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Experimental assessment of occupancy patterns of rooms in an office building. Comparisson of different approaches

José Alberto Diaz#, María José Jiménez#1

#Energy Efficiency in Buildings R&D Unit, CIEMAT. Avenida Complutense nº40, MADRID, E-28040, SPAIN
1mjose.jimenez@ciemat.es

Abstract
This paper reports the study of different options to estimate the level of occupancy of rooms in an office building from test campaigns. It aims to find an efficient way to represent this level, optimizing accuracy, cost effectiveness and intrusiveness of measurements, which is very useful in terms of commercial applications.

Measurements of CO₂ concentration and electricity consumed by computers have been considered as alternative indicators of the occupancy level. Both indicators have advantages and drawbacks which are analysed in this work. In both cases intervals when the room is empty for sure and intervals when the room is occupied for sure have been identified. This study is based on histograms that represent the occurrences of each interval of the considered indicator along the studied period. Afterwards the identified intervals have been used to obtain occupancy patterns of the rooms. Information previously available from the rooms such as typical working period, lunch time when the rooms are empty, holidays weekends, etc., have been used to validate the results.

Data corresponding to seven years, while the building was regularly used, have been used. The analysis using all these data gives robustness to the results.

Keywords - Building energy; Occupancy; Thermal parameters; Full scale outdoor testing; Performance indicators; System identification

1. Introduction

The occupancy pattern and the energy supplied to a building due to metabolic activity are relevant inputs to models used for control applications and energy performance assessment of occupied buildings. It is very difficult to accurately estimate the contribution due to metabolic activity to the energy balance of occupied spaces. The main difficulties are related to determining how much energy each user supplies, and how many users are in the room. Usual assumptions and approximations to estimate these contributions bring high contributions to the uncertainty budget of the estimated parameters and outputs of these models.

The work reported in this paper studied different options to estimate the level of occupancy of rooms in an office building from experimental data. It intends to be a step forwards regarding previous works that also considered the same indicators to estimate occupancy level ([1] and [2]). The most
efficient way to represent this level has been investigated. Efficiency is here referred to accuracy, cost effectiveness and intrusiveness of measurements. This is very useful in terms of commercial applications. Measurements of CO$_2$ concentration and electricity consumed by computers have been considered as alternative indicators of occupancy level. Both options have advantages and drawbacks that are analysed in this work.

CO$_2$ concentration is an evident indicator of human presence. However it is also influenced by other variables such as the status of doors, windows and mechanical ventilation system. Consequently these other variables have been taken into account in the study based on CO$_2$ concentration.

The use of computers has been considered also as a potential indicator of occupancy taking into account that the studied rooms are used as offices. Each user has a computer switched on when he or she is in the room, then there must be a relationship between electricity consumption due to computer use and the number of users in the room. It is also known that when each computer is switched on its electricity consumption varies in a certain interval depending on the activity of its CPU.

In both cases (using CO$_2$ concentration or electricity consumption) intervals when the room is empty for sure and intervals when the room is occupied for sure have been spot. This study is based on histograms that represent the occurrences of each interval of the considered indicator along the studied period. The histograms considering only nights aim to identify the level of the considered indicator when the room is empty for sure. The histograms considering only periods when the light are switched on aim to identify the level of these indicators when the room is occupied for sure.

Afterwards the identified intervals have been used to obtain occupancy patterns of the rooms. Information previously available from the rooms such as typical working period, lunch time when the rooms are empty, holidays weekends, etc., have been used to validate the results.

Data corresponding to a period of seven years, recorded while the building was regularly used, have been employed. This first analysis considers all these available data giving robustness to the results.

2. Experiment set up

Two offices are studied. They are expected to be used during week days by 1 to 3 people, beginning at 7:30 a.m. and finishing in the evening. One office is facing south (D13), the other one is facing north (D20), both are 22 m$^2$ placed in the ground floor.

The building is located in CIEMAT headquarters in Madrid (Spain). This building is a 4-floor building, with north-south orientation and an area of 2047.30 m$^2$. It houses laboratories and other special facilities. Machinery and installations rooms are located at the basement; offices and meeting room are in the ground floor, while in the first and second floor there are biomedical laboratories. It was constructed in SSP-ARFRISOL –a project of
bioclimatic architecture and solar cooling. It has a series of passive and active systems aiming to reduce the energy consumption while being comfortable, and also that it is widely monitored. More detailed description on this building is included in references [2] to [7], which also describe other different studies based on the same set up.

Both offices have CO\(_2\) and electricity power measurement devices. The monitoring equipment and set up is detailed described in [8] to [10]. The monitoring software is reported in ref [11]. Data corresponding to a period of seven years, while the building was regularly used, have been used.

Fig. 1 - 15 day monitoring measures from winter 2015 for two different offices – D13 and D20. Frequency displayed: 1 minute (green) and hourly moving averages (purple).

3. Data analysis

The work reported in this paper studied different options to estimate the level of occupancy of rooms in an office building from experimental campaigns. This first analysis considers all the available data giving robustness to the results. Measurements of CO\(_2\) concentration and electricity consumed by computers have been considered as alternative indicators of the
occupancy level. In both cases (using CO₂ concentration or electricity consumption of computers) intervals when the room is empty for sure and intervals when the room is occupied for sure have been identified.

Fig. 1 evidences some patterns that demonstrate the relation between the considered indicators and the levels of occupancy. Daily and weekly patterns are qualitatively observed in this figure. However identifying accurately such intervals may be difficult as discussed in the following.

In principle CO₂ concentration is an evident indicator of human presence. However there are many factors that make difficult identifying intervals of CO₂ concentration corresponding to levels of occupancy. Some of these factors are the following:

- Imprecise relation between the CO₂ production and the number of users in the room.
- Accuracy of the sensors that measure CO₂ concentration.
- Inhomogeneity in the concentration of CO₂ in the room.
- Low difference between levels of concentration of CO₂ produced for different levels of occupancy, regarding the accuracy of the measurement of CO₂ concentration, could make difficult distinguish different levels of occupancy.
- Representativeness of the measurement point.
- Status of doors, windows and mechanical ventilation system.

The use of computers is also a potential indicator of occupancy taking into account that this room is used as an office. Each user has a computer switched on when he or she is in the room, then there must be a relationship between electricity consumption due to computer use and the number of users in the room. The main factors that make difficult identifying intervals of electricity consumption of computers corresponding to levels of occupancy are the following:

- Sometimes the users don’t switch off the computer when they leave the room.
- The electricity consumption varies in a certain interval depending on the activity of its CPU when each computer is switched on.
- If the intervals of electricity consumed by different number of computers overlap, the identification of correspondence between number of computers working and consumption level would be difficult.
- Fluctuations of the power source.
- Accuracy of measurements of electricity consumption.
- Any other device using the same power source as computers.

In order to facilitate the identification of these intervals, this study is based on histograms that represent the occurrences of little intervals of the considered indicator along the full range of the studied period. The
histograms considering only nights aim to identify the level of the considered indicator when the room is empty for sure. The histograms considering only periods when the light are switched on aim to identify the level of these indicators when the room is occupied for sure.

Additionally to the histograms considering one minutely recorded measurement, the same study based on data filtered by one hour moving averages has been done aiming to improve resolution and avoid noise.

Afterwards the identified intervals have been used to obtain occupancy patterns of the rooms. Information previously available from the rooms such as typical working period, lunch time when the rooms are empty, holidays weekends, etc., have been used to validate the results.

The analysis carried out for each considered indicator is more detailed described in the following.

When CO$_2$ concentration is used as indicator it makes sense to assume that different concentration intervals will be identified depending on the status of doors, windows and mechanical ventilation system. Histograms considering if the doors and windows are closed or “not closed” and if the mechanical ventilation system is working or not, have been represented to analyse if these variations of the levels of CO$_2$ produced by the different mentioned status are detectable.

It makes sense also to assume that the number of users in the room is related to the speed of the increase of CO$_2$ concentration in the room. Increments of CO$_2$ concentration from one measurement to the next one, have been considered as indicator of this speed. A study analogous to the one done for the CO$_2$ concentration has been done based on these increments.

4. Results

In the raw data case of CO$_2$ increase per minute (represented in Figs. 1c, 1d, and 2) the noise level is such that appears not to give information. However, using 1 hour moving averages of the same variable, it is perceived a different shape between in the central hours of the weekdays, and nights - weekends. Therefore, it is considered this as possible measurement.

![Fig. 2 – CO$_2$ variation per minute histograms. Green: room not used. Yellow: Room used.](image-url)
Fig. 3 – Office 13. Normalized histograms showing breakpoint in each case, left. Occupation patterns for a fortnight in 2015, right.
**Fig. 4** – Office 20. Normalized histograms showing breakpoint in each case, left. Occupation patterns for a fortnight in 2015, right.
Histograms were made in different thicknesses during the study, in order to compare the value of the cases with and without occupation, they are normalized and displayed simultaneously - from here we can locate breakpoints, relative maxima and minima: Find patterns.

These patterns obtained are compared with actual data for a period of 15 days - so that in some cases there can be estimated "occupied" and "unoccupied" timetable, and in other cases up even what’s the occupation (0,1,2, 3 or more people). Histograms and patterns are displayed in Figs 2, 3 and 4. Breakpoints deduced from the histograms are summarized in table 1.

<table>
<thead>
<tr>
<th></th>
<th>D13</th>
<th>D20</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ - Raw data (ppm)</td>
<td>388</td>
<td>465</td>
</tr>
<tr>
<td>CO₂ - Hourly Moving averages (ppm)</td>
<td>379</td>
<td>463</td>
</tr>
<tr>
<td>ACO₂ - Hourly Moving averages (ppm/min)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>UPS - Raw Data (W)</td>
<td>180, 280, 410</td>
<td>120, 180, 225</td>
</tr>
<tr>
<td>UPS - Hourly Moving averages (W)</td>
<td>180, 280, 390</td>
<td>120, 180, 240</td>
</tr>
</tbody>
</table>

### a. CO₂ concentration

8 histograms (Two offices, Occupied / Empty and both raw data (a) and hourly moving average (c)) have the same distribution shape (unequal bell - Data never is down certain value, after a quick reach of the maximum it decreases more slowly). There is a clear difference between occupied and unoccupied state: The crossover point between the graphs taken night and light as state border point.

The occupation corresponding to this point displays more state variation in the raw data use, while the hourly mean values display more regular use of the office. At the same time, we can see the day the occupancy begins rounding 7 and 9 a.m – expected time, perhaps a bit earlier - while occupancy is displayed until late.

### b. Increments of CO₂ concentration (ΔCO₂)

Raw data is too noisy to consider it as useful (See Fig. 2a– And Fig. 2b) The histograms representing hourly average have approximately Gaussian shape around 0 - with different thickness (nocturnal values are more stable). Although there are two breakpoints (one positive and one negative), we just take the positive value as frontier point. The explanation is that if room is empty, decay or maintenance of concentration is expected.

From this value we got a not very realistic occupation pattern; if the reference is twice this value (Figs. 3 and 4, e and f), we can see a lot of variation in the O/E during the hottest hours of the weekdays state - but also looks much stability in times in which the office is expected to be not busy.
c. Computer electricity consumption

The two compared histograms have a very different shape. The night values are concentrated around three or four very distinct peaks in the 4 studied graphic; while values in the case of busy office are much more distributed - although always see several relative maxima and minima - the latter being more evident.

It will be considered the intersection point between the highest peak of the night histogram with the histogram of occupation, as the border between occupation / emptiness of the room. However, we will also take the relative minimum points as border between the number of users.

It is not expected to exceed 3 users except, and it coincides with the daytime peaks displayed on the histogram. So we get three points separating four states: Empty Office, 1 user, 2 users, 3 or more users.

The representations show a smaller occupation than CO$_2$, but they seem very close to the expected use of both offices – being the graph using the moving average scenario the clearest.

5. Conclusions

This study has shown that the human presence in a room influences on several measurable magnitudes, and the analysis of these allow to know the state of occupation or a stay, even with the number of people inside.

CO$_2$ concentration is a good state indicator, from the crossing of normalized histograms of measurements with and without occupying a value is localized border occupied / empty quite reliable. The temporary increase of CO$_2$ concentration is a less accurate – but using in hourly moving averages of this variable, the graph is useful to recognize extended periods of non-occupation.

The computer power consumption is not just a pretty reliable magnitude, but allows to elucidate the number of occupants - as long as the active devices correspond to the actual users.

This first analysis considers all these available data giving robustness to the results. The accuracy obtained when shorter experimental campaigns are used, will be considered in further works.

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