Detecting and tracing building occupants to optimize process control

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ABSTRACT

.Occupant behaviour has been shown to have a large impact on the energy consumed in buildings than other thermal related process. For worthwhile energy savings, it is therefore crucial that occupant behaviour be included in the process control of building systems. For this set of control objective with the user central in the control of building systems, it is most important to detect the individual user on a specific workplace within a time span of minutes because the inertia of the building systems is in this order of his magnitude. The indoor occupancy detection system should be able to detect every individual in a spatial area and to be able to track and trace the person. Therefore an indoor occupancy detection and positioning system is being designed which, can communicate with a Building Energy Management System (BMS). The results of a first experiment are described in this paper.

Keywords; occupancy, HVAC control, user behavior, energy.

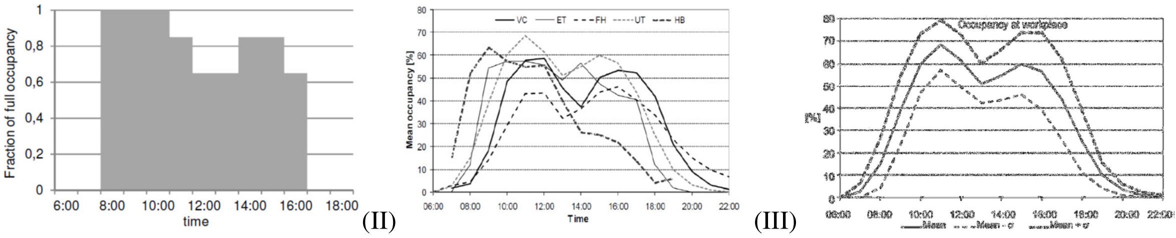
INRODUCTION

Energy consumption in commercial office buildings has been rapidly increasing in the last two decades, rising by about 70% between 1980 and 2005 in the US alone (IEA 2011). The energy consumption of the built environment is now around 40% of all energy used in the Netherlands. An intelligent electrical energy supply grid is being developed, i.e., the Smart Grid, to cope with fluctuations in energy generation from the different energy sources. Currently the focus of energy policy is towards diversification of energy supply (distributed energy resources (DER) and especially distributed generation (DG), and deployment of renewable energy (RES) within Smart Energy Systems (El Bakari et al. 2009). The possible interaction of decentralized renewable energy sources with the existing energy infrastructure of a building, the nanoGrid (Nordman 2009, Nordman 2011, Marnay et al. 2011), needs to be optimized. This leads to intensified intermittency of supply, resulting in challenging operational aspects. The objectives in uncertainty reduction in smart energy systems require novel system concepts in the control and management of Smart Energy Systems, which must include the essential connection to the user and its real behaviour.

To achieve improved overall energy efficiency it is necessary to better match energy demands and energy need in buildings. Therefore the process control of the energy infrastructure within the built environment, the so called micro grid, needs to become smart, intelligent and capable of adaptable behaviour in changing conditions. The sustainability demand leads to buildings which will use more and more renewable energy sources and will have energy storage capacity. Office buildings become a potential source of energy flexibility which can be offered to the grid as a Virtual Power Plant (VPP). In order to minimize uncertainty in the balance between energy supply and demand, it is necessary to develop realistic process control strategies based on real behaviour of user, installations, energy storage devices and grid interaction. Monitoring the needs and preferences of users is crucial to predict future states of the demand for the Smart Energy Systems (e.g. based on real human behaviour and energy needs). An automated adaptive process control is needed to optimize interaction between offices and Smart grid. Building Management Systems (BMS) could reduce the energy use within the micro grid by controlling the thermal indoor environment on the perceived comfort by the individual occupant in relation to the dynamic outside conditions like air temperature, solar radiation and wind. However the current BMS are limited in their ability to perform intelligently and show adaptive behaviour under changing circumstances. By the intended use of multi-agent technology in combination with state-of-the-art Building Management Systems, new possibilities occur. It will enable real time interaction between outside environment and indoor conditions, process control based on the behaviour of occupants as well as a nanoGrid strategy which aims for optimal interaction with the Smart Grid. According to Robinson et al (2011) one of the greatest sources of uncertainty in building simulation and in the real behaviour of buildings are the individual differences in presence and behaviour of building occupants. From another study byParijs et al (2011), the authors suggested using a range of values between 0.5 to 0.9 for the parameter of turn-up in applications of uncertainty analysis when no building specific data on the occupancy are available. Together with the uncertainties relating to occupants t control of shading devices, windows, artificial lighting, thermal environment and the use of electrical appliances, these actions combined increases the level of uncertainty. . The uncertainty introduced by occupants behaviour is undeniable (Burak Gunay et al 2014). More knowledge and insight about the real occupants behaviour is necessary to better predict the heat/cold flows in buildings as well as the electrical power demand of lights, appliances and HVAC equipment (Robinson et al. 2011). The focus of the project is on occupancy on workplace/floor level, this to be able to optimize the energy interchange with Smart Grid energy supply on building level based on the actual energy demand derived from the real user behaviour.

METHODOLOGY

Building occupancy information is a crucial factor that should be considered in the control strategy of building operations for improved energy efficiency and occupant comfort. Building systems generally operate according to fixed schedules and to assumed occupied and unoccupied periods of the day as in EN 15232 (e.g. 8 AM to 7 PM). They do not consider when buildings are partly occupied which could be of influence as occupancy in buildings varies from day to day and from time to time (2-4).



(I) (II) (III)

Figure 1 **(I)** Occupancy profile according to the standard EN 15232, modified from (EN 15232), **(II)** Mean occupancy level for a reference day. VC: International organization (Vienna); FH: University (Vienna); ET: Telecom. services (Eisenstadt); UT: Insurance (Vienna); HB: State government (Hartberg) (Mahdavi, 2008) **(III)** Mean occupancy level at workplace and standard deviation for an insurance office Vienna, for 14 months, 89 workplaces, modified from (Mahdavi, 2011)

To get a better understanding of the occupancy, Mahdavi extracted behavioural trends and patterns for groups of building occupants from long-term observational data from different buildings (Mahdavi et al., 2009). Figure 1 shows that there are considerable difference in the mean occupancy at workplaces for the different building types. Analysing further, from observations in an insurance office, see Fig. 1 (III) a standard deviation up to 15% is visible. Although these figures give a better representation of occupancy patterns in different office buildings. However, still a lot of information is missing, e.g.: Variation of occupancy from time to time; location of the people within the building and which individual is at what position in the building. To overcome the first two missing points, a more dynamic approach was presented by Wang et al (2005) which presents occupant presence by using so-called ‘’diversity profiles’’. The profiles depend on the type of building and sometimes even on the type of occupants. Wang et al., (2005) tried to understand, and predict the transient nature of occupancy during nominally occupied periods. Wang examined the statistical properties of occupancy in single person offices of a large office building in San Francisco. Fig. 2 shows the distribution of hourly occupied time as function of time of day.

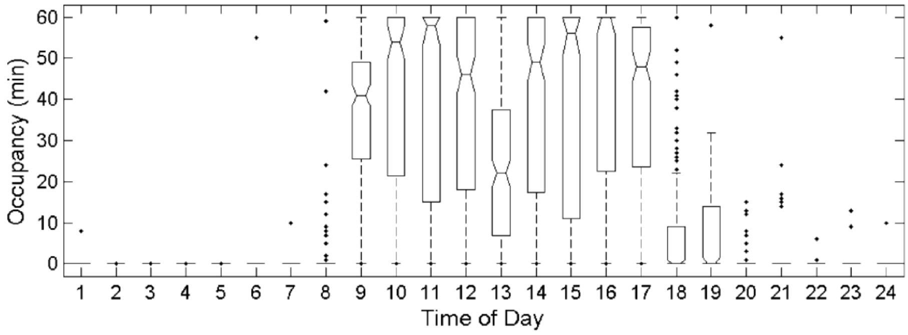


Figure 2 Distribution of hourly occupied time over 24-h of day for an office in San Francisco (Wang et al., 2005)

This figure indicates that from 8.00 to 17.00 h 75% of the workers are more than 25 minutes at their workplace hourly, except 12.00 to 13.00 h giving a more reliable vision on occupancy. Both the research of Wang (Wang et al., 2005) and Page (Page et al., 2008) looked at the probability of the vacancy interval. Fig. 3 and Fig. 4 show similarities, where the probability of short vacancy is the highest and lower for the longer vacancy intervals.

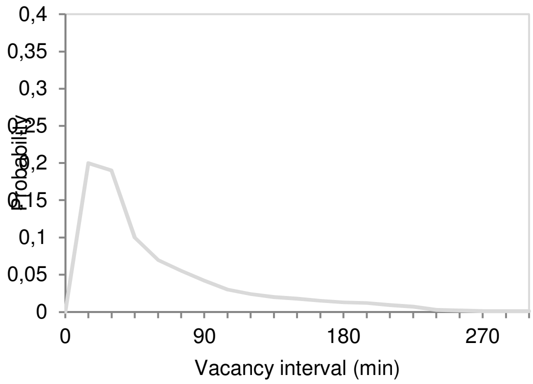


Figure 3 Probability distribution of the vacancy intervals for an office, modified from (Page et al., 2008)

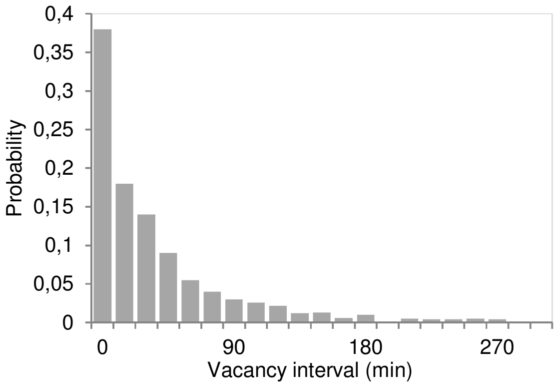


Figure 4 Probability distribution of the vacancy intervals for an office, modified from (Wang et al., 2005)

These probability functions can be used as input for building simulation models, and are better describe the deterministic occupancy behaviour of the individual building occupant. The weakness of probability profiles lies in the repetition of one or possibly two profiles and the fact that the resulting profile represents the behaviour of all the occupants of a building. “The latter simplification reduces the variety of patterns of occupancy particular to each person by replacing it with an averaged behaviour. The former simplification neglects the temporal variations, such as seasonal habits, differences in behaviour between weekdays (that appear in monitored data) and atypical behaviours (early departures from the zone, weeks of intense presence and of total absence, unpredicted presence on weekends in the case of office buildings—events that all appear in monitored data)” (Page et al., 2008).

Despite all effort, no current model is capable of describing the individual human position in buildings. This was also acknowledged by Mahdavi et al. (2009), who concluded that different researches tried to describe the human position and its actions by a model. From all the models he investigated it turned out that interactions with buildings’ environmental systems are difficult or even impossible to predict at the level of an individual person. User presence is a complete stochastic and random process, where even the next state of presence cannot be described by the previous. For optimal building operation, real-time information about the building user is needed. Dynamic control of building services systems in relation to actual building occupancy profile presents an opportunity for more efficient use of energy for improvement of occupants comfort. However, human occupancy information was not until recently considered in buildings energy performance analysis (Zeiler et al 2012). The use of real-time occupancy information has been shown by a number of studies (Khoury et al 2009, Dong et al 2010, Melfi et al 2011, Li et al 2012, Martani et al 2012, Erickson et al 2013), to have the potential to provide the worthwhile energy savings required to reduce the energy consumption of office buildings without compromising on occupant's thermal comfort needs.

EXPERIMENT WITH WSN AND RFID IN AN EXISTING BUILDING

Spartaru and Gauthier (2014) tested he performance of various technologies for monitoring people within buildings, systems which can help to asses potential energy reduction due to activity and occupancy and energy use. They found that each technology has intrinsic restrictions (Spartaru and Gauthier 2014). Based on our evaluation (Zeiler et al 2012) we applied RFID (Radio-frequency identification technology to incorporate human occupancy in demand driven HVAC control applications using a typical office building as a test-bed. (RFID) is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking The study focused on the use of RFID systems for a number of reasons: first, RFID systems are intrinsic devices commonly found in large office buildings in the form of identification cards and door/room access cards. Secondly, RFID technology can provide adequate accuracy; it is cost efficient; it does not require line of sight conditions and has the capability to incorporate additional functionalities such as building asset management (Li et al 2012).

Low-budget wireless sensor networks combined with portable nodes (RFIDs) are very promising technologies (Ruiz-Garcia et al 2009, Vishwakarma and Shukla 2013) and have the potential for real-time indoor localization for demand driven HVAC applications. Therefore static wireless sensor nodes were mounted on the floor and communicated with mobile nodes depicted in figure 5 (or in the future smart phones) carried by the occupant to determine the position of building occupants on workplace level. RFID system uses a number of active mobile tags worn by building users and multiple readers to triangulate the position of tags. The feasibility of this system in HVAC control in a large office building was explored by Li et al (2012) using battery powered RFID tags; mobile occupants were identified and tracked over a period of time. The collected data was used in calibrating an occupancy prediction model but the author showed it was possible to make use of the system for real-time localization for demand driven HVAC control.

Measurement set-up

A wireless sensor network (WSN) based on RFID technique was installed on the case study office floor of Royal Haskoning. Using the complete third floor of an office building with surface area of approximately 475m2, comprising two large open-plan office spaces and 6 cell offices, the possibility to incorporate RFID tags into the operation of the building were studied. The applied system RFID localization system has the following characteristics features:

- The static and mobile nodes are physically the same (Fig.5). The static nodes are programmed with a known location, and mounted on known spots of interest e.g. between the workplaces, nearby the printer, coffee machine and toilet;
- Mobile nodes are attached to occupants to denote occupants' locations, meanwhile the static nodes are deployed in the environment to provide references for location estimation with their own known locations;
- Based on signal strength from the surrounding static nodes, the mobile node takes over the location of the closest static node. The location is sent to the receiver which uploads the ID, time and location to the online cloud;
- This sensor network is a completely self-organizing WSN, meaning nodes need no configuration to form a network where nodes can freely enter and leave existing networks. Thereby the operation of the network never depends on particular topologies or on single nodes. The platform of the WSN is modular designed, meaning all other kind of different sensors and communication modules can be connected to the network.

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The wireless static nodes as depicted in Fig. 5 for position tracking of the occupants were placed at locations on the floor with high occupant flow and use pattern, such as workspaces, printers and coffee machine location.
In total eighteen employees wore a mobile node the six weeks duration of the experiment. The employees were randomly chosen and represent almost 80% of the building occupants working on the case study floor. The measurements on the case study floor only took place for a period of six weeks in winter period. Firstly this means that the obtained results may only be accounted to this measurement period and secondly they are only valid for this case study floor.. After the measured period the employees were asked with what accuracy they think the node worked well. Different reasons for dysfunction are empty battery; forget to wear the node; node seemed not to work; etc. The accuracy of the nodes was weighted to the time the employee said to be present during the measured period. The average weighted accuracy of the measurements is 85% over the period of 6 weeks. The accuracy was that low because two occupants had a node that was not functioning properly all the time during the experiment. Therefor these results had to be skipped out, leading to useable data for sixteen employees.

Figure 5. Floor plan with the measured grid in the case study office (orange), formed by 30 static nodes, Floor occupancy hotspots as factor of the most occupied spot during the measured period.

RESULTS

The mean floor occupancy for a period of 3 weeks for the tracked participants as shown in Fig.6 is below 50%. The occupancy patterns varies for each day of week. Fig. 7 shows the occupancy level between 7AM and 7PM, with the highest floor occupancy on Tuesday which is much lower than the designed and the lowest on Thursday.

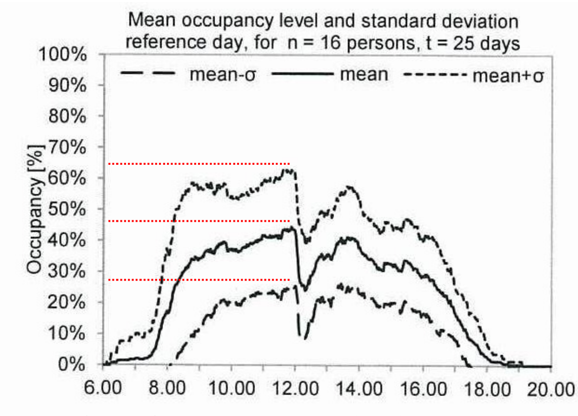

Figure 6. Mean occupancy level.

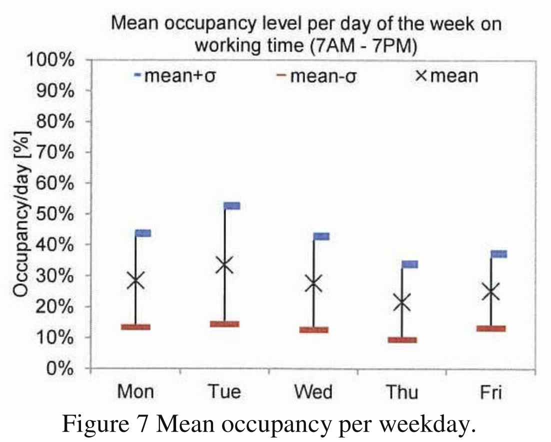

Figure 7 Mean occupancy per weekday.

Occupancy on workplace level

Since the interest is on the user, a closer look is made at the workplace level. Figure 8 shows the occupancy rate for four CAD workplaces in zone 22. Figure 9 shows the occupancy rate for four office workplaces in zone 20. A time step of 5 minutes is used.

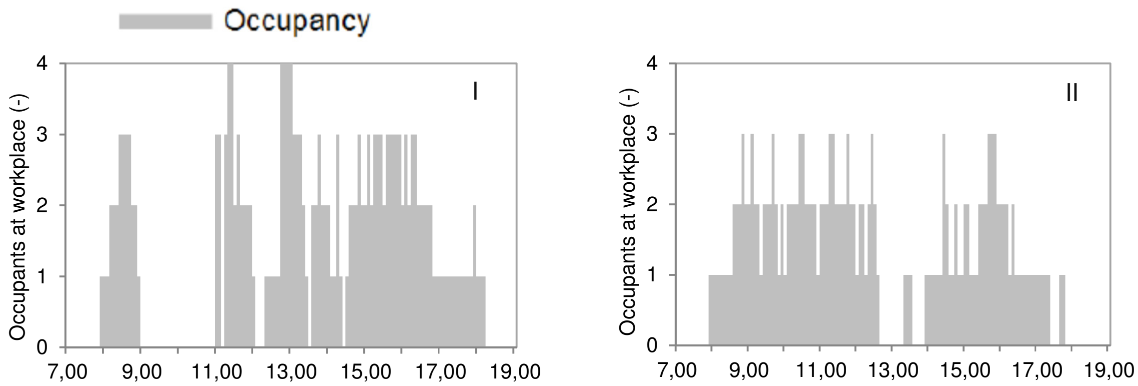

Figure 8 Occupancy of 4 CAD workplaces and electrical load, time step = 5 min, date I and II.

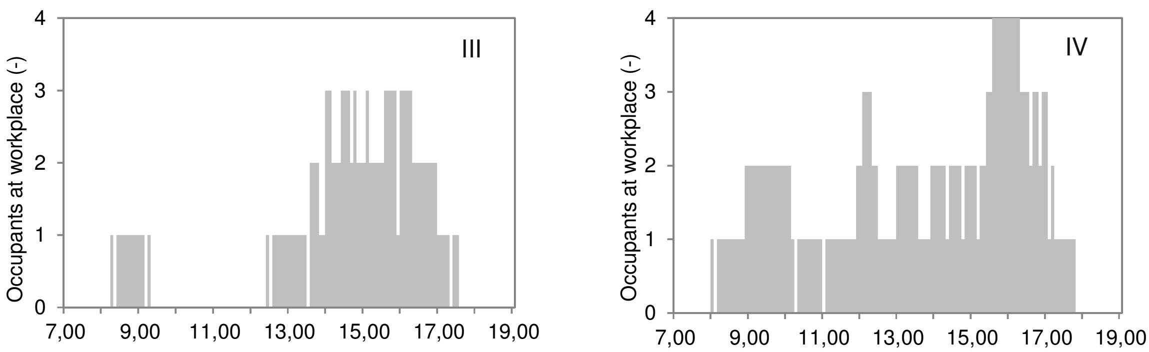

Figure 9 Occupancy of 4 office workplaces time step = 5 min, date III.and IV.

Modelling of the movement of occupants

Besides the level of occupancy we are also interested in the locations and movements of the occupants. The location of occupants can be represented within a timeline, see Fig. 10. Of more interest is to trace the movements of the occupants with the floor area, For a part of the floor, see Fig. 11 this was done. The movements of the occupant were drawn in the floor map to get a graphical representation of the movement. What is visible in Figure 12 and Figure 13 is that 13 of the 20 movements the user stays less than 10 minutes at his position. In these figures the lines

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of one person moving one day inside the building already gives a complex view.

Figure 10 Timeline with the position for a reference day of an occupant

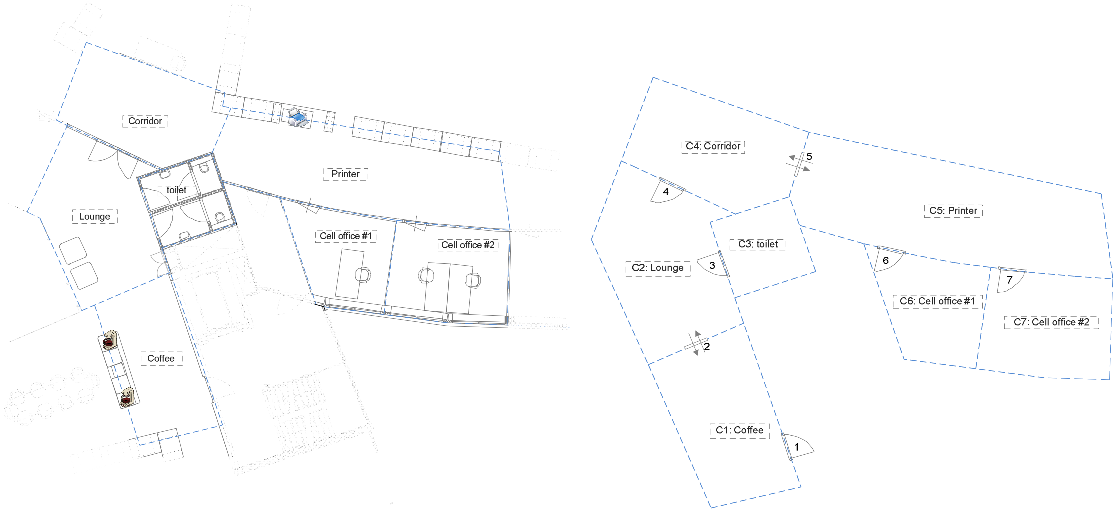
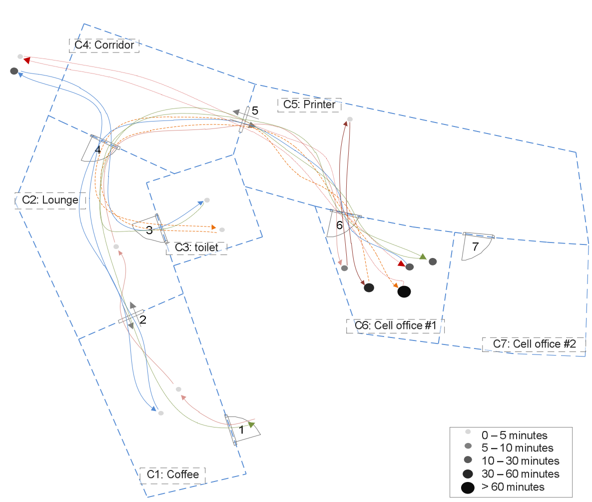


Figure 11 Part of the building model used for modeling, with the coffee machine, lounge, printer and toilet as special spots included in the model.



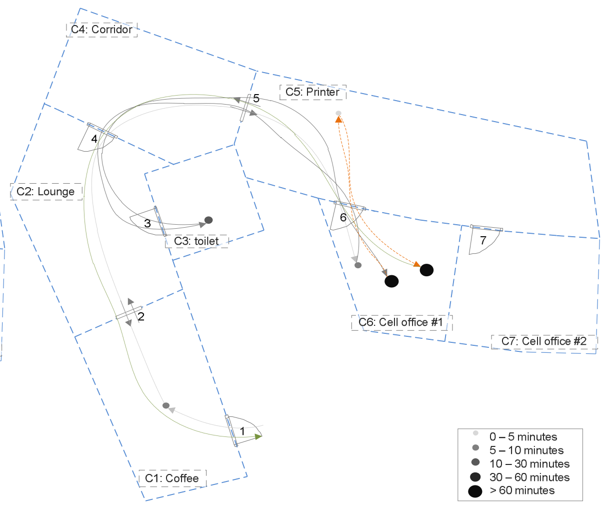


Figure 12 Movement over the floor before leaving the floor. Figure 13 Movement on the floor in the afternoon

DISCUSSION AND CONCLUSIONS

The measurements on the case study floor only took place for a period of six weeks in winter period. Firstly this means that the obtained results may only be accounted to this measurement period and secondly they are only valid for this case study floor. Mahdavi et al. (2009) already described that results from one building cannot be transposed without extensive calibration measures, considering differences in buildings use.

A number of implementation challenges were experienced during the study, besides the issue of privacy of the occupants, the most important being occupants adaption to the use of RFID technology. Occupants at some points forgot to make use of the tags, which equivocally affected the results obtained. The accuracy of the nodes was weighted to the time the employee said to be present during the measured period. The average weighted accuracy of the measurements is 85% over the period of 6 weeks. However, further experiments with the use of mobile phones and user identification cards equipped with localization capabilities are been planned for use in further studies. Benezeth et al (2011) proposed a vision-based system for occupancy detection based on video analysis, using a static camera. The total accuracy of counting the occupants found by Benezeth is 83%. So clearly our new approach is within the same level of accuracy.

Real-time measurement of actual building occupancy was shown through this experiment to represent a fraction of the standard occupancy profile. Despite the sparse and partial floor occupancy, the installed HVAC system remained operational at full capacity resulting in inefficient use of energy, so there is a potential for energy demand reduction.

Our experiment showed that it is possible to locate the user position, which in principle enables to apply energy to the spots where there is a demand of the building user based on his or her individual comfort. This does not mean that control devices, operable windows, and other adaptive user actions on room or workplace level are superfluous. As the study by Huizenga et al, (2006) and Hoes et al. (2009) already showed, the ability for a person to control his environment has a significant impact on occupant satisfaction. This asks for a system which combines (i) localizing the building occupant and automatic conditioning of his workplace, and (ii) the possibilities for adjustments of the users' environment. To apply the individual preferences on the workplace, the human should be included in the loop through controlling his individual comfort level to prevent discomfort and energy consuming behaviour of the occupant to restore his comfort level.

Having the data for occupancy it is still unclear how to present them in the best way to get the maximum insight of them. Especially using the data to track the individual persons is still a challenge which needs more research.

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