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A methodology for creating building energy model occupancy schedules using personal location metadata

James Parker*, Adam Hardy, David Glew, Christopher Gorse

Centre for the Built Environment, Leeds Sustainability Institute, Leeds Beckett University, Broadcasting Place, Woodhouse Lane, Leeds, LS2 9EN, United Kingdom

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ABSTRACT

Occupants affect energy consumption in buildings by contributing internal heat gains, increasing internal carbon dioxide levels and adapting their behaviour. Estimated occupancy schedules are used in building energy models for regulatory compliance purposes and when empirical data are not available. Metadata, such as personal location data, is now collected and visualised on a global scale and can be used to create more realistic occupancy schedules for non-domestic facilities, such as large retail outlets. This paper describes a protocol for extracting and using freely available metadata to create occupancy schedules that are used as inputs for dynamic simulation models. A sample set of twenty supermarket building models are used to demonstrate the impact metadata schedules have when compared with models using the estimated schedules from regulatory compliance. Metadata can be used to create bespoke occupancy profiles for specific buildings, groups of buildings and building archetypes. This method could also help reduce the gap between predicted and actual performance. In the example models, those using the regulatory compliance schedules underestimated heating demand by approximately 10% and overestimated cooling demand by over 50% when compared to models using the metadata schedules. Although this work focuses on UK facilities, this methodology has scope for global application.

1. Introduction

Amid the global need to reduce greenhouse gas emissions, the built environment offers substantial scope for increasing energy efficiency and reducing the amount of anthropogenic carbon dioxide (CO_2) released into the atmosphere [1]. Non-domestic and commercial buildings account for a significant proportion of CO_2 emissions and represent approximately 18% of the UK's total carbon footprint [2]. Building occupants form part of a complex system within non-domestic facilities and have a direct impact on energy performance. They therefore represent an intrinsic data input within building energy models [3].

As part of the ambition to reduce energy consumption within the built environment, building energy modelling is now an established and cost-effective tool used in the design process for both new-build and major retrofit projects [4,5]. The design stage offers the first opportunity to reduce building energy consumption and building energy modelling plays a pivotal role in this process [6]. The importance of occupancy patterns and occupant behaviour has been emphasised in recent years through the IEA Annex 66: Definition and Simulation of Occupant Behaviour in Buildings [7]. Occupancy patterns and occupant behaviour become even more critical to energy and thermal performance when modelling buildings that include occupancy-based controls [8].

Occupancy schedules are used in building energy models to dynamically control occupant density and internal heat gains within the thermal envelope. Ideally, designers will have access to empirical data when creating these occupancy patterns. When producing models for non-domestic regulatory compliance in the UK, estimated occupancy schedules are used to control the temporal distribution of the internal heat gains from people within these models; the National Calculation Method (NCM) provides estimated occupancy schedules for a range of non-domestic buildings that can be used in dynamic simulation modelling (DSM) [9]. The NCM and associated DSM calculations are used, along with other forms of analysis, to underpin the development of Government policy in relation to energy consumption and carbon emissions from the non-domestic building sector [10]. The NCM schedules (and similar default schedules in other countries) can also be used when no empirical occupancy data is available to building energy modellers. As well as controlling the passive internal heat gains

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* Corresponding author.
E-mail address: j.m.parker@leedsbeckett.ac.uk (J. Parker).

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associated with building occupants, they can also be used to control other variables such as ventilation rates or lighting operations.

This paper describes a methodology for the use of metadata to create more realistic occupancy schedules that can be used in DSM models of commercial buildings and, potentially, other non-domestic facilities. The term 'metadata' is used to describe a diverse range of data in the modern world but can be succinctly described as "data about data" [11]. It has also been described as data-driven 'knowledge' and it is this definition that is most practical in the context of this work [12]. Metadata are now collected on a global scale and personal location data is used to illustrate the temporal popularity of various locations, including buildings that are open to the general public. It is estimated that over 80% of people within the UK now use smartphones on a daily basis and it is this type of device that is the main source of the location data used here [13].

This work uses data collated and visualised by Google as part of their business analytics services. A method for collecting the published data and converting them into DSM occupancy schedules is described. A sample set of 80 UK supermarkets are used as a case study to demonstrate how this method can be applied. The sample set is used to create schedules that describe average occupancy within this building type and used to create personal location metadata schedules (referred to in the remainder of this paper as 'metadata schedules' for convenience). The metadata schedules are then used within a smaller sample of 20 supermarket DSM calculations to quantify the impact that they have on estimated energy performance.

It is common for there to be significant gaps between the predicted energy consumption of a building and the metered energy consumption of the operational facility [6,14]. There are multiple reasons for this gap, which has been recorded as being over twice that predicted for some non-domestic buildings in the UK [14,15]. It is, however, possible to create accurate building energy models by improving the quality and accuracy of input data [5,16–21]. In many cases, the gap between modelled and measured energy performance is a result of comparing metered data with outputs from models created to achieve regulatory compliance [14,15]. The work presented in this paper aids the creation of more realistic occupancy schedules for this type of compliance modelling which can, in turn, play a role in improving the accuracy and pragmatism of the model energy performance estimates. The methodology and resultant occupancy schedules are also of practical use to the wider community of building designers, engineers and researchers in the field of building energy performance for both new build and retrofit projects. As energy efficient building technologies mature, their theoretical limits are becoming narrower and, especially in the future, this will place greater emphasis on producing robust design. It will also place more emphasis on energy conservation measures [22]. Producing more accurate occupancy schedules and models of user behaviour can help to maximise the savings from energy efficient technologies and to quantify the potential impact of behavioural change.

In the following section, literature concerned with the simulation of occupancy in building energy models is reviewed. Although there is a broad range of work published on this topic, the review demonstrates the original nature of the approach defined in this work. The methodology section describes how the published data can be collected and formed into occupancy schedules that are suitable for use within DSM software. Results illustrate the occupancy schedules informed by the metadata and compare them with those included in existing regulatory compliance guidance. The results section also compares predicted energy and thermal performance from DSM models using the metadata schedules with models using the default occupancy estimates.

2. Occupancy schedule data for simulation

As mentioned in the introduction, the role of building occupants in building energy simulations is the subject of an IEA Annex [7]. As noted by Yan et al. [4], the importance of occupants was previously highlighted by Annex 53: Total Energy Use in Buildings, which identified occupant behaviour as one of the key influences on building energy performance along with climate, building envelope, building services, indoor design criteria, and operation and maintenance [4]. The aim of Annex 66 is to define occupant behaviour in buildings and to account for this behaviour in building energy simulation models [7]. Of particular relevance to this work, Yan et al., have published a review of the current state-of-the art in this field, as well as identifying areas for further work [4]. Occupants can interact with a number of building elements and artefacts, including opening windows, lighting systems, shading devices, HVAC controls and use of appliances [4]. These interactions can also be defined as resulting in either passive or active effects [23]. Occupants often have very little opportunity to interact with control systems in commercial and non-domestic buildings. Their presence within buildings is, however, a driver for energy performance due to occupants passively adding sensible and latent internal heat gains and influencing the need to condition the spaces that they occupy [3]. Occupants also increase internal CO_2 levels during occupied periods. Occupant impact on building performance can usefully be divided in to two main influences as defined by Wang et al. [8]. The number of people present in a building or zone at any given time can be defined as *occupancy* [8]; this definition is also consistent with that defined by Liao et al. [24]. The interaction of occupants with building systems can be defined as *occupant interaction*.

For occupancy modelling to be useful to designers and engineers, it must "...balance practicality with accuracy" [4]. Yan et al. cite work published by Melfi et al., which identifies the different resolutions that relate to building occupancy [25]. These are divided into temporal resolution, spatial resolution and occupancy resolution. Following the Melfi et al. model, the occupancy patterns created in this work are at an hourly temporal resolution, at a building-level spatial resolution (in this case, supermarkets) and at an occupied state/number of people occupancy resolution. In the context of the work presented in this paper, it is also important to note that Yan et al. describe models with 'excessive inputs' and that are 'excessively complex' as being 'over-fitted' [4]. This is relevant to the occupancy schedules described here as the data are used to create average weekly profiles, rather than complex profiles that differ from day to day and from week to week in an attempt to capture constantly dynamic and stochastic behaviours. The schedules created in this work are intended for use in models where there is no empirical data available, in early stage design calculations and regulatory compliance calculations. It is therefore practical to use simple weekly average profiles when creating models for representative facilities within a particular classification of building type.

There can be a significant difference between estimated occupancy patterns for building archetypes and those found in operational facilities; this variance is illustrated in Section 4 of this paper. In a study conducted by Sun & Hong, it is noted that observed occupied hours in a case study office building are significantly lower (under 50%) than the normalised occupancy schedules published by the Department of Energy (DOE) in the USA [22]. The same study also found there to be significant differences in both the frequency and density of occupancy in various zone types when compared with the DOE schedules [22]. This will have an impact on the thermal conditions in each space and the energy performance of the building as a whole.

Most commonly, the presence of occupants in a space is represented in building energy simulations using deterministic