Comparison of Detailed Occupancy Profile Generative Methods to Published Standard Diversity Profiles

Dimosthenis Ioannidis[bc], Marina Vidaurre-Arbizu[a], César Martín-Gómez[a], Stelios Krinidis[b,], Anna Adamopoulou[b], Amaia Zuazua-Ros[a], Dimitrios Tzovaras[b], Spiridon Likothanassis[c]*

[a] Dep. of Construction, Building Services and Structures
School of Architecture, Universidad de Navarra
31009, Pamplona, Spain
mvidaurre@unav.es; cmargom@unav.es; azuazua@unav.es

[b] Information Technologies Institute
Centre for Research and Technology Hellas
Thermi-Thessaloniki, Greece
djoannid@iti.gr; krinidis@iti.gr; adamanna@iti.gr; Dimitrios.Tzovaras@iti.gr;

[c] Computer Engineering and Informatics
University of Patras
Rio, Patras, Greece
djoannid@ceid.upatras.gr; likothan@ceid.upatras.gr

***Abstract*— Knowledge of the actual occupancy of a building is a main research interest for several domains. Building energy performance simulation software considers occupancy through the use of diversity profiles usually contained in predesigned templates. This paper aims to explore the extent of possible discrepancies between standard predefined occupancy diversity profiles, profiles extracted by business process modelling and profiles generated from real on field occupancy measurements. Occupancy measurements are obtained utilizing a novel robust and highly accurate real-time occupancy extraction system which is based on a depth cameras network. Results show that the incorporation of real accurate occupancy data and the appropriate understanding of the business processes that take place in building spaces have the potential to significantly enhance current Building Performance Simulation (BPS) software tools.**

***Keywords*— Occupancy; Diversity Factors; Business Process Model; Energy Performance; Building Simulation; Depth Cameras.**

I. Introduction

A. Building Occupancy

Knowledge of the actual occupancy of a building is a main research interest for several domains ranging from security to energy saving, especially in complex buildings with various internal kinds of usage [1]–[6]. Building energy performance simulation (BPS) software considers occupancy through the use of diversity profiles or occupancy schedules. The daily profiles consist of 24 values, one for each hour of the day. These values are called diversity factors. According to [7], *diversity factors are numbers between zero and one, and are used as multipliers of some user-defined maximum load*. BPS tools usually provide templates with predefined schedules for various space and building types (e.g. OpenStudio [9]).

However, there is a gap between predicted and measured energy performance of buildings that researchers are trying to bridge ([9], [10]). This gap is in part due to the simplifications and the assumptions that modellers make when modelling a new building, as well as due to many uncertainties that cannot be fully controlled, such as real infiltration rates, actual weather conditions, and real occupancy behavioural patterns [11]. Research on the discrepancies between predefined industry standards and detailed project-specific models/profiles can improve the existing diversity factors templates and consequently the simulations results of BPS tools, assisting towards bridging the existing gap between simulated and actual energy performance.

In the literature there are several techniques to detect the occupants of a space, ranging from user surveys, interviews or walkthrough inspections ([11]–[16]) to more or less complex deployment of sensors within the area of study ([1], [2], [4], [17]–[19]). The sensors most commonly used include: i) CO2 sensors, which have slow response in detecting an increase in the level of CO2 [20]; ii) Passive infrared (PIR) sensors, which have difficulty with detecting immobile users [17]; iii) Video cameras for tracking occupants' movements, which present the problems of high post processing time and intimacy or privacy violation issues; iv) RFID (Radio Frequency Identification) sensors. Depending on the layout of the receivers, the zones can overlap and falsely detect occupants going from one zone to another while they are not moving [21].

In this paper occupancy measurements are performed based on a new innovative occupancy extraction system [22] which utilizes depth image cameras. This system is quite robust, reliable and accurate providing results very close to ground truth (95% accuracy). Moreover, it offers data anonymity and is privacy preserving.

* Corresponding author: Stelios Krinidis. Tel.: +30 2311 257 764; Fax: +30 2310 474 128; E-mail address: krinidis@iti.gr

B. *Objectives, Methodology and Contribution*

Using a health care facility area as a case study, the authors aim to compare the discrepancies between: (1) standard, predefined, publically-available diversity profiles for occupancy; (2) occupancy profiles generated from business process modelling, based on interviews with key personnel; (3) occupancy profiles generated from field observations, using a robust and highly accurate occupancy extraction system [22].

Comparison between 1 and 3 provides an idea of the possible extent of the current discrepancies in energy simulation results, while comparison between 2 and 3 provides a means to compare key personnel perceptions and preconceived ideas to field evidence. The ultimate goal of these comparisons is to examine whether accurate real occupancy measurements can contribute in generating more precise and realistic occupancy profiles than the ones currently used by building simulation software packages, towards enhancing the building simulation process.

The methodology followed is this study in order to achieve the defined objectives comprises of the following steps: (1) selection of a health care facility as a case study; (2) selection of building areas as the most representative ones; (3) selection of the standard predefined diversity profiles from popular BPS tools which best match the spaces under examination; (4) definition of the business processes taking place in the examined building areas; (5) generation of occupancy profiles from BPM (Business Process Modelling) based on interviews with occupants; (6) installation of depth cameras and necessary infrastructure in the examined areas and proper calibration; (7) testing of the proper operation of the installed occupancy extraction system; (8) occupancy tracking and collection of real occupancy data for a long period of time (almost a year); (9) extraction of various occupancy profiles based on the collected measurements; (10) comparison of the extracted occupancy profiles with standard predefined diversity profiles and BPM profiles.

Finally, the contribution of this paper in the research field can be summarized as follows:

- Comparison of the discrepancies between occupancy profiles derived by on field real occupancy measurements, standard predefined diversity profiles and BPM profiles.
- Extraction of occupancy profiles for the examined space types of a health-care facility (meeting – working rooms, corridors, lift area) based on real highly accurate occupancy measurements covering a large period of time (1 year) and various cases (weekdays, weekends, holidays etc.).

II. MATERIAL AND METHODS

A. *Description of the Case Study*

The Clínica Universidad de Navarra (CUN), a medical centre and hospital located in Pamplona, Spain, has been selected as a case study, since it constitutes a commercial building with multifaceted areas and sub-areas, well-defined everyday business operations which are highly correlated to specific business services, respective business episodes and occupancy patterns. The selected area is in the intermediate 8th floor. The covered spaces are: i) 2 meeting-working rooms, ii) corridor iii) and a lift area, a space where lifts disembark and which contains a small waiting area, acting as a connection between the meeting-working rooms and the main consultation area. The meeting-working rooms are used by the residents for their scheduled and extra meetings as well as for regular working at the computerized hospital system.

B. *Standard Predefined Diversity Profiles*

Nowadays, BPS software packages (e.g. EnergyPlus [23], OpenStudio [8]) provide templates of occupancy diversity profiles and examples to be used during the first stages of a building design. In the scope of our study, templates from EnergyPlus and OpenStudio were considered due to their popularity as BPS tools.

OpenStudio 1.4.0 offers 17 templates (15 building types plus minimal template and master template) that include construction, schedules and internal load data for various vintages and for all U.S. climate zones. The *Hospital* and *Outpatient* templates have been selected as the most suitable for the examined spaces to be compared with the measured occupancy data of the case study.

In particular, the *Corridor*, *PatCorridor* and *Office* space types of the *Hospital* template have been selected. The lift area is considered as a corridor. The occupancy schedule selected for the *Corridor* and the *PatCorridor* is the *Hospital Critical Occ*, and for the *Office* the *Hospital Bldg Occ*. In the *Outpatient* template there is not a template for corridor. Thus, for meeting rooms and corridor the space type selected is the *Office*, while for the lift area the selected space type is the *Lounge*. The corresponding schedule is the *Outpatient Bldg Occ.*

EnergyPlus contains schedule information for various common (e.g. *Office Occupancy*) scheduling instances. Schedules are listed alphabetically, with general schedules first, followed by the ten 90.1 building type schedules [24]. The Example File generator web site [25] provides default people density values according to different building types. The schedules of the *Health* building type have been selected as the most suitable for the examined spaces to be compared with the measured occupancy data of the case study.

C. *Profiles from Business Process Modelling (BPM)*

Apart from the occupancy diversity profiles, another objective of the current work is to monitor and model the daily business processes and activities of the occupants following a top-down approach by analysing the design and typical process flow. Although there are various ways of modelling business processes and workflows, we have used the methodology developed in [13] as the most efficient.

Fig. 1 and Fig. 2 present the two main business tasks performed by the users of the meeting-working rooms that affect the occupancy of the space: i) patient consultation (*BP UNAV Patient Consultation*) and ii) MIR (Medical International Research) (*BP UNAV MIR Research*).

The first task initially takes place in the meeting-working room where the residents (MIR) prepare for the day's consultation appointments studying the medical history of each patient who is going to visit the doctor. The MIR then leaves the meeting-working room and joins the doctor in the consultation room awaiting the first patient's arrival.

The second task takes place in the afternoon. Residents are usually in their meeting-working room between 3pm and 8pm carrying out their on-going research, including gathering research material, writing papers and preparing for sessions with their supervisor. They have to document all their research activities. During the afternoon session they study the individual cases they are working on and search for additional information online. If they need further input from the doctors, they contact with them and finally they have to write a report for each workday.

BPM provides the capability to design also an approximate and simple occupancy schedule for the meeting-working rooms. During the interviews performed in the scope of our study, residents pointed out that on Mondays, Wednesdays and Fridays, they usually have a time to present their research to other colleagues and doctors from 9am to 10am. They also declared that up to 24 people are in the meeting-working rooms during those sessions. Moreover, they stated that they have lunch from 2pm to 3pm and that then they go back to work to the meeting rooms until 8pm or 9pm. The occupancy schedule resulting from the business process interviews is illustrated in Fig. 3.

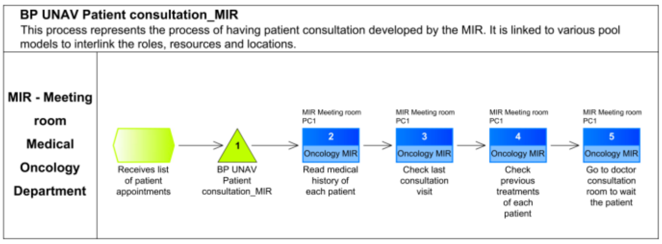

Fig. 1. Detailed business process model task. Part of the BP UNAV Patient consultation_MIR, schema that takes place in the meeting-working rooms

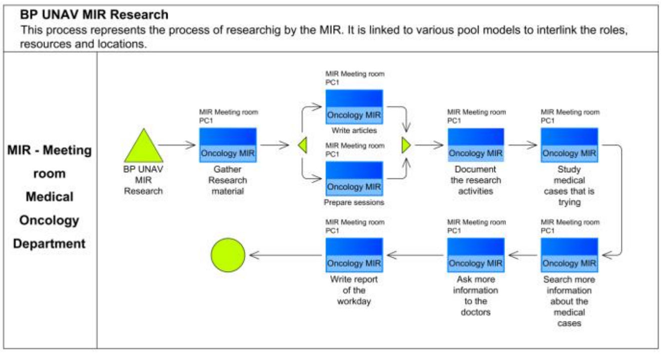

Fig. 2. Detailed business process model task. BP UNAV MIR Research.

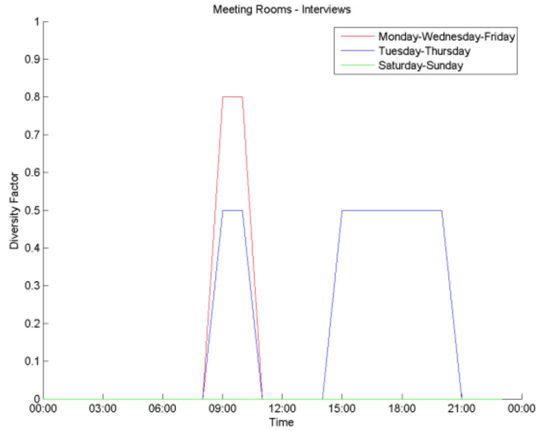

Fig. 3. Occupancy schedule extracted from the business process interviews with the residents

D. *Methodology to Generate Occupancy Profiles from Real Measurements*

1) *Building Installations*

Occupancy measurements were collected from a 100 sqm. area of the CUN Oncology Department comprised by two meeting-working rooms (39 and 21 sqm.), a lift area (25 sqm.) and the corridor connecting all these areas (15 sqm.). In order to measure the occupancy of the area under interest, a sensor cloud consisting of eleven depth cameras has been utilized. Depth information was selected because it offers data anonymity and privacy. The location of each camera at the test bed building is depicted in Fig. 4. Data collection was performed for one year (September 2013–August 2014). The entire installation is detailed in [26].

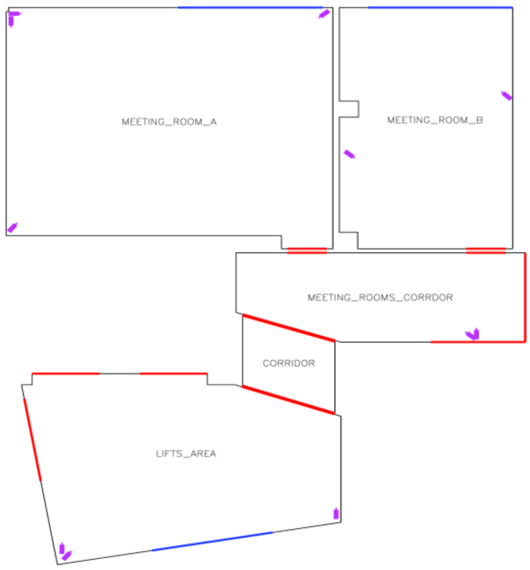

Fig. 4. Deployment of depth sensors at the test bed building.

2) *Occupancy Tracking – Data Extraction*

Occupancy measurements extraction was performed utilizing the installed depth cameras network and the centrally controlled real-time client-server system described in [22], [27]. The occupancy extraction system is able to handle the dynamic changes of the environment utilizing an adaptive dual-band background algorithm [22]. Furthermore, the system can handle partial occlusions utilizing a virtual top-view camera [22].

The client is responsible for handling the depth cameras attached to it, performing the detection and sending features of the detected occupants to the server. On the other hand, the server application gathers, merges and tracks the detected occupants. The overall occupancy extraction system is fully automated, and it is able to run continuously for months without any particular problem. It is important to note that the system extracts detailed occupancy information, since it has the overall occupant's trajectory from his/her entry to the covered area until his/her exit. The utilized occupancy extraction system stores the detailed raw occupancy information (occupants' trajectories) for further processing. This detailed raw occupancy information can provide important semantic information about the building, such as regions of interest, popular regions, correlation with equipment, and so on.

In the scope of this work, the extracted detailed occupancy measurements have been post-processed in order to acquire the diversity factors of the covered area. The post-processing procedure follows each occupant's trajectory and adds a factor equal to 1/3600 per single second to the corresponding occupied space and to the overall monitoring area statistics. The statistics are finally extracted per hour, although the procedure is able to provide more detailed information, such as statistics per 10 minutes, per minute, per second etc. The statistics are normalized with the maximum number of occupants, in order to generate the diversity factors. A number of different cases are considered: single working day; single weekend day; single holiday day; full normal week (comprised of all working week days); full normal weekend (comprised of Saturdays and Sundays); full holiday week (comprised of all working week days); full holiday weekend (comprised of Saturdays and Sundays).

III. EXTRACTED OCCUPANCY PROFILES BASED ON ACTUAL MEASUREMENTS

A. Meeting – Working Rooms

The graph of the meeting-working rooms for an average weekday (Fig. 5) shows a peak of 0.625 in the morning, coincident with the task *BP UNAV Patient Consultation* (Fig. 1). After an hour the diversity factor decreases. This is the time when the residents leave the space and go to the consultation area. Afterwards, according to the BPM the space remains with lower occupancy until 3pm when the task *BP UNAV MIR Research* begins (Fig. 2). At around that time the monitored occupancy shows an increment, reaching a second peak of 0.375 at around 5pm. The month with the lowest diversity factor is July, August comes second, June is the month with the highest occupancy in general and April presents the highest level of occupancy in the afternoon.

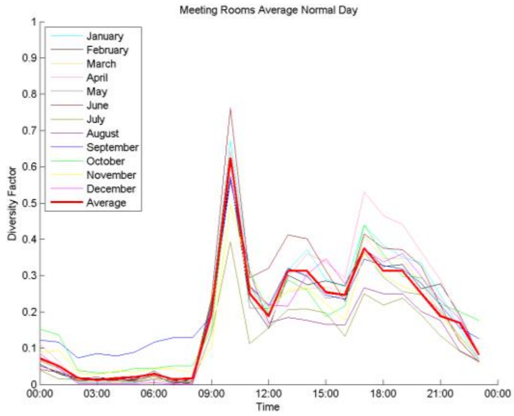

Fig. 5. Meeting-working rooms' average diversity factor for weekdays for each month and total average.

The average of each of the weekdays from Monday to Friday (Fig. 6) shows that the meetings take place on Monday morning and Tuesday afternoon despite what was stated during the interviews. The days with the highest occupancy are Monday and Tuesday, while Wednesday and Thursday have an intermediate occupancy and Friday has the lowest. During weekends (Fig. 7) the profile is flatter and an average peak close to 0.125 is found.

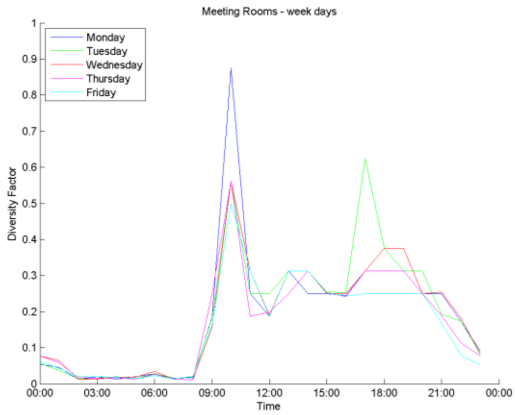

Fig. 6. Meeting-working rooms' average diversity factor for weekdays. Represents the real use of the spaces, not the theoretical.

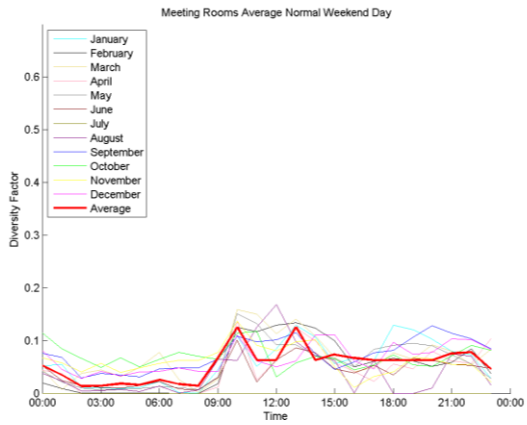

Fig. 7. Meeting-working rooms' diversity profile for weekends for each month and average.

B. *Corridor*

The extracted profile for weekdays for the corridors (Fig. 8) shows an average peak value of 0.20, while the maximum peak is presented at 9pm. The small peaks at 6am correspond to the time of cleaning the area. Occupancy starts to increase around the time of arrival (8am), then stays more or less flat at a value of 0.13, drops from 6pm to 7pm, reaches a peak of 0.30 at 9pm and drops again until midnight. September has the lowest occupancy value and June the highest. Although July and August present lower occupancy in the meeting – working rooms, here in the corridors they have values closer to the average.

During the weekend (Fig. 9), the average profile is almost flat. It rises a bit from 9am to 11am. This is correlated to the occupancy of offices during weekend. During rest hours occupancy stays more or less continuously at a value around 0.03. C. Duarte et al. [6] state that such spaces have flatter profiles and an average value of 0.75-0.88. The number of sensors they had was limited but the difference among their measurement and ours is high, showing the need to continue the research in this kind of spaces.

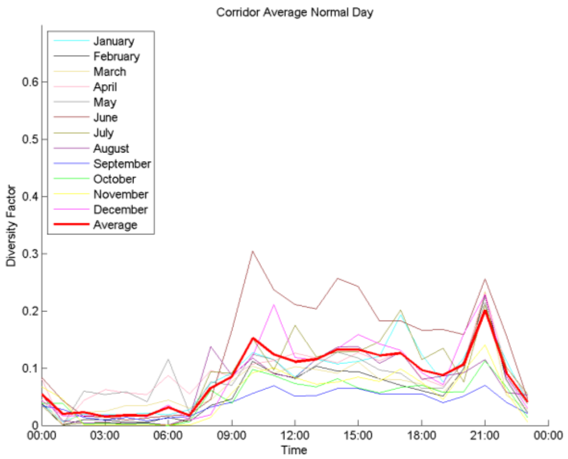

Fig. 8. Corridor occupancy diversity profile for weekdays for each month and average.

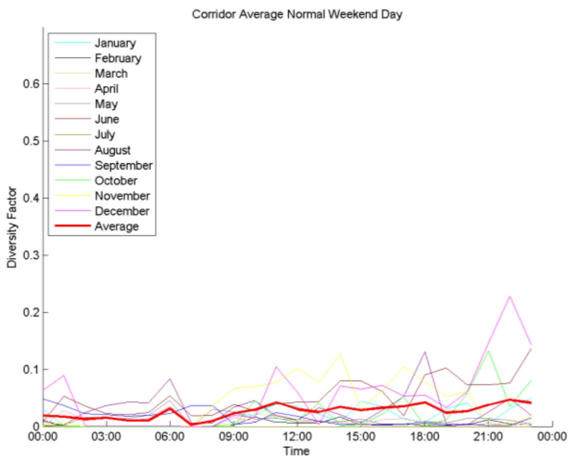

Fig. 9. Corridor occupancy diversity profile for weekends.

C. *Lift Area*

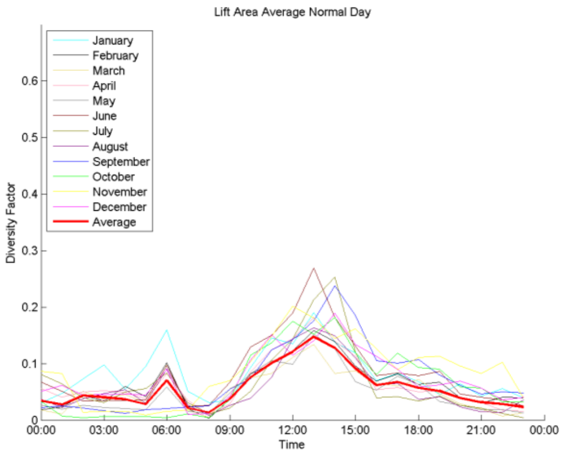

Fig. 10. Lift area occupancy diversity profile for weekday.

This area, where lifts disembark, is considered separately due to the existence of a waiting area in it. The average profile (Fig. 10) shows again the peak at 6am, due to cleaning the area. The curve rises at 9am, reaches the maximum value of 0.148 at 2pm and then smoothly decreases until midnight. As it happens with the corridor area, the lowest occupancy is not detected during the typical holiday months but in March. June is the month with the highest occupancy profile, similarly to the rest monitored spaces. During the weekend (Fig. 11) again the remarkable peak occurs at 6am and then the profile stays flat at a value around 0.027.

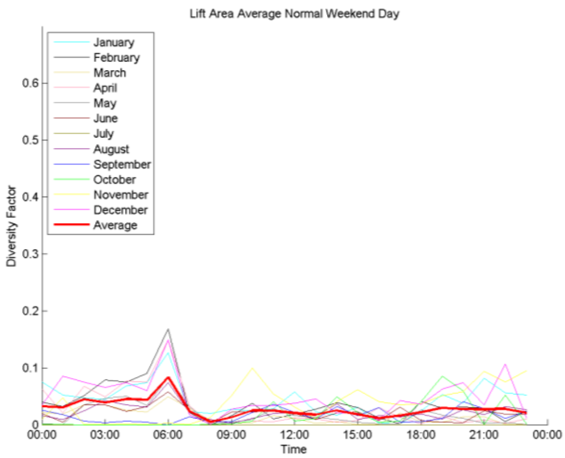

Fig. 11. Lift area occupancy diversity profile for weekend.

IV. COMPARING MEASURED DATA TO BPS SOFTWARE TEMPLATES AND BPM PROFILES

A. *Comparing measured data to standard BPS templates*

The maximum number of people in a space due to the use of template data ([23], [8]) is up to 22 times lower than the maximum occupancy detected by the depth cameras in the examined site (lift area). Thus, the comparison between template schedules and monitored occupancy should not be made through diversity factors but through the number of people derived from the full use of templates. Below the comparison results for the examined spaces are presented and discussed. The evaluation metric used is the % percentage of the difference between the average value of the measured data and the template data taking as reference the measured data.

1) Meeting – Working Rooms

Fig. 12 shows the number of people derived from the use of the OpenStudio and EnergyPlus templates as well as the average monitored occupancy of the meeting-working rooms for weekdays. Comparing the templates to the average occupancy derived from on field measurements, it can be argued that the use of the templates in this case would provide an inaccurate estimation of the occupancy in the meeting-working rooms in terms of both the occupancy number and the distribution over time (e.g. arrival and departure time, peaks, intermediate falls etc.). For example, based on the measurements occupants arrive around three hours later than the templates. The template which seems to be closest to the measured data is the OpenStudio *Hospital* template. In particular, the difference between the measurements and the *Hospital* template is around 15%, 44% for the *Outpatient* template and 59% for the *Health* template.

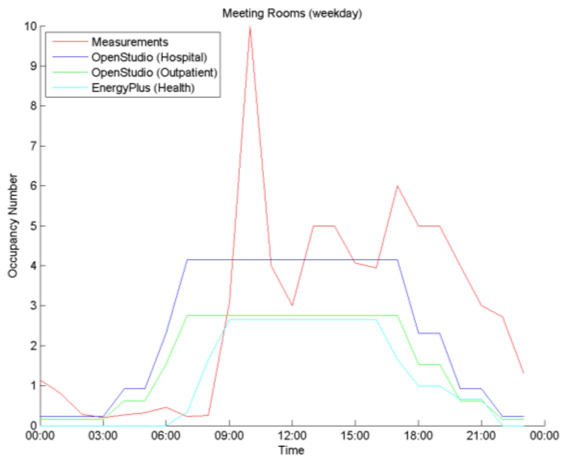

Fig. 12. OpenStudio office space type (weekday), EnergyPlus Health building type vs. measured weekday occupancy of the meeting-working rooms.

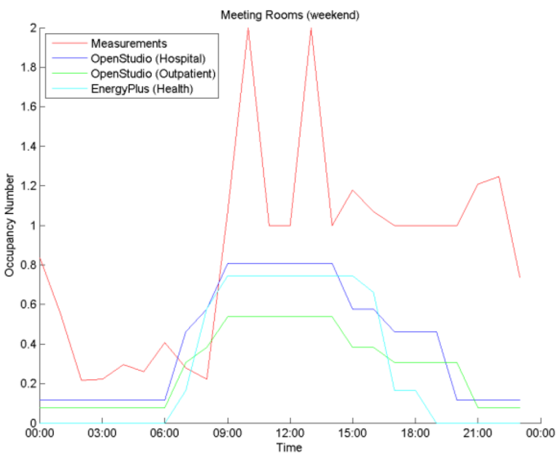

Fig. 13. OpenStudio office space type (weekend), EnergyPlus Health building type vs. measured weekend occupancy of the meeting-working rooms.

Regarding the weekend (Fig. 13), the difference between the templates and the actual measurements is even higher (52% - 67% less number of people would be considered with the use of templates). The closest of the templates to the measured data is the OpenStudio Hospital template, while the less compatible would be the OpenStudio Outpatient template.

2) Corridor

Fig. 14 depicts the OpenStudio *Hospital* template and the EnergyPlus *Health* template for the corridor in comparison to the measured occupancy for weekdays. Here, EnergyPlus overestimates the occupancy (22% higher), while OpenStudio underestimates it (52% lower).

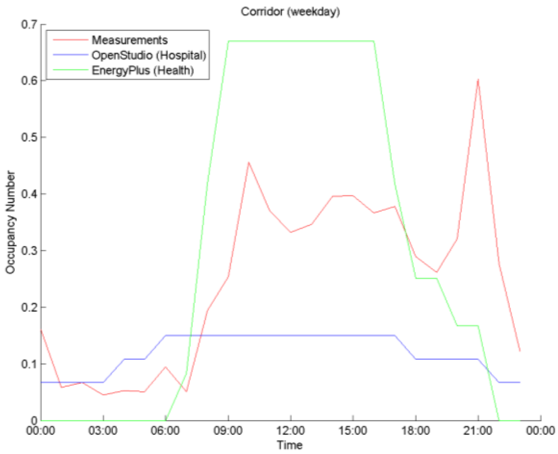

Fig. 14. OpenStudio Hospital Corridor space type (weekday) and EnergyPlus Health building type vs. measured weekday occupancy of corridor.

Regarding weekends (Fig. 15), the OpenStudio *Hospital* template considers higher occupancy than the measured (57%), while the difference for the total number of people between the EnergyPlus *Health* template and the measurements is only 1%.

Having also a look to the diversity factors of the OpenStudio *Hospital* profile for weekdays it is obvious that it is absolutely different from the actual one. In particular, the peak measured diversity factor merely gets to 0.201, while the profile proposed for this space type ranges between 0.4 and 0.9.

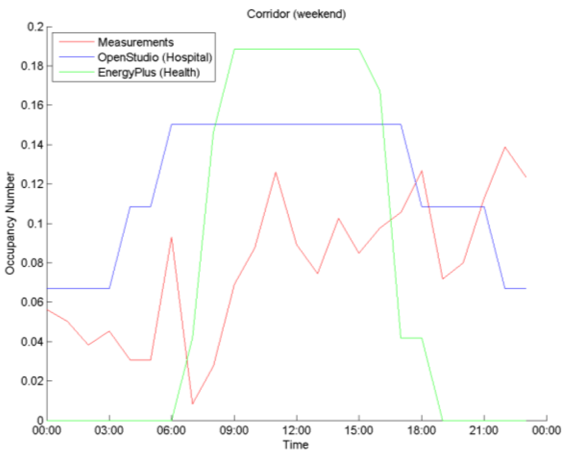

Fig. 15. OpenStudio Hospital Corridor space type (weekend) and EnergyPlus Health building type vs. measured weekend occupancy of corridor.

3) Lift Area

The results of applying the BPS templates to this area and the average monitored occupancy for weekdays are provided in Fig. 16. While OpenStudio *Hospital* and *Outpatient* schedules differ greatly from the measured occupancy, EnergyPlus *Health* seems to be the most accurate in this case. Regarding the weekend (Fig. 17), the template that is closer to the average measured occupancy is the OpenStudio Hospital (corridor space type). Note that both in this graph and the previous one the peak at 6am is due to cleaning and at 9pm it is when the residents leave the meeting-working rooms.

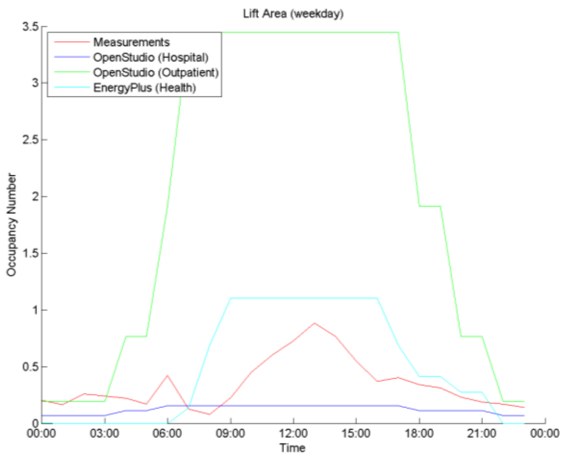

Fig. 16. OpenStudio Hospital Corridor space type (weekday), OutPatient Lounge space type and EnergyPlus Health building type vs. measured weekday occupancy of Lift area.

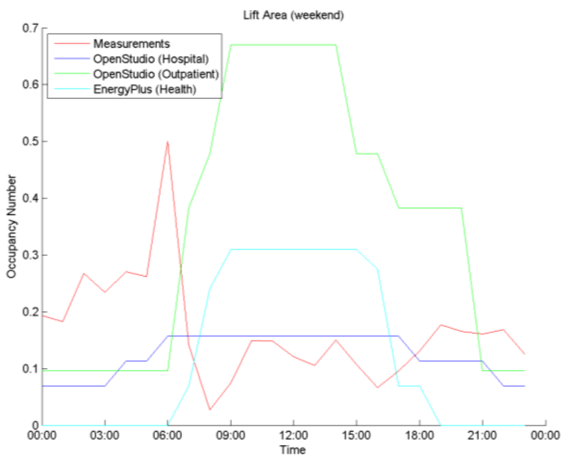

Fig. 17. OpenStudio Hospital Corridor space type (weekend), OutPatient Lounge space type and EnergyPlus Health building type vs. measured weekend occupancy of Lift area.

B. *Comparing Measured Data to BPM Profiles*

The BPM requires interviews with the users of the spaces to detect their activities. As explained in section 2.3, based on these interviews it was possible to create an approximate occupancy schedule for the meeting – working rooms. The measurements seem to follow the schedule derived from the BPM interviews but not in an absolute way (see Fig. 18). The comparison is made as in section A. The measured occupancy increases at 9pm with a peak of 40 – 60%, then it drops to 15% but never gets to zero since on average there is always somebody in the office after 10am. Occupancy increases after 3pm reaching 20 – 30% at 6pm and at around 8pm - 9pm it decreases again. Despite the differences, the profile derived from BPM interviews is quite close to the occupancy measured by the depth cameras. Therefore, it could be stated that the knowledge of the business activities of an enterprise can lead to better occupancy simulation results.

The maximum number of people cannot be confidently established based on interviews, since although the occupants declared that the maximum occupancy is 24, the sensors showed that it was actually 16. Moreover, when no business task is being performed (e.g. lunch time, weekends) occupancy cannot be considered as zero. Also, the areas that are not directly related to a business process, such as corridors, hallways or lift areas cannot have a schedule derived from BPM as they do not follow a typical occupancy pattern.

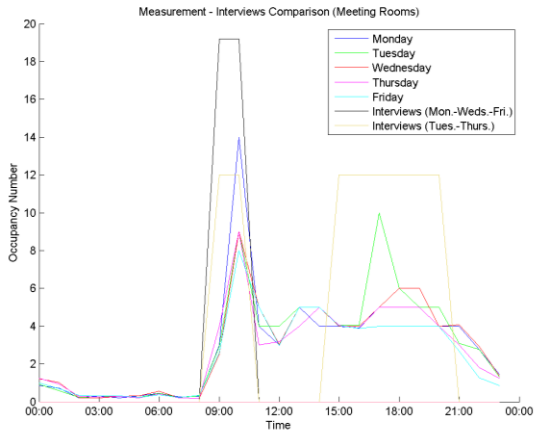

Fig. 18. BPM Interviews schedule (weekday) vs. measured weekday occupancy of the meeting-working rooms.

In conclusion, it seems that real occupancy measurements provide much more accurate profiles than both standard BPS templates and BPM profiles. Real measurements from a lot of building spaces of the same type and operation can significantly contribute to the generation of more realistic templates improving the results of current simulation tools.

V. CONCLUSIONS

This study provides occupancy profiles for various space types in a hospital as a result of occupancy monitoring for twelve months with a novel centrally controlled real-time client-server system which is based on a depth image cameras network. These profiles are used in order to demonstrate the extent of potential divergences between standard predefined occupancy diversity profiles (used by BPS software tools), profiles extracted by BPM based on occupants’ interviews and profiles generated from real on field occupancy measurements.

This research provides valuable information on the occupancy of secondary areas in a hospital, such as meeting – working rooms, corridors, hallways and lounge areas, which have not been deeply studied before. The schedules of the meeting-working rooms may be very specific for this certain case study and the business processes that take place in them, but the diversity profiles of the other areas provide valuable information for future research in this field of knowledge. The use of the occupancy extraction system of [22] allows the extraction of highly accurate occupancy data while preserving users' privacy.

Moreover, it is demonstrated that the knowledge and understanding of the business processes/activities of a company may assist modellers towards achieving better simulation results. Comparison outcomes also indicate that the templates currently used by some building simulation tools may be inaccurate with regard to the ground truth in certain cases, thus introducing errors in simulation results. Furthermore, it seems that the incorporation of real accurate occupancy information in the templates to be used in BPS software has the capability to enhance their effectiveness and performance.

Finally, future work could include more extended comparisons concerning other building spaces of the hospital or more advanced BPM profiles, as well as the investigation of the potential inconsistencies for other building types through the installation of the necessary infrastructure and the collection of real occupancy measurements.

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