired set point.
vii. Learning the energy consumption patterns.
viii. Increasing the flexibility of control.

Table 2 provides a survey on past researches done related to the HVAC system based on occupancy detection in balancing energy usage and comfort level. The different approaches carried out by the studies to control HVAC system using occupancy detention are categorised as follows:

i. Presence (Imaging sensor)

Roselyn et al.[28]in their study used camera and thermal sensor to detect the occupancy presence accurately and used the information to control the lighting and fan on/off automatically. An image processing and a thermal sensor algorithm was proposed. The study was done for an interval period of eight days to examine the result of before and after implementation of occupancy detection algorithm. The finding shows a decrease of 30.52 % from the total energy consumption that include the electrical appliances. A month of using the algorithm has resulted in 46% decrease of energy use and could save up to 25kWh per month.Diraco et al.[29] developed an occupancy detection method based purely on depth data using 3D camera (Kinect and SR4000). The privacy preservation is better when using 3D camera compared to traditional camera. The experimental results show an accurate count and localisation in a crowded situation.

Zou et al.[30] has proposed a video-based occupancy detection algorithm that detects the head accurately. This detection can be done both off-line and online by analysing the surveillance video. The algorithm had been tested on an 80-hour surveillance data in an office. The results show an accuracy of 95.3% with a processing speed of 721ms which allow for real-time application. For future study, the authors suggested the need to test this algorithm in HVAC and lighting control systems and compare the energy consumption.

ii. Presence (PIR sensor)

Susnea et al.[31] has proposed a solution of generating a variable reference values for the thermostat using artificial neural network (ANN) rather than switching the HVAC on and off instantly. It used a degree of occupancy concept generated from both PIR sensors and capacitor which activate the system gradually after some time.

iii. Location and Tracking

Capozzoli et al.[32] proposed and experimented an energy saving using data analytics to control the HVAC system. The case study was undertaken for a period of four months in Zanstand Town Hall, Netherland. Flex where system was used to track the occupancy pattern in the multi-zone building. Accordingly, for pattern recognition, CART algorithm was used. The result of controlling the HVAC system has shown approximately 20MWh (14%) of saving compared to scheduled operation.

Table 2: Papers and Journals on HVAC system

Reference /year	Findings/benefits	Detailed devices	Algorithm or technique	Energy saving	Duration/ location of study
[28] (2017)	The image processing algorithm proposed is able to detect stationary and moving people effectively.	PIR sensor and Camera	Image processing algorithm Thermal sensor algorithm Background subtraction and Regions of Image (ROI) based segregation models.	A decrease of electricity consumption of 30.52% was reported and can save 25kWh a month.	Eight days
[32] (2017)	HVAC occupancy-based system was introduced and implemented. This replaced the fixed schedule type in the three thermal zones, with studying the occupancy pattern. This method could save 27hours of HVAC operation in a week.	Flexwhere system (to track occupancy pattern)	CART algorithm	There was about 20 MWh (14%) of decrease in electricity usage. The optimised schedule shown to reduce the electricity use of the HVAC system during the monitored periods by about 20 MWh (14%).	Four months Zaanstad Town Hall, Netherland
[29] (2015)	A 3D depth camera has advantages compared to normal camera such as does not reveal the person identity.	In-depth camera (MESA SR4000 and Kinect camera)	Gaussian average background model, Linkage agglomerative clustering and Real AdaBoost classifier EnergyPlus simulation software	An energy saving of 28% has been reported when compared to a fixed schedule (using simulation method).	Four months Institute for Microelectronics and Microsystems of the Italian National Research Council located in Lecce, Italy
[33] (2020)	The occupancy information-based control algorithm and adaptive control can reduce the energy usage effectively without affecting the occupancy comfort.	Simulation based	EnergyPlus simulation software	Depending on the location of city, adaptive control can save up to 54% of energy consumption, and the occupancy information can add additional energy saving impact by 20%.	Two-story single house models in five USA cities to simulate a diverse climate zone (simulation).
[30] (2017)	The results show that the accuracy of using the algorithm in real time occupancy measurement is 95.3% (for head presence) and the computational time taken for a measurement is 721 ms. Able to use in off-line by extract data from videos and also on-line occupancy detection.	Surveillance camera	Head detection and occupancy measurement algorithm	Not reported	80 hours surveillance videos

4.2. Lighting and Occupancy

Energy consumed by the lighting system is dependent on building's features and functions, and human activities. This is due to the fact that energy consumption is determined by the illuminance of the lighting and the usage's interval of time. Though human activities affect illuminance, the level of occupancy does not seem to.

A study by Assimakopoulous et al. [15] suggests that illumination does not correlate with occupancy level. One of the observations made was that a large number of occupants may be in a relatively shady environment during a lecture whilst at other times, a small number of occupants may turn on all the lights due to circumstances such as examination periods or studying. This indicates that illumination may not necessarily be affected by the occupancy level. Hence, illumination is mainly influenced by the building's characteristics and human activities.

4.2.1. Sensing-based lighting control

While illumination does not correlate with occupancy level, occupancy detection method can be used to control the lighting system via sensor. Because illumination is influenced by human activities, adopting sensing-based lighting control system can reduce energy consumption. Several types of sensing system are used for lighting system which include Passive Infrared (PIR), ultrasonic sensors, Radio Frequency Identification (RFID) and video imaging [34].

Figure 1 shows the classification of sensing control scheme for controlling the lighting system. There are two ways of controlling the lighting system which are illuminance based and occupancy based. The control scheme for both illuminance and occupancy can be further classified into two techniques: switching and dimming. These executions will be performed by the controllers through input from light and occupancy sensor.

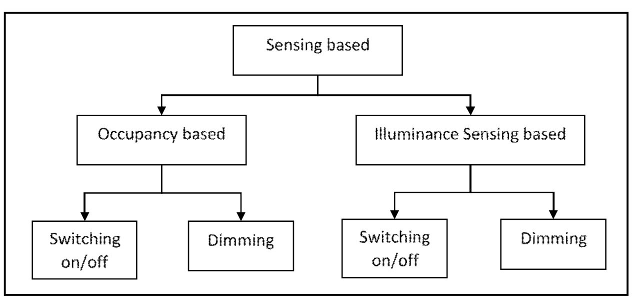

Figure 1:Control scheme of Sensing based lighting system

Illuminance based is also known as daylight adaptation which allow the dimming level to be adjusted automatically either by reducing the illuminance when the daylight is sufficient enough to accommodate the indoor illuminance, or increasing the illuminance when the outdoor turns dark. Daylighting is allowing the daylight to luminate the indoor space through windows during daytime rather than depending solely on artificial light thus saving the energy. On the other hand, occupancy based detect the presence of occupants through various types of sensor and automatically switching on/off or change the dimming level.

In addition to occupant's activities, another factor that should be considered in employing the lighting control system is the placement of the sensor. In this regard, three sensor placement parameters need to be considered: (i) field of view (FoV), (ii) number and (iii) position. The FoV of each sensor cannot overlap between each other in order to reduce installation cost with the sensors quantity [35].Hence, strategically, the occupancy behaviour pattern and placement of the sensor should be studied well at the design stage before implementing the lighting control system in the building. This way the optimum balance between energy saving and user satisfaction can be achieved [34]. Unnecessary costs of installing the lighting control system can also be avoided.

Table 3.0 summarizes past researches related to the lighting system based on occupancy detection with the objective to achieve energy saving. Literatures from the last five years are chosen to assess the most recent approaches and methods adopted. All the studies employ Wireless Sensor network. Some of the sensor technologies used are PIR, WiFi-based and light sensor. Studies[36], [37] and[38] are experiment based while studies[39] and[40]are simulations. Despite being motivated by different objectives, the studies in common adopt the following methods of occupancy-based and illuminance-based control strategies:

i. WiFi based sensor

Zou et al.[36] proposed a centralised occupancy based lighting control system by using WiFi system for occupancy detection. This allow for zones control by adjusting the brightness of lights automatically in real time based on the occupancy information gathered. The WiFi based occupancy detection is provided by WinOSS [41] which utilise the existing WiFi infrastructure and mobile devices carried by the occupants. Each light has a local controller that adjust the brightness when instructed by the central control. A 24 weeks study was done in a multi-functional office building in Singapore using the proposed method. It was reported that an energy saving of 93.09% and 80.27% was achieved compared to static scheduling control method.

ii. Motion sensor

Labeodan et al.[37] reported an in-depth experimental study of using wireless sensors and actuators network (WSAN), PIR sensor and chair sensors [42] for occupancy driven lighting control. The experiment was done on 2-storey office building in Netherland for a duration of three weeks. An average of 24% of energy saving from electrical consumption was recorded at the end of the study.

Table 3: Papers and Journals on Lighting system

Reference /year	Findings/benefits	Detailed devices	Algorithm or technique	Energy saving	Duration/ location of study
[36] (2018)	Proposed a lighting control system which can adjust the brightness of light in real time with the non-intrusive occupancy detection called WinLight. It used the existing Wi-Fi infrastructure.	Wi-Fi based	Lighting control algorithm	This method reduce the energy usage by 93.09% and 80.27% compared to a fixed scheduled lighting control system and PIR	A multi-functional office located in Singapore and experiment carried out in 24 weeks
[37] (2016)	A lighting control system with wireless sensors network and actuators network was implemented.	PIR sensors and chair sensors	Z-wave sensors and gateway.	About 24% of average energy usage reduction was reported.	Conducted at a two-storey building in Netherland for two weeks
[38] (2015)	An LED lighting control system by controlling the brightness in respond to user luminosity preference has been proposed	Motion sensor and light sensor	Zigbee radio	About 55% of energy saving was achieved	Conducted at VerdeLED company office for six months
[39] (2015)	An enhanced PI control law has been introduced to mitigate the packet loss problem occupancy and daylight adaptation	Motion sensor and light sensor	Simulation tool DIALux and TrueTime	Not reported	Open plan office model (simulation)
[40] (2015)	A Personal lighting control system and simulations on an open plan office lighting model occupancy and daylight adaptation	Motion sensor and light sensor	Simulation Tool DIALux	About 20 to 43 % of energy saving achieved.	Open plan office model (simulation)

Magno et al.[38] proposed a method of reducing the lighting energy consumption by controlling the brightness of LED lights panel according to user luminosity preference. This method used motion sensors to detect any occupancy and light sensors to monitor the luminosity of the LED light panel in the specified area. The wireless sensor network is based on Zigbee communication which connects all sensor nodes (motion and light sensor) and LED drivers (controlling the brightness) to the main host device. A six-month experiment was done in an office building and the result showed a reduction of 55% in power consumption.

iii. Daylight and occupancy adaptation

Peruffo et al.[39] has proposed a method of wireless lighting control through occupancy and daylight adaptation. This system consists of a standalone PI control law located in the central controller and multiple luminaire which individually contain light sensor and occupancy sensor. The PI control law has been enhanced to mitigate the packet loss problem which could lead to an increase in luminaires settling time. The proposed method was tested using two simulation tools; DIALux to create a lighting model of open plan office and TrueTime to test the network lighting control system. The results of simulation were presented. The analysis done include the packet loss probability effect on settling time, overshoot during occupancy change and load network.

Rossi et al.[40] proposed a personal lighting control system and simulations on an open plan office. This concept allows user to fine tune control the illuminance based on the light sensor feedback. It also allows to personalise the preferred illuminance on the user's occupied area without affecting other area. The controller could then set the optimal dimming levels of each luminaire. It is based on daylight and occupancy adaptation in which each luminaire has occupancy sensor and light sensor similar to [39]. The performance of proposed control algorithm was assessed through simulation DIALux. The result showed energy saving recorded from fine tune controlled dimming level compared to a fixed dimming level.

5. CONCLUSION

Studies from the past have evidently shown that occupancy has a fundamental role in space and energy utilisation of building. There is significant correlation between occupancy level and both energy utilisation and space utilisation. In this respect, occupancy information is crucial as it provides the data needed to systematically manage the use of space and energy in a building to ensure the optimum balance between efficient performance of space and energy with occupant's need and satisfaction. Occupancy information comprises of six features of spatial–temporal properties which include presence, location, number of occupants, activity, identity and tracking movement. To gather occupancy information, various occupancy detection methods have been explored by past studies. The research technique depends on the variables intended to be examined; either space, HVAC or lighting. Each sensor has different capability of measuring spatial temporal properties. Hence, selecting the correct sensors is important to achieve the intended results. Most of the studies used fusion of many sensors to obtain accurate results. Another important aspect to be considered is the placement of the sensors. Data gathered in this paper and the taxonomy built are aimed to assist future studies on occupancy detection. Analysis on past researches, however, indicates that studies on the aspect of occupancy on space utilisation is limited. Hence, there is a need for future studies on the relation between space utilisation and occupancy detection. Conclusively, findings from the studies reviewed in this paper have collectively shown that employing occupancy detection results in space utilisation and comfort awareness, and energy saving.

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