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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.

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

[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.