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Clustering of household occupancy profiles for archetype building models

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Abstract

The continued penetration of renewable energy sources in electricity generation and the de-carbonization of the domestic space heating and hot water sectors is increasing the importance of demand side management (DSM). The development of end-use energy consumption models that can be easily integrated with electricity dispatch models is crucial for the assessment of the integration of supply and demand. The energy consumption of the domestic building stock is highly correlated with occupant behaviour, however the inclusion of occupant behaviour in energy models is challenging due to its highly variable nature. Nevertheless, in order to obtain reliable models of domestic energy consumption at high time resolution, the analysis of occupant behaviour patterns is fundamental. This paper aims to develop a new methodology to generate realistic occupancy patterns that can be representative of large numbers of households. This method is based on the clustering of household occupancy profiles using the UK 2000 Time Use Survey data as a case study. The occupancy profiles that result from this method can be used as input to residential building energy end-use models, thereby giving improved overall model performance.

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Keywords: building model; occupancy profile; k-mode clustering

1. Introduction

Due to the increasing penetration of renewable energy sources in electricity generation portfolios and the de-carbonization of the domestic space heating and domestic hot water sectors, demand side management (DSM) is assuming a fundamental role in the development of new energy policies. The assessment of the integration between demand and supply of electric energy is fundamental and it can be achieved by integrating unit commitment and dispatch models with large scale simulation models of the building energy sector [1]. The simulation of building energy demand at large scale is challenging and it is approached in different ways by different researchers [2]. In general, two main methodologies can be identified: top-down and bottom-up. The top-down approach is based on the analysis of the whole residential sector energy consumption, and it does not distinguish individual end-users. In contrast, the bottom-up approach is based on knowledge of the energy consumption of each single building. For

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this reason, it is useful when the aim of the simulation model at large scale is the assessment of the contribution of each building towards the aggregate energy consumption of the domestic stock. If the model must be used for the assessment of DSM, it is important to monitor customer engagement at an individual level, especially when the electricity demand is modified. In this case, the choice of the bottom-up approach is essential.

The bottom-up approach can be sub-divided into a statistical approach and an engineering approach [2]. A key feature of engineering approaches is that they do not need any historical data, so they are preferred to the statistical approach in case of a lack of past information of building energy consumption. The engineering approaches include: distributions, archetypes and samples [2] techniques. Between these three techniques, the methodology that appears to assure a high degree of accuracy with lower computational effort is the archetype technique. It is based on the classification of buildings in groups with similar characteristics called archetypes, and on the simulation of these buildings instead of the overall buildings belonging to the building stock. Each archetype is defined by specific features into four main areas: form, envelope, system and operation [3] . The total energy end-use demand can be scaled up by multiplying the results of each archetype by the number of houses represented by each archetype.

In the case of residential buildings, it seems that while a considerable number of researchers have focused on the division of the building stock according to form, envelope and system characteristics of the building [4–8], just a few have focused on the relevance of occupancy patterns, which can define the archetype in the operation area. Richardson et al. [9] proposed a method based on the use of Monte Carlo simulations to produce random occupancy patterns based on the behaviour of large and heterogeneous populations. The profiles that can be obtained from this methodology are the results of combined occupancy profiles, and they cannot be used to characterise an archetype. Yao and Steemers [10] argued that the main characteristics influencing residential building energy consumption are the number of occupants and the length of the periods in which the houses are occupied. In their research, five fixed common occupancy profiles for UK households were proposed, based on authors experience. These profiles were used to characterise the archetypes in the operational area. This approach has a lower computational cost because it eliminates the necessity to implement a Monte Carlo simulation for each household, but it introduces errors due to the arbitrary choice of the occupancy scenario, which are not based on quantitative data.

The aim of the methodology presented in this paper is the development of characteristic occupancy profiles that can be applied to characterise archetypes considering the operational area. The profiles are obtained using a new approach based on a statistical clustering technique, which groups together the households with similar daily occupancy profiles. Once the characteristic occupancy profiles are identified, they can be coupled with the archetypes identified considering just the form, envelop and system characteristics, to create a complete archetype, with specific physical and also operational characteristics, as described in [3].

In this paper, the methodology, which is presented in Section 3, is applied on the data available from the UK 2000 Time Use Survey, which is described in the Section 2. The occupancy profiles that are obtained by applying the methodology to the UK building stock are shown in the Section 4.

2. Time-Use Survey data

The UK 2000 Time Use Survey [11] (UK TUS 2000), is a national survey which was conducted in UK in 2000, to record the everyday routine of 11700 UK citizens belonging to 6500 households. One household is defined as a person or group of people who have specified the accommodation as their only or main residence and either share at least one meal a day or share the living accommodation. The survey respondents occupied private houses which were evenly spread into the 5 regions of Great Britain: South East (excluding London) and South West; London; North West, North East and York/Humberside; Wales and Scotland; Northern Ireland. The respondents were asked to complete a household questionnaire, an individual questionnaire and two diaries, respectively one for a weekday and one other during the weekend, where the activities conducted were recorded every ten minutes.

The household questionnaire allows the determination of the number of members of each household, which defines the household size, and the type of accommodation in which they live. From these data it is possible to understand the breakdown of different size households by type of accommodation, which can be associated to a defined archetype. Figure 1 shows the percentage of the different accommodation types, identifies in the UK TUS 2000, occupied by households with different number of members. This figure, for example, shows that the percentage of accommodation occupied by one occupant is more than 60% (62.6%) for the flat/apartment, but it does not exceed 35% for the other