The human behavior: a tracking system to follow the human occupancy
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Published in:
Proceedings of the International Conference on Cleantech for Smart Cities and Buildings (CISBAT 2013), 4-6 September 2013, Lausanne, Switzerland

Published: 01/01/2013

Document Version
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

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ABSTRACT

Various control strategies have been adopted to improve energy efficiency in commercial office buildings, particularly the alignment of energy consumption for space conditioning and lighting patterns with human occupancy. Considerable uncertainty however exists in these patterns but advancement in information and communication technology (ICT) has made it possible to reduce these uncertainties. More fine-grained building occupants information can now be gotten in real-time for dynamic demand-driven space lighting and conditioning controls. In this paper the performance of one of such technologies; radio frequency identification (RFID) system is accessed in the determination of human occupancy and location from experiments carried out in a typical office building in the Netherlands. The correlation between energy use by office appliance and human occupancy was also investigated. Furthermore, steps that could be taken to improve energy consumption for comfort through a demand-driven process control strategy are identified.

Keywords: RFID, energy, occupancy

INTRODUCTION

Energy consumption for space conditioning and lighting loads (L-HVAC- Light, Heat, Ventilation and Air Conditioning) together account for 70% of all energy consumed in a typical office building[1]. Current building energy management systems (BEMS) used in commercial office buildings typically operate control settings dictated according to assumed schedules that are disconnected from actual space occupancy[2][3]. Human presence and behaviour in buildings have been shown to have significant impact on space heating, cooling, ventilation, lighting, appliances, and building controls[5], however human occupancy information was not until very recently considered in buildings energy performance analysis[4].

Human occupancy is stochastic in nature and as shown in Fig.1 above has both passive and active effect on a buildings energy use. Passive actions, the mere presence of occupant(s) in a building affects energy consumption but is dependent on activity, number of occupants and internal gains[5]. In the same vein, active actions of occupant(s), operation of windows, shades and radiators also have significant effects on a buildings energy consumption [6]. A variety of models have been developed from technologies such as neural network, fuzzy-logic, markov chain and direct logical inference from sensor data[7] for scheduling occupancy...
in BEMS. Considerable uncertainty does however exist in these models[6]. Building occupancy is difficult to simply infer solely from building function and type as there are high tendencies for a buildings usage to change with time and occupants might over time display varying patterns of presence thus automatically altering the predicted occupancy model [6][8]. Advancement in ICT has however made it possible to reduce these uncertainties. More fine-grained real-time building occupancy information can now be ubiquitously obtained and connected to the BEMS for demand-driven control hence improving energy efficiency. In subsequent sections of this paper, we present results from experiments conducted in a typical office building in the Netherlands using one of such technologies; RFID to obtain real-time human occupancy information and correlation between energy use by appliance.

BACKGROUND

Occupancy detection systems in general can be classified based on the measurement technology as; motion detection systems, CO\textsubscript{2} detection systems, visible light detection systems, acoustic detection systems, radio frequency detection systems. Alternatively, classification based on functions and methods can also be made as shown in Table 1.

\textbf{Table 1:Occupancy Detection Systems}

<table>
<thead>
<tr>
<th>Measurement Technology</th>
<th>SENSOR</th>
<th>Function</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Individuализed</td>
<td>Non Individuализed</td>
</tr>
<tr>
<td>Motion[10,12]</td>
<td>PIR, ultrasonic</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2} [11]</td>
<td>NDIR</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Acoustics[10]</td>
<td>Microphone</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>RF signals[11,14,15,16]</td>
<td>WLAN, RFID, GPS, UWB, Ultrasonic</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Pyroelectric infrared (PIR) and ultrasonic motion sensors as stand-alone and hybrid nodes are widely used in buildings for occupancy detection [9], particularly for control of lighting systems, while this technology has the inherent advantage of non-terminal based methods, extendibility, non-intrusiveness, easy deployment and cost [10], it gives only binary information and stationary occupants are often not detected [11]. CO\textsubscript{2} detection systems however provides better but indirect measure of actual occupancy, it is often used in combination with PIR and acoustic Sensors [12]. CO\textsubscript{2} sensors have a slow response time, are also influenced by other surrounding physical phenomena such as outdoor air quality and ventilation rate [11]. Though advancement in wireless sensor network (WSN) technologies has extended the range as well as usability of the above mentioned detection systems in various environment mostly residential [10][7], it is still difficult to implement individualized functions capable of identifying and providing coordinates for multiple occupants which is the norm in office buildings [11].

Vision based detection systems are capable of both individualized and non-individualized functions [13]. Though capable of detecting multiple occupants, privacy, difficulty in providing occupants coordinates information and computational complexity are limitations that however prevents its wide implementation [11].

Radio Frequency (RF) systems (WLAN, UWB, indoor GPS, RFID, GSM) on the other hand are able to provide occupants coordinates to a higher degree of accuracy than all other detection systems by using tags with appropriate receivers/tags from which the location of tagged users can be conceptually determined and continuously tracked through a number of nodes (access points, receivers, readers, etc.) deployed at fixed positions indoors and
connected to a central processor/server [14]. In choosing the appropriate RF measurement technology, a number of selection criteria such as; cost of deployment, required accuracy, resource requirement, computational complexity, privacy, type of environment and effects on energy consumption have to be considered [15]. Wireless local area Networks (WLAN) systems have a very low infrastructure and deployment costs, but considerable high localization uncertainty [16]. Ultra-Wide Band (UWB) systems offer a good compromise with sub-meter tracking but considerable high deployment cost [14]. Indoor Global positioning systems (GPS) also have a very low position uncertainty however its deployment cost is high [14]. RFID systems however have intermediate deployment cost as well as moderate accuracy [11] hence its preference for use in this study.

<table>
<thead>
<tr>
<th>Table 2: Selection Criteria applied to indoor Localization (Adapted from 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Indoor GPS [14]</td>
</tr>
<tr>
<td>RFID [11]</td>
</tr>
<tr>
<td>WLAN [14]</td>
</tr>
<tr>
<td>UWB [14]</td>
</tr>
</tbody>
</table>

- ☒ - GOOD, ☒ - MODERATE, ☐ - FAIR, ☒ - POOR

**METHODOLOGY**

For real-time human occupancy detection, a wireless network comprising of RFID tags and readers with the following components; static nodes, mobile nodes, receiver and a (cloud) server for data collection were installed on the 3rd floor of the case study building. The RSSI technique embedded in active RFID technology was used in determining the coordinates of occupants from meshes created around the office floor. The case study office floor is made up of an open-plan flexible office setup with 29 workspaces, 5 cell offices, 3 meeting rooms and a lounge. The workspaces are separated by closed bookcases a common feature in most office buildings in the Netherlands. The floor has 11 thermal zones, 3 of which are in the open-plan workspace. In the meeting rooms, open-plan spaces and cell offices high efficiency artificial fluorescent lightings in reflective luminaires with no motion sensors are installed. The artificial lighting in the open-plan workspaces are centrally operated while that in the cell offices are locally operated. The lighting is turned on between 8AM and 8PM (12hours) during weekdays and the temperature in all thermal zones on the floor is maintained at 22°C (winter) with the ability to change the set point by ± 1.5 °C. For measurement of the electricity use by appliances, a power logger was installed at every desk and on other points of interest (printer, coffee machines). In total fifteen power loggers were installed for logging the active power of plugged appliances.

A total of 16* employees randomly selected and making up 80% of employees designated to work on the case study floor participated in the experiment.

**RESULTS**

**Floor Occupancy**

The mean floor occupancy for the duration of the experiment as shown in Fig. 2a was below 50% with the occupancy pattern varying each day of the week. Highest floor occupancy as shown in fig. 2b during working hours(7am-7pm) was recorded on Tuesday and the lowest was recorded on Thursday. Participants were at their workspace 64% of the time when present on the floor as shown in Fig. 3, 6% of the time at locations such as meeting rooms and printing areas while for the remaining 30% of the time participants were at other informal locations on the office floor.

*Though 18 employees participated, only data from 16 participants was used in this study*
Correlation between appliance use and human occupancy
Comparison between average occupancy profile and use of electrical appliances for the duration of the study revealed a strong correlation with a determination coefficient of 0.94 see Fig 4. On the workspace level, comprising mostly work appliances (personal computers) the correlation was weak see Fig 5.

It was observed that during lunch and coffee breaks, appliance energy usage on the workspace showed no significant change despite the absence of large percentage of participants from their workspaces at the time. This collaborates with the weak correlation between energy use by appliance and occupancy on the workspace level.
DISCUSSION
Presence Detection Accuracy
18 employees participated in this study through the complete duration. The accuracy of the RFID occupancy detection system was compared against the ground truth, times when participants registered presence at their workspaces during the course of the study. This was found to be 85% as against 100% in some other studies [11] in which user behaviour in the use of tags was not considered. Participants were randomly chosen to be tagged and no incentive was given for been tagged. There were therefore times in the course of the study that some participants were present on the floor but without tags. Also, faulty tags resulted in the exclusion of data from 2 participants. Though a representation of a typical Dutch office building, as no two workplaces as exactly the same [16], these results cannot be generalized for use in other office buildings [6].

CONCLUSION/FUTURE WORK
Opportunity to Improved Efficiency
It was one of the objectives of this study to identify opportunities to improve energy efficiency in the case study building, particularly in the use of HVAC and lighting systems for subsequent retrofitting. Being a typical office building, the HVAC and lighting systems are totally disconnected from human occupancy resulting in inefficient use of energy. The control strategy in use is dictated based on assumed occupied and unoccupied periods with no consideration for times during working hours when the floor is unoccupied. Most rooms on the floor were maintained at the same thermal comfort level despite no human occupancy during the duration of the study. Optimal use of daylight as shown from various studies [2] could also improve energy savings as against the current strategy which is based on assumed occupancy profiles.
The positive correlation between occupancy rate and electricity use on the floor presents the opportunity for worthwhile energy savings. Implementing control strategies dictated based on human presence in rooms on the building floor would significantly improve the buildings energy efficiency. At the moment further research is ongoing to implement a demand-driven multi-agent control strategy which would align HVAC and lighting systems use with occupancy.

ACKNOWLEDGEMENT
The employees of Royal Haskoning DHV B.V. Rotterdam Netherlands are gratefully acknowledged for their supporting through the duration of this study.
REFERENCES