Understanding the energy consumption and occupancy of a multi-purpose academic building

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ABSTRACT

Building energy use associated with non-domestic buildings accounts for approximately 19% of the total UK CO_2 emissions. Energy consumption in a non-domestic building is a complex issue due to a wide variety of uses and energy services and therefore the energy demand of individual buildings need to be understood. A pilot study was undertaken to analyse the relationship between the electrical energy demand profiles and user activities for a university building. To gain insight into how the building is used, operated and managed on a daily basis, an online questionnaire was distributed to staff and students as well as interviews conducted with key management personnel. Analysis was performed on the half-hourly electrical demand data for the case-study building to identify key trends and patterns in energy use. The shape and magnitude of energy demand profiles show a significant trend which does not seem to be strongly connected to occupancy patterns. It was found that the building was mostly controlled by a building management system (BMS) where building users have minimal access to the controls. However, it was interesting to find that the detailed information on the occupancy patterns could help the management team to redesign control strategies for optimum energy performance of the building.

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1. Introduction

Buildings represent a very high energy consumption percentage compared to other economic sectors. Although percentages vary from country to country, buildings are responsible for about 30–45% of the global energy demand [1,2]. The proliferation of energy consumption and CO_2 emissions in the built environment has made energy efficiency and savings strategies a priority objective for energy policies in most countries [3]. A clear example is the European Energy Performance of Buildings Directive (EPBD) which places a high demand on building professionals to produce buildings to near-zero energy use levels [4]. Commercial buildings, and primarily office and university buildings, are classified amongst the buildings presenting the highest energy consumption [5,6]. The commercial building sector has therefore become the focus of many governmental energy reduction initiatives to achieve more sustainable development [7]. Previous research shows that modern office buildings have high energy savings potential [8]. An on-site survey of existing university buildings conducted by Chung and Rhee [6] determined the potential for energy conservation in the range 6–29%. According to the carbon trust, a carbon reduction of 70–75% can be achieved in non-domestic buildings at no net cost [9]. Advances in technology are increasing to achieve the desired reduction in energy consumption goals but this does not necessarily lead to an overall reduction. Large discrepancies are being observed between predicted and actual building energy performances, typically averaging around 30% and reaching as high as 100% in some cases [8]. The post-occupancy review of buildings and their engineering (PROBE) studies [10] investigated the performance of 23 non-domestic buildings concluding that the actual consumption was usually twice as much as predicted. The measured electricity demands can be approximately 60–70% higher than predicted in both schools and general offices, and over 85% higher than predicted in university campuses [11].

Long term energy savings can be achieved by improving the building design as well as conserving energy during the operation phase. In order to determine the sources of errors and improve these predictions, the sensitivity of building energy models to different input parameters needs to be evaluated. Studies in literature have extensively evaluated the sensitivity of models to the buildings' technical design parameters, where the areas of organisational energy management policies/regulations and human factors (i.e. energy users' behaviour), which are very important elements influencing building energy consumption, have rarely been evaluated [7,12]. Studies [13–16] show that more than half of the total building energy is typically consumed during the non-working hours

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mainly due to occupancy related actions (e.g. equipment and lighting after-hours usage) and can be reduced through behavioural changes. As cited by Nguyen and Aiello [17], occupancy presence and behaviour in buildings has shown to have large impacts on space heating, cooling and ventilation demand, energy consumption of lighting and space appliances, and building controls where careless behaviour can add one-third to a building's designed energy performance, while conservation behaviour can save a third.

A central heating, ventilation and air-conditioning (HVAC) system is widely used in large buildings, such as office buildings, commercial buildings and shopping centres [18]. The HVAC systems are the largest energy end use in the non-residential sector [3] where inefficient operation and maintenance of the HVAC system can cause energy wastage, customer complaints, poor indoor air quality and even environmental damage [19]. In order to achieve energy efficiency in buildings, the energy optimisation of HVAC systems is particularly important [20] where the energy performance of such systems is affected by operating conditions as well as time sensitivity to a building's heating and cooling energy needs. According to Cho et al. [20] an energy evaluation methodology based on quantifying the energy consumption characteristics of HVAC systems may be used by engineers and designers to assess the effectiveness and economic benefits of HVAC systems. Electric lighting is one area where energy savings are possible at reasonable cost in new buildings as well as in retrofit projects. According to Dubois and Blomsterberg [21] some barriers to these energy savings may be related to the difficulty to switch-off lights at night due to extended office hours, user-acceptance issues related to the proposed low light levels or to the occupancy switch-off and daylight dimming control systems.

The UK government is committed to an 80% reduction in CO_2 emissions by the year 2050 [5]. According to the UK Green Building Council [9] there is almost twice as much potential for cost-effective carbon mitigation in the built environment in comparison to any other sector. The UK government has begun targeting the non-domestic sector with increasingly stringent building regulations and methods of measuring as-built and operational performance, such as energy performance certificates (EPCs) and display energy certificates (DECs) [22]. Although these initiatives are likely to improve the performance of buildings detailed knowledge of the non-domestic building stock is still limited [23]. Practically, energy consumption in non-domestic buildings is a very complex organisational issue due to the heterogeneity of activities (for e.g. as lecture halls, laboratories, and offices) that take place as well as the energy services such as HVAC, domestic hot water (DHW), lighting, refrigeration and food preparation [3,6]. Achieving a balance poses a challenge: on the one hand, to consume energy to satisfactorily meet the energy needs of users and maintain comfort standards and on the other hand, to minimise energy consumption through effective organisational energy management [12].

Universities in the UK consume significant amounts of energy [24,25] and according to new legislation [26], most of the UK's colleges and universities are now required to report on their energy use and improve their efficiency. The energy demand behaviour in university buildings are less well understood than other non-domestic buildings including schools and offices [27,28]. Reducing energy use is impossible without good data on which to make management and investment decisions [9]. A pilot study was undertaken aiming at understanding the reasons for excessive energy consumption for a university building in operation. In this paper the electrical demand profiles were analysed as well as information gathered on the daily occupancy and the key activities that take place within the case-study building. Interaction with building users was carried out via a questionnaire to determine the influence that they exert on the electrical demand of the building. Interviews with key management personnel were conducted to understand how the building is routinely managed and operated and to illicit any issues relating to energy consumption. This study differs from a normal energy audit in that it provides useful information in terms of the day to day operation of the building in question. This paper focuses on mapping the pattern of measured daily electrical consumption of the case study building against the daily room activities and occupancy, with insights from the questionnaire and the interviews. Carrying out a mapping in this way helps to identify the potential electricity savings that can be achieved. This is explained in detail in later sections.

2. Methodology

2.1. Case study building

Adopting a case study approach, this paper focuses on the electrical consumption of an academic building of Heriot-Watt (HW) University, Edinburgh, Scotland. The post-graduate centre (Fig. 1) is located within the North Campus of Riccarton [29] and provides both educational and social facilities for post-graduate (PG) students. The centre also contributes to undergraduate (UG) learning and allows delivery of a Continual Professional Development programme. The choice of case study was determined by the following factors:

- Availability of electrical consumption data at a half hourly resolution.
- A multipurpose building (activities include lecturing, research, administration, cafeteria and social gatherings/events).
- Newly constructed building with an EPC rating of 'D'[1] – from Section 1 and according to Carbon Buzz this may mean that the actual consumption might be 1.5–2.5 times predicted values [30].

2.1.1. Building description

The area of the building is approximately 2000 m^2 and is the winner of an architectural competition for an 'iconic' building [31]. The floor plan of the building is shown in Fig. 2. The building houses 12 cellular office spaces for staff members, a lecture theatre (PG G01), two seminar rooms (PG 201, PG 202), three meeting rooms (PG 301, PG 302, PG 303), a café, social space and study space. The building has four floors and three distinct zones. The south zone contains a cafe, offices and smaller seminar and meeting rooms requiring good day lighting, natural ventilation and minimal mechanical systems.

The central zone houses vertical circulation, toilets and stores. The north zone accommodates larger spaces, many requiring limited or no day lighting and all requiring mechanically controlled environments. At the east end of the central zone, located next to the entrance is the main stair, enclosed in glass allowing diffused daylight to flood into the central atrium. An elevator lift rises up through the atrium serving all floors [29]. A revolving door provides draught protection with a controlled door adjacent giving wheelchair access. Flowing directly off the central exhibition area, with the café opposite, is a generous crush area leading to the lecture theatre. The stepped roof in the study space on the top floor allows natural light into the centre of the study area whist the perimeter full height glazing allows full advantage to be taken of the panoramic views to the north. Mechanically operated high-level

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[1] Under the European Energy Performance of Buildings Directive (EPBD) [3], in the UK the National Calculation Method (NCM) models the annual energy use for a proposed building and compares it with the energy use of a comparable "notional" building, to produce an "asset rating" in the form of an EPC [4]. EPCs present the energy efficiency on a scale of 'A' to 'G', with 'A' being the most efficient and 'G' the least.

Fig. 1. The post-graduate centre (case-study building).

louvres in the atrium assist in the natural ventilation of lower level areas under the stack effect.

These arrangements are meant to provide a logical architectural solution and also allow the service and structural engineers' requirements to achieve the most economical solutions with regards to ensuring orientation and grouping are best met [29]. The building however, is sitting at an EPC rating of 'D' which is below average with potential to improve to D+ based on the

Fig. 2. The post-graduate centre floor plan.

recommendation of installing solar water heating, a building mounted wind turbine and solar panels.

2.2. Data collection

2.2.1. Electrical consumption data

The HW University's Estates Services are responsible for the energy management and development and implementation of the University's environmental, energy and sustainability policies. For the present study, the Estate office provided the data from June 2012 to 2013 on electrical, gas and water consumption in the post-graduate (PG) centre. This paper presents the analysis on the data for the second and third term to understand the electrical energy consumption patterns and their relationship with the activities that are undertaken within the building. The term dates for the year 2012/13 are as follows:

Term 1 (10/09/12 to 30/11/12), term 2 (07/01/13 to 22/03/13), term 3 (02/04/13 to 07/06/13).

2.2.2. Occupancy data

To collect occupancy information of the case study building an efficient occupancy sensor [32] has been installed at the main entrance of the building. The occupancy sensor is based on the latest technology and uses a bi-directional infrared beam to count people entering or leaving the building. It creates an invisible barrier of two parallel infrared beams across the entrance and counts each interruption caused when a person enters or leaves the building. Information can be downloaded in the form of an excel file for every in/out, with total in/out counts at every 30 min and daily resolutions. All physical instruments inherent some instrument error. The manufacturer of the installed occupancy sensor suggests that this instrument is more accurate than traditional methods of people counting through a clicker, though accuracy should not be expected to be more than 90%.

2.2.3. Room activities

For the second and third term, the schedule for the teaching rooms in the PG centre was downloaded from the Heriot-Watt University web timetables. The daily room activity has been estimated by counting the total number of hours the six teaching rooms (PGG01, PG201, PG202, PG303, PG304 and PG305) are occupied. The room capacity for each room is obtained and the room activity data has been weighted for the room capacity using the following
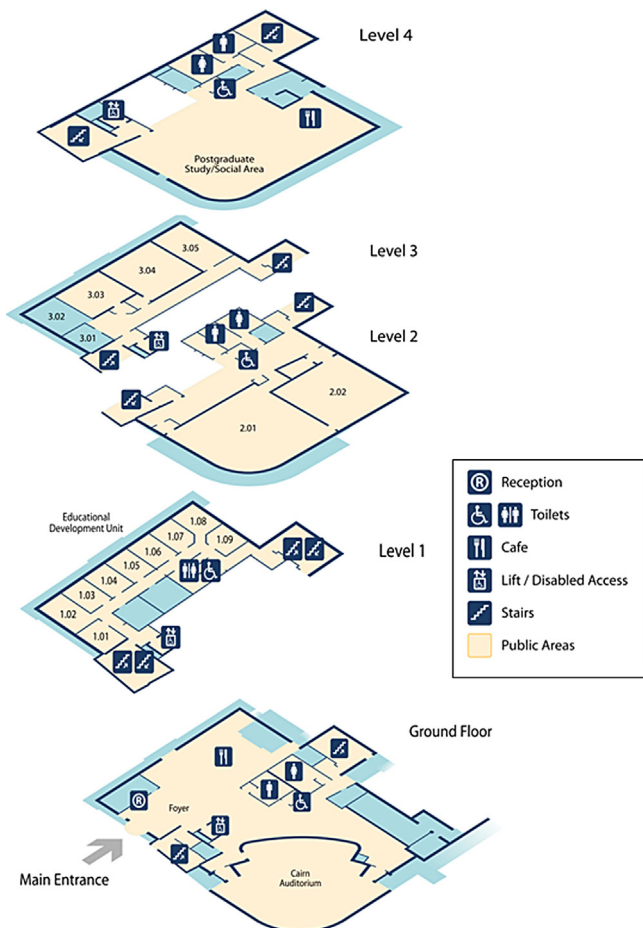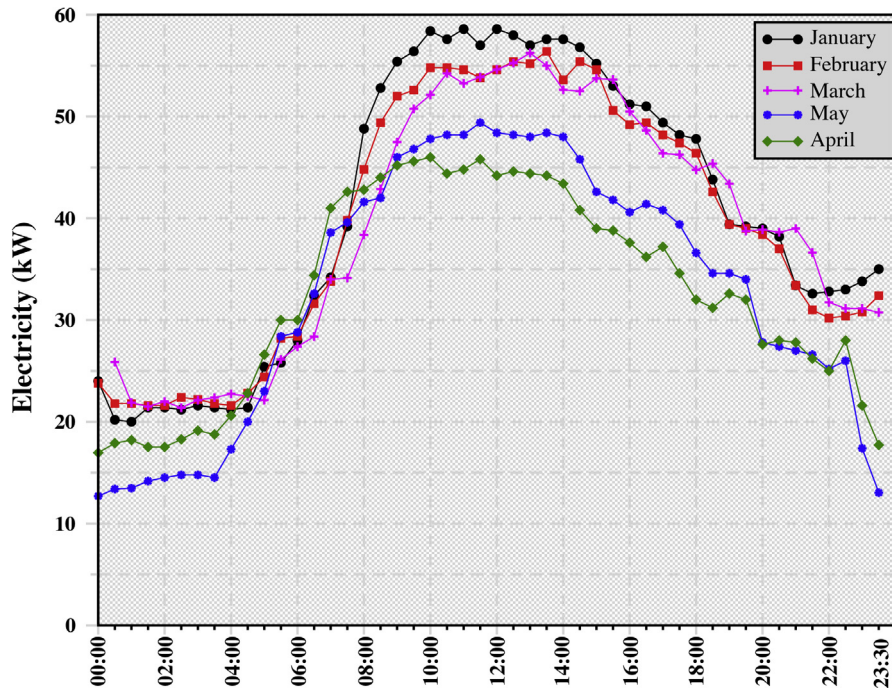
Fig. 3. Average daily electrical demand profile of the PG centre for January, February, March, April and May 2013.

relation:

Room activity during the day

= Total number of hours room occupied

∗(room capacity/100)   (1)

2.3. Participants and design

Building users and key management personnel were invited to participate in an online survey and interviews. The survey was designed and distributed in semester two to all staff and students at the PG centre via an electronic link. For students a paper copy of the questionnaire was also distributed by the lead author before each class and collected after the class to ensure completion and return. The questionnaire is specifically designed to obtain information on the users of the building and the activities that they carried out within the building which will be helpful in explaining the energy consumption profile of the building.

The qualitative data analysis involved semi-structured interviews with the PG centre building manager, café staff, control engineer and energy manager to shed light on the current issues pertaining to the PG centre and effective energy management. The interview questions mainly focussed on extracting insight as to how the building is operated, maintained and used on a day to day basis to identify areas where potential energy savings can be made.

3. Average daily electrical consumption

Fig. 3 presents the monthly average plots to demonstrate daily electricity consumption patterns of the building during terms 2 and 3 (as specified in Section 2.2.1). The analysis has been carried out at each half hour point of the day (starting from 00:00 to 23:30). Fig. 3 has been complied in to five graphs to distinctly present electricity consumption patterns in month: (a) January; (b) February; (c) March; (d) April and (e) May. It should be noted that only weekdays in terms 2 and 3 have been used for the purpose of this analysis. This

figure highlights that different months have very similar patterns of electrical consumption, with similar gradients in energy use at similar times.

On comparing average consumption between 8.30 am and 7:30 pm across different months it can be clearly seen that there are considerably lower values in April and May than in January, February and March. This could be due to the effect of heavy usage of the building during term 2 when teaching activities are in full swing in comparison to term 3 when most of the students are preparing for exams and may not be on campus. This is discussed in the following section below. This variation could also be due to weather related changes as the days get brighter and a bit warmer in April and May. This requires climate data information which is not in the scope for this paper. From Fig. 3 it is evident that the maximum electrical consumption occurs in January (58 kW) followed by February in term 2. In term 3, plots for April and May show a reduction in the range of 11–14 kW from the peak consumption in January. This may be attributed to a higher heating load in the winter season, whilst in May the heating is switched off centrally.

The plots in Fig. 3 follow a general trend where the demand profile starts rising at a certain point in the day (4.30 am) and continues to increase until the building opening hours (7 am), to its peak value (noon). The peak occurs in the afternoon followed by a gentle decrease from 7 pm onwards with further decrease from 9.30 pm. The profile then slowly slopes back towards the base (base load is discussed in Section 4.3.1) around midnight. It can be seen that during the month of January the maximum average load occurs at 58 kW and the minimum average load is around 24 kW.

4. Results

Section 3 provided an initial analysis of the electrical demand data which involved creating average daily profiles to determine the shape of the PG centre's energy use. To get an understanding of what constitutes the shape of the profile it is important to gather building usage information. The research instruments used to collate this information are questionnaire and semi-structured interviews and the results are given below.
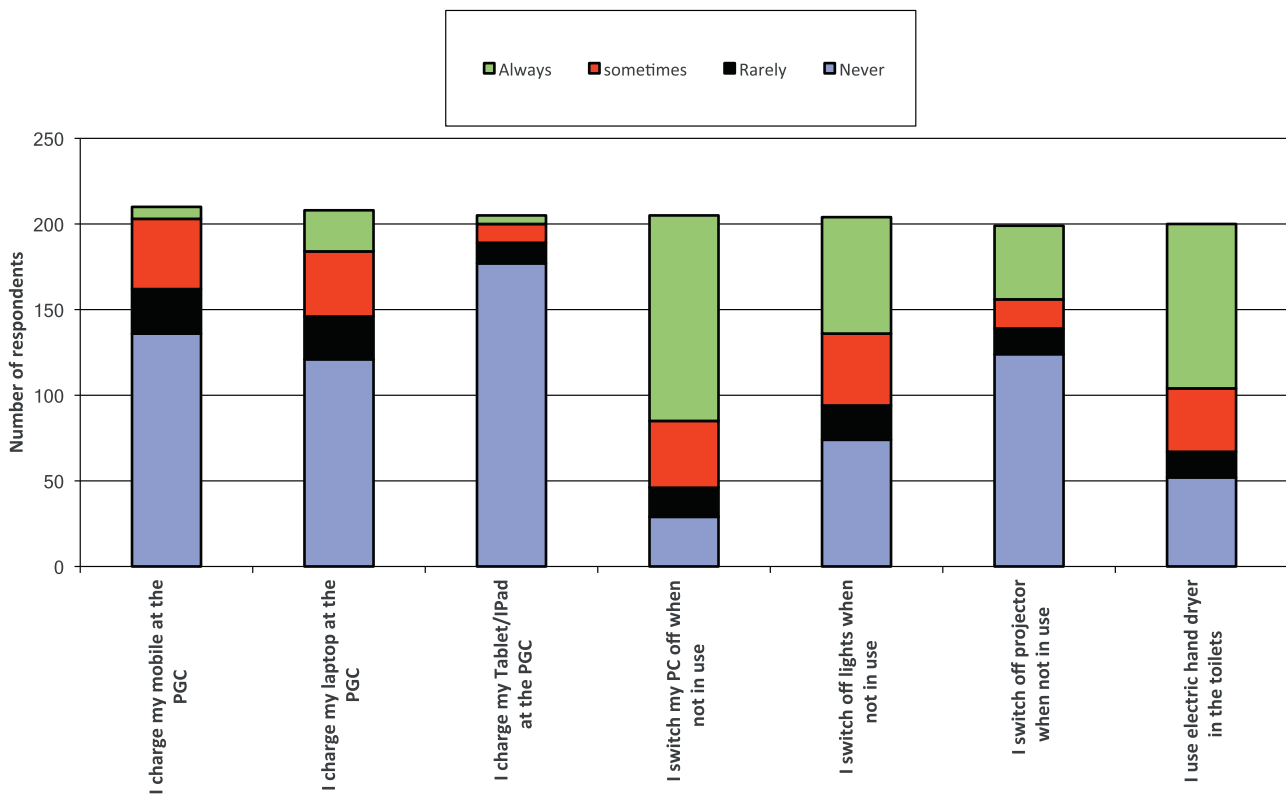
Fig. 4. Rating of actions by the user.

4.1. Questionnaire

A total of 208 responses were received: this included 81 post-graduate (PG) students, 116 undergraduate (UG) students, two academic staff and eleven support staff members. The first few questions revolved around the demographics and asked the respondents about gender, age and occupation. The results of the questionnaire indicated that 70% of the respondents fell within the 15–24 age band, 21% between 25 and 34, 7.5% between 35 and 44, 1.4% between 45 and 54 and only 0.5% between 55 and 64. 68% males and 32% females completed the survey and included 39% PG students, 55% UG students, 1% academic staff and 4% support staff. This indicates the major users of the building are PG and UG students where the staff based in the building constitutes a minor proportion.

The second section of the questionnaire aimed to get an indication of the purpose of visiting the PG centre and the amount of time spent in the building. The questionnaire results demonstrate that 92% of the building users were visitors, with only 8% of the users claiming to have a permanent office in the building. The participants were then asked about their purpose of visit to the PG centre. The major response (90%) was to attend a lecture, where 10% of the respondents said they were there to use the cafe and a similar proportion visit to use the study area on the top floor. Participants were then asked about how often they visit the PG centre. It is established that 63% of the respondents visit the building twice a week during week days, 14% visit every day, 13% visit once a week and the rest rarely or occasionally visit the building. The participants were then asked about the length of time on average within a week that they spent at the PG centre. The majority of participants indicated that the average amount of time spent at the PG centre is between 1 and 4 h. This is understandable as most of the respondent visits the building to attend a lecture which is usually 3 h long. A small number of respondents (predominantly staff with offices in the building) do spend between 7 and 9 h daily at the

PG centre. A few respondents also stated that their stay could be variable depending on when the lecture finishes or depending on where their work takes them around the campus and off campus where it could be anything between 9 and 0 h daily.

The final set of questions explored the nature and usage of the electrical equipment used by the participants at the PG centre. It was found that 67% of the respondents use a laptop, 14% use a PC and 37% use a tablet or an IPad. Around 6% (this figure mainly pertains to staff) said that they use an electric kettle and table lamp, 12% use printers, 7% use photocopiers, 4% use microwave ovens and only 2% use portable heaters. The respondents were asked to tick all the choices that apply to them. It was also found that photocopying or printing is not a major activity where around 90% of the respondents never print or photocopy at the PG centre and only 7% of the respondents print 1–10 pages per day.

To get an indication on how this usage might influence the electrical consumption of the building, the participants were asked to rate their usage using 'always', 'sometimes', 'rarely' and 'never' responses. Fig. 4 shows that around 60% of the respondents never charge their mobile phones, laptops or tablets at the PG centre and therefore do not add on to the electrical consumption of the building. A negligible number of respondents say that they always charge their mobiles and laptops with around 20% respondents saying that they rarely charge their mobiles, laptops or tablets. Fig. 4 shows that 32% of the respondents switch off lights when not in use whereas only 14% of the respondents say that they switch off their PC when not in use. The majority of responses 'never' switch off the projector when not in use. Finally approximately 50% of the respondents use electric hand dryer in the toilets.

4.2. Semi-structured interviews

The key information obtained through the interviews with the building manager, café staff, control engineer of the PG centre as well as with the university energy manager is as follows: The

normal working hours for the PG centre are from 7 am to 6.30 pm from Monday to Friday. There is limited access until midnight on weekdays and from 8 am to midnight on Saturday and Sunday. The building is alarmed and secured after midnight. The out of hours use of the building pertains mainly to the use of study space on the top floor or if there is an evening event. A total number of 16 members of staff including the building manager, three academic staff and 12 support staff are based in the building. The routine working hours for most of the staff are from 9 am to 5 pm with access to lighting controls, a personal computer (PC) and shared network printers and photocopiers. The building manager also has access to personal printer and photocopier. Some staff members work on a part-time basis and some choose to work from home most of the time. There is a small kitchen on the first floor for staff containing a microwave oven, dishwasher, a small fridge and an electric kettle. The dishwasher has never been used. A small kitchen is also provided for the students in the study area on the top floor and includes a fridge, microwave oven and an electric kettle. There are only two electric hand driers in the toilets in the building.

It was told that the cleaning staff comes in at 7 am and leaves the building at 3 pm. Daily activities include vacuum cleaning of the common areas such as corridors, social/study area, stairs and toilets in the morning. Teaching rooms and office spaces are cleaned once a week and floor polishing is done once a month. Issues were raised with the design of windows in the atrium in terms of access and cleaning. It is also mentioned that the use of new electric hand dryers in the building actually save the university some money over paper towels which block toilets when people flush them since they do not disintegrate like toilet paper.

Information is collected on the activities that occur in the café from the catering staff. The café opens from 8 am to 3.30 pm from Monday to Friday and is serviced by two members of the catering staff. With the exception of the under-counter fridges 1 and 2 and another fridge and freezer which are constantly switched on, appliances such as the coffee machine, display fridge, electric till, soup kettle and turbofan oven run only from 8 am to 3.30 pm. This information is useful in understanding the base load of the building when not occupied. The other appliances, which stay on for the full duration of the café opening times, such as coffee machine, display fridge, electric till, soup kettle and oven, help to explain the electrical consumption profile of the building.

It was explained that the building is both naturally and mechanically ventilated, where mechanical ventilation is controlled by the building management system (BMS) operated by the university Estates department. There are three air handling units (AHU) which control the ventilation rate in lecture theatres, the meeting/seminar rooms and the study space. The timings for the AHU are fixed and do not change during the year. For 2012/13 the AHU operates from 8 am in the morning to 9 pm in the evening for all the teaching rooms and from eight in the morning until midnight for the study/social spaces. For the BMS, the control sensors remain active constantly and enable pumps and boilers to protect the building from frost damage when the outside temperature drops below 3 °C in winter. Inside, the PG centre has a set temperature of 22 °C where the BMS maintains this temperature by switching on/off the heating and cooling systems depending on the decrease or increase in internal temperature. The basic times for the plant are as requested by the building management but the plant optimises itself (on/off) depending on outside and inside temperatures. There are no carbon dioxide sensors in the buildings, where exhaled carbon dioxide by people can be a useful indicator of a room's ventilation needs based on the number of people in the room.

Issues were raised with the design and maintenance of mechanically operated high-level louvres in the atrium. The automatic windows on the top floor study area are switched on all the time and have sensors to open or close automatically depending on external conditions of wind, weather, rain and temperature. These widows however, do not close properly and occasionally jam which has implications in terms of energy consumption. Increases in temperature over a certain threshold require windows to be closed as the chillers activate for air-conditioning.

It was told that the lecture/seminar rooms are fitted with audio-visual (AV) equipment and are used quite heavily during term time. There remains a chance that a lecturer may forget to switch all systems off completely after the last lecture of the day. PCs may be shut down but the control panel which shuts down the projectors could potentially be left on. This means that the projector bulb could potentially be left on all night resulting in energy consumption as well as bulb damage. Projector bulbs are also expensive to replace. A software program used throughout the whole University shuts down the systems (lights, projectors, PCs) in all the lecture rooms at midnight to prevent projectors being on throughout the night.

It was highlighted that the staff did generally switch the lights off in the corridor if they were the last to leave but this is no longer the case. A female staff member complained that she nearly tripped over as she was the last one to leave the centre and the lights were off. The lights were switched off for energy efficiency purposes but posed a health and safety risk. This implies a restriction on energy savings due to electric lighting which is also highlighted as one of the barriers by Dubois and Blomsterberg [21]. The top floor lights are usually left on as students do not tend to switch them off. Most of the time it is the cleaning staff who come in the morning at seven who switch them off. The night lights are on timer and come on depending on the sunset times over winter and summer. Due to inefficiency and lack of control over heating and cooling systems some staff use electric heaters in their offices.

It was mentioned that the stair case does get extremely hot in peak summer days due to glazing and seems deserted. There is no shading and the use of lifts increases as people avoid taking the stairs due to it being so hot. At the same time there also seems to be a lot of unnecessary use of lifts as many users look able to walk up the stairs. It is proposed that the energy consumption data needs to be monitored monthly and recharged to the energy management group to analyse and look at the optimisation of systems. The biggest barrier to this however, is the lack of resources in terms of finance, time and man power.

4.3. Room activity, building occupancy and average daily electrical consumption

The main focus of this paper is to determine the influence of room activities and occupancy in terms of lectures, seminars and meetings on the energy consumption of the building from January 2013 to May 2013.

Fig. 5 compares the daily average electricity consumption, total daily occupancy (total number of people entering the building) and daily room activities for weekdays in January (when the term is at its peak) and May (when most of the lecturing is finished). In Fig. 5, the upper panel shows 'daily average electricity consumption', the middle panel shows total 'in occupancy' and the lower pane presents 'room activities' where the red dashed lines represent the monthly average values. From the figure it can be seen that the electrical consumption, daily occupancy and daily activities are higher for January in comparison to May. It can also be noticed that there is some variation in the average electricity consumption of January and May, whereas from the middle panel one can notice a comparatively large variation in the daily occupancy of the building. All variables seem to follow a similar trend which is more significant for January, whereas for May a decrease in electrical consumption can be linked to lesser room activities and occupancy at some instances only.
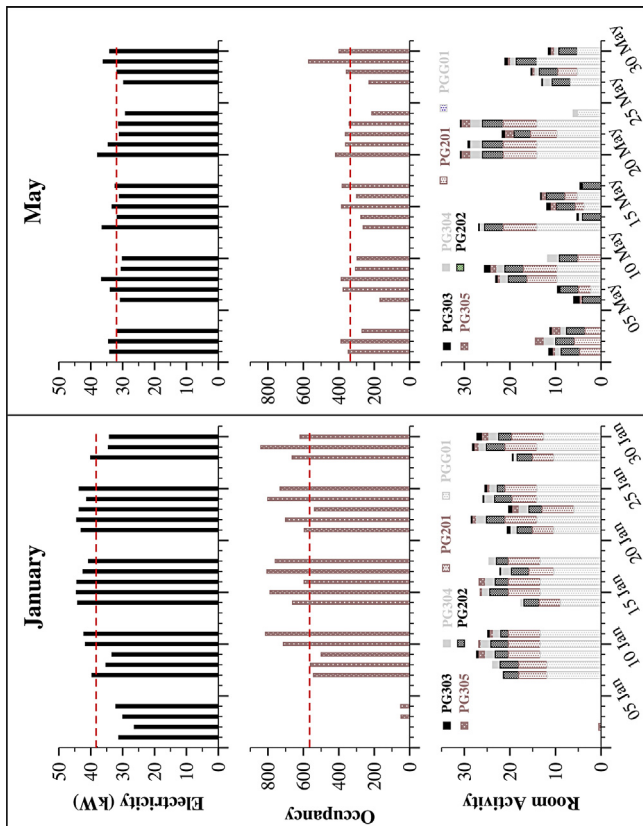
Fig. 5. Average daily plots for January and May. Upper panel: daily average electricity consumption (kW); middle panel: total daily in occupancy (count data of number of people entered in the building); lower panel: room activity staked bar graph (estimated by Eq. (1) for PGG01, PG201, PG202, PG303, PG304 & PG305).

Table 1
Main activities and automatic systems operational times.

Systems	Start	Finish	Operator
Air handling unit			
Teaching rooms	08:00	21:00	Estates
Study/social	08:00	00:00	Estates
Toilet extract	08:00	00:00	Estates
Hot water	06:00	00:00	Estates
Lighting	Depends on requirement		Staff/students
Activities			
Cleaning	07:00	09:00	Staff
Café	08:00	15:30	Staff
Teaching	09:30	18:00	Staff
Support services	09:00	17:00	Staff
Lift	07:00	00:00	Staff/students

4.3.1. Hourly analysis

Using a daily average profile can mask the variations that occur in energy use at a small resolution such as an hourly or half-hourly level. Further analysis was therefore performed at half-hourly levels to explore the variations which might occur in the electrical consumption due to the influence of the number of people entering the building or the room activities. For this purpose three days were selected from each month by locating days with minimum, maximum and near average energy consumption value from the monthly average values shown in Fig. 3. Presently, for January, 02/01/2013, 15/01/2013 and 07/01/2013; and for May 24/05/2013, 20/05/2013 and 15/05/2013 were selected and the results for electrical consumption (top pane), occupancy (middle pane) and room activities (bottom pane) are shown in Figs. 6 and 7. Fig. 6(a) depicts the results for January 2nd where one may conclude that electrical consumption is due to the base load only since there is no occupancy detected and no activity being undertaken due to it being a public holiday. Drawing on the idea of Firth et al. [33] the base consumption of the centre may include the electricity consumed by continuous appliances which have to remain switched on all the time e.g. security cameras, display monitors and computer servers and cold appliances such as refrigerators. The electricity consumed by active appliances (e.g. lights, kettles, computers, printers, photocopiers, microwave ovens, electric hand dryers) and standby appliances (e.g. desk-top computers, display monitors and printers) is flexible consumption, because these kinds of electric equipment and appliances can be switched on/off at any time, depending on the behaviour of users.

Fig. 6(b) presents the plots for January 15th, where it can be observed that there is a step increase in electrical consumption around 10 am when the room activities start. It can also be seen

that the number of entrants is also quite high which may have some bearing on the electrical demand of the building. The point to be noted here is that the occupancy plots do not show the variation in occupancy at half hourly level. Instead they only show the number of people entering the building and do not provide an account of how many people are actually present in the building at that time.

Based on the questionnaire results, it is apparent that the major activity during term 2 is for the lectures (predominantly UG) that take place in room PGG01. The questionnaire also tells us that most of the students visit the building for lectures and tend to stay there for the duration of the lecture which is on average between 2 and 4 h/day. There is a dip in room activities around 2 pm which might indicate the end of morning lectures and users leaving the building. The room activities rise again at 3 pm when the number of entrants increase considerably but with no change in electrical consumption. From 6 pm onwards the number of people entering the building is minimal and based on questionnaire information most of the users have also left the building at this point, since all the lectures have finished. However, the electrical consumption remains quite high until 8 pm even with no room activities after 6 pm. Fig. 6(c) shows the results for 7th January which correspond to the near average daily electricity consumption for the month of January. It can be seen that the occupancy varies considerably whilst the room activity and the electricity profile remains mostly constant. Similar trends are observed for Fig. 7, where the least amount of room occupation corresponds to the fact that most students are away on exam leave in May. It is apparent from Fig. 7(c) that the decreased occupancy or room activity has no significant impact on the electrical consumption profile which remains quite high.

5. Discussion

From Section 4.2 the major activities and the automatic system's operational times are summarised in Table 1. Fig. 3 can now be examined in light of this information. It may be deduced that the initial ramp could be the result of the switching on of electrical heating pumps and fans for the heating or cooling systems [34]. Further increases in electrical demand could be attributed to the running of AHUs and use of active appliances (e.g. vacuum cleaner, lights, kettles, computers, printers, photocopiers, microwave ovens) and standby appliances (e.g. desk-top computers, display monitors and printers). The peak occurs in the afternoon when the use of café and room activities are in full swing followed by a gentle decrease from 7 pm onwards with a further decrease from 9.30 pm when the out of hours access applies. The profile then slowly slopes back towards the base, and reaches the base load value after the building is closed (midnight) and all the AV equipment is turned off by a centrally controlled program.

It is presumed that the more rooms that are occupied the greater the electrical demand of the building. This would mean that
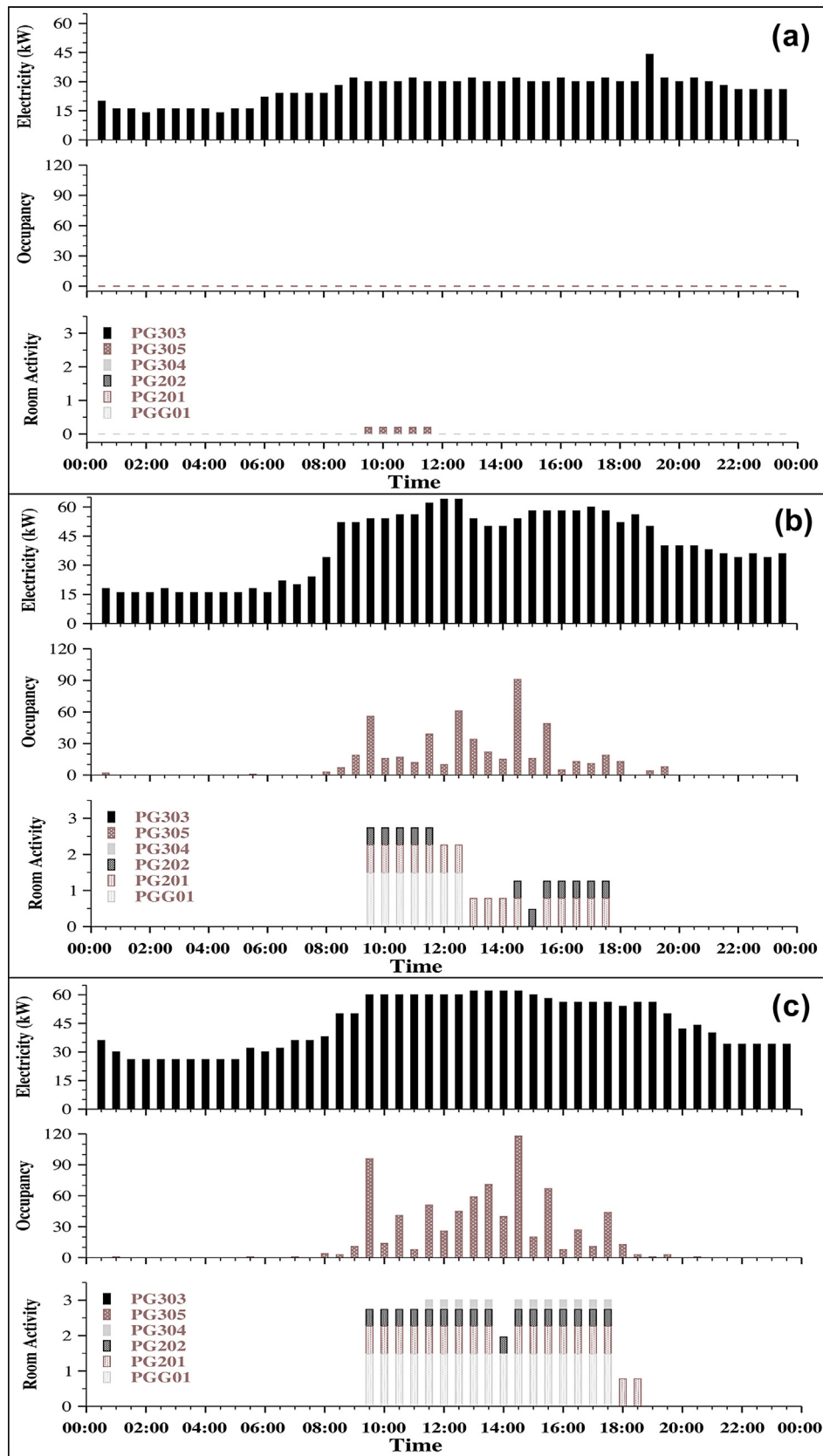
Fig. 6. Hourly plots for electrical consumption (kW) (upper panel), occupancy (middle panel) and room activity (lower panel). (a) Day with minimum daily electrical consumption (02/01/2013), (b) day with maximum daily electrical consumption (15/01/2013) and (c) day with near average daily electrical consumption (7/01/2013).
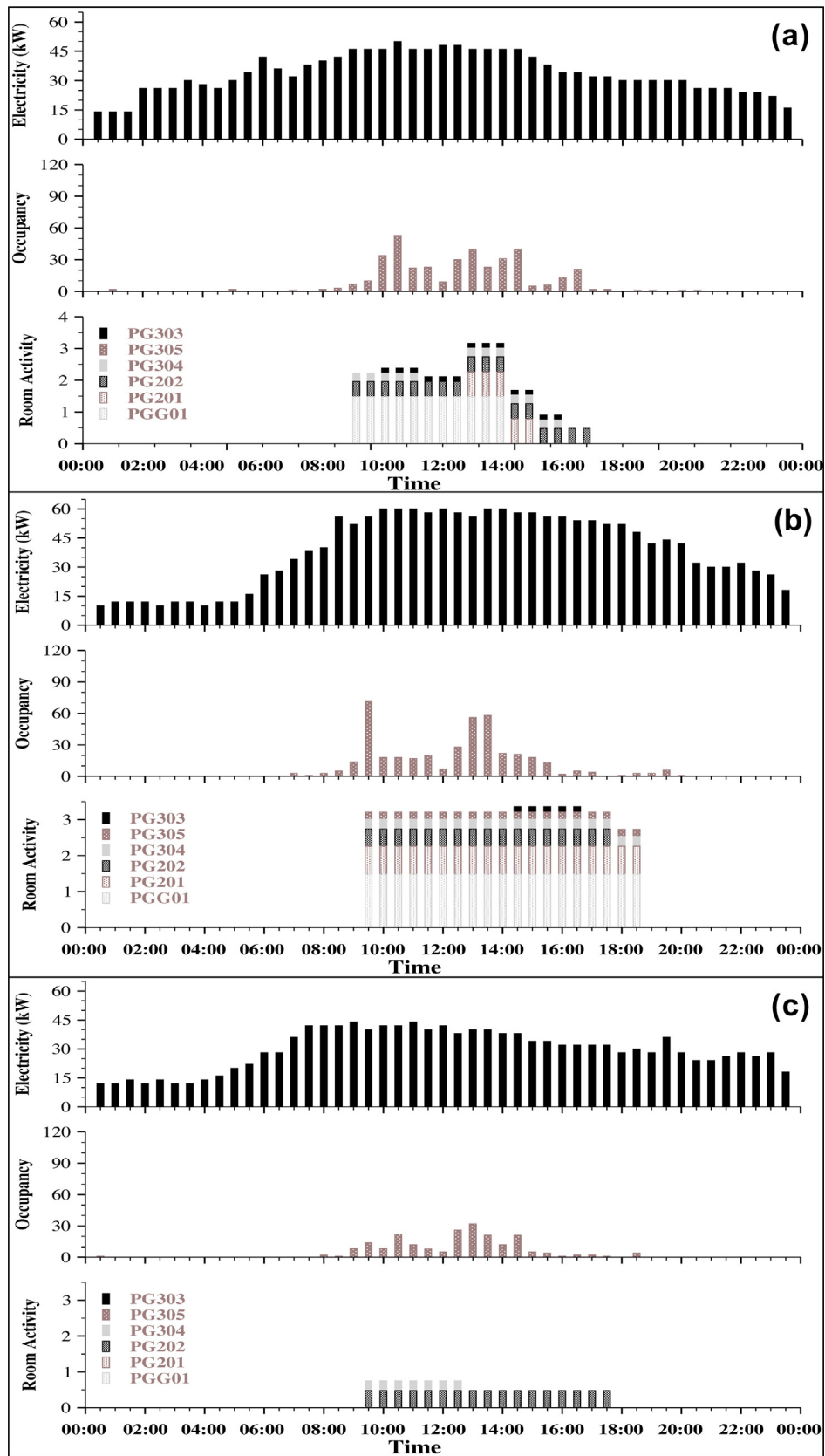
Fig. 7. Hourly plots for electrical consumption (kW) (upper panel), occupancy (middle panel) and room activity (lower panel). (a) Day with minimum daily electrical consumption (24/05/2013), (b) day with maximum daily electrical consumption (20/05/2013), (c) day with near average daily electrical consumption (15/05/2013).

increased activities are likely to influence the electrical consumption profile due to the usage of electrical appliances such as PCs, monitors, projectors, lighting and mechanical ventilation. Fig. 6(b) shows that from 10 am to 12 noon, room activity as well as the number of entrants is quite high whereas from 12 noon to 5.30 pm the room occupancy is very low but there is not a significant drop in electrical consumption. A tremendous increase in the number of entrants around 2 pm however, may have a bearing on the electrical consumption of the café or the use of the study area on the top floor. According to Emmanuel and Baker [35] in a non-domestic building in the UK around 19% of the total operational carbon emissions are from lighting, 16% for mechanical ventilation, 16% for electrical appliances whilst catering constitutes only 4%. This corresponds to an equivalent percentage of energy consumption. This implies that the increase in café usage does not contribute significantly to the electrical consumption of the building.

Similar trends are observed for Fig. 7 where it is apparent that decreased occupation do not significantly impact on the consumption profile. The question arises as to why these activities do not match the electrical profile.

From the interviews (Section 4.2) it was confirmed that the heating and cooling systems of the PG centre are controlled by the BMS. The aim of a BMS is to control all systems in the building to assure the proper management of the energy demand, to conserve energy, to improve the comfort levels including indoor-air quality, and to increase the building's productivity through leveraging information [36]. The BMS is therefore a critical component in managing energy demand. Improperly configured BMS that are rigid tend to increase building energy usage. In a building like the PG centre where all rooms will not be used throughout the day, the strategy for energy efficiency should be to configure systems such as mechanical ventilation to allow the ventilation to individual rooms to be reduced back to the minimum set-back rates when not in use. This will save energy in heating and cooling and will also significantly reduce fan power consumption. One would think that the BMS strategy for the PG centre would be that the ventilation systems are configured and controlled to enable the system to run at reduced flow rates during times of low occupancy or when the rooms are not being used. This contradicts the findings of this study where higher electrical consumption was observed when there are no occupants in the rooms and no activities are being carried out. This implies that the automatic systems are running irrespective of the room occupancy and activity status.

Automated building control and enhanced reporting offer enormous potential for energy saving [8]. Although facilitating the interpretation and archiving of energy use; the practice of eliciting actual performance from a BMS is rarely explored [27]. As highlighted in Section 4.2, to be able to carry out a change in the setting of automatic systems, Estates are required to carry out monthly and systematic analysis of buildings activities and equipment usage. According to Wang et al. [37] the available data from properly designed and maintained building management system (BMS) supplemented with measurements from electricity metres and temperature loggers are generally sufficient to obtain a clear picture of the energy use of typical HVAC systems. In this way, the energy performance of a HVAC system and energy conservation opportunities may be readily identified and implemented at very low or even negligible costs. Cho et al. [20] proposes the development of an energy evaluation program aimed at understanding the energy consumption characteristics of the HVAC and refrigeration systems to improve the energy efficiency of buildings. A 'subsystems approach' [38] can also be adopted for the energy analysis of HVAC systems in order to improve energy efficiency within the building sector.

There is some opportunity for energy savings where building users are responsible for the operation (Table 1). For instance making sure that AV equipment is turned off after a lecture, switching the lights off, shutting down the PCs when out of office for a meeting and giving stairs precedence over elevators.

The feedback from Section 4.2 suggests that a targeted awareness raising campaign at the building level would be beneficial in achieving the potential energy savings and could be carried out as a part of the University's energy management strategy. Au-Yong et al. [18] recommended that the management should develop an effective communication platform such as a meeting and online feedback system, involving all key participants with commitment and contribution towards the maintenance activities.

6. Conclusions

A pilot study was undertaken to analyse the relationship between the electrical energy demand profiles and user activities and occupancy for a multi-purpose university building. To gain insight into how the building is used, operated and managed on a daily basis, an online questionnaire was distributed to staff and students as well as interviews being conducted with key management personnel. The analysis of daily electricity consumption patterns of the building indicated that different months had very similar patterns of electrical consumption, with similar gradients in energy use at similar times. There are however, considerably lower values in April and May than in January, February and March due to the effect of heavy usage of the building during term 2 when teaching activities are in full swing in comparison to term 3 when most of the students are preparing for exams and may not be on campus.

The results of the questionnaire indicated that 92% of the building users are visitors, where the remaining are support staff and academic staff who have a permanent office space in the building. The cleaning and catering staff works from seven in the morning until half past three in the afternoon. During term time when the building is mostly used for teaching activities, students are the major users where the average amount of time spent by them is between 1 and 4 h/day to attend a lecture. A small number of respondents (predominantly staff with offices in the building) do spend between 7 and 9 h daily at the PG centre. It was identified that the activities undertaken by the building users and in particular the students have a small influence over the electrical consumption of the building. In terms of the nature and usage of electrical equipment, it was highlighted that 67% of the respondents use a laptop, 14% use a PC and 37% use a tablet or an IPad. Around 6% said that they use an electric kettle and table lamp, 4% use microwave ovens and only 2% use portable heaters. It was also found that photocopying or printing is not a major activity where around 90% of the respondents never print or photocopy at the PG centre and only 7% of the respondents print 1–10 pages per day.

It was highlighted that around 60% of the respondents never charge their mobile phones, laptops or tablets at the PG centre and therefore do not add on to the electrical consumption of the building. 32% of the respondents switch off lights when not in use whereas only 14% of the respondents say that they switch off their PC when not in use. The majority of responses (from students) 'never' switch off the projector when not in use. Analysis was performed at half-hourly levels to explore the variations which might occur in the electrical consumption due to the influence of the number of people entering the building or the room activities. This study has shown that electrical consumption does not vary significantly due to changes in occupancy levels when students leave the building or with no room activities such as a lecture finishing or the closure of the café at half three in the afternoon. It has been highlighted that the major source of electrical consumption is the pre-set heating/cooling systems of the building operated by a BMS which is controlled by the University Estates department

which does not take into account the room activity or occupancy status. The ways by which buildings in operation are managed significantly affect energy use. Activities that are dependent on the user behaviour e.g. turning off the AV equipment and lights after a lecture finishes, shutting down the PCs and monitors when not in use, have the potential to save energy and can be tackled by raising awareness via a good energy management strategy.

This paper has highlighted that whilst designing the operational timings for the automated systems, the occupancy patterns of the case study university building were not considered. What this study has unearthed would not have been identified from a normal energy audit. Identifying gaps in terms of day to day operation of the building certainly has the potential to reduce energy consumption along with installing energy efficient equipment. This study proposes that a thorough and detailed investigation is required to get a better understanding of the effect of various factors and their complex interaction with the energy requirement of the building. The relationship between the energy demand profile and behavioural aspects of users as well as gathering operation data to get an understanding of the energy intensity of electrical appliances and systems with respect to floor area is required. This information will be helpful in re-configuring the PG centre BMS and form the basis for developing a forecasting model based on the activities of a building at any given time of the year. It is hoped that the applicability of such a model would span to other buildings of similar type and can help energy/facility managers to plan optimum schedules for the automatic systems to achieve significant amount of energy savings.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

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