Energy & Buildings 174 (2018) 13–25

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

A comparative analysis of building energy estimation methods in the context of demand response

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ARTICLE INFO

Article history:
Received 6 November 2017
Revised 23 April 2018
Accepted 2 June 2018
Available online 19 June 2018

Keywords:
Demand side response
Estimation comparative analysis
Method review
Electricity demand

ABSTRACT

A critical element of assessing a building's suitability for Demand Side Response (DSR) is understanding its turndown potential to ensure that DSR participation will be financially viable. While research has been undertaken on site level DSR estimation methods, there is currently no research that compares the outcomes of these methods. This paper compares four non-domestic energy estimation methods used for understanding the DSR potential of electrical appliances in a building to provide insights about uncertainty levels based on input requirements. Each method is deployed to estimate the DSR potential of HVAC chiller assets at two UK hotels over two years. The results show the methods have a range of error levels from the highest Mean Average Percentage Error (MAPE) of 159% to the lowest MAPE of 39%. The input requirements followed a general trend of more complex informational inputs resulting in lower error values. The outcomes of this research enable users to make informed decisions in selecting DSR estimation methods based on information availability and acceptable estimation error levels.

1. Introduction

Demand Side Response (DSR) programmes generally require a detailed understanding of the turndown potential of participating buildings to accurately forecast DSR capacity for electricity system balancing. This detail is needed as DSR programmes will apply penalties if contracted levels of turndown are missed. As an example, the UK Short Term Operation Reserve (STOR) programme requires participants to provide a guaranteed turndown kW amount for set periods of time of up to 14 h per day [20]. If STOR participants underdeliver by more than 5%, then financial penalties are applied and progressively increased with the potential for ultimately removing non-performing participants from the programme if they fail in meeting guaranteed turn down levels too many times. The severity of penalties will vary by country and DSR programme. For example, the American San Diego Gas & Electric programme has a low severity based on payments being reduced proportionally to the contracted amount delivered [25]. Whereas the Spanish programme is very strict with exclusion if the site fails to meet their obligations twice [27]. This means that correctly determining the long-term DSR potential of a building is important for appraising its suitability for DSR.

As DSR aggregators play a key role in provide 80% of DSR capacity [27], this research has focused on the estimation methods aggregators apply when determining the turndown potential and suitability of buildings for DSR. DSR aggregators operate by combining small flexible loads from multiple buildings into a virtual single load and take responsibility for managing the DSR process. Research into how aggregators decide if a building is suitable shows that the key assessment tasks focus on determining the long-term DSR potential of a buildings' assets [5]. Therefore, the ability to correctly analyse a building's DSR potential is a critical element of an aggregator's business process. This is expressly important when dealing with small to medium enterprises with smaller overall levels of DSR potential as the ability to lowering the contracted amount of DSR to avoid penalties due to estimation uncertainty is limited. While an aggregator can perform building surveys to gain a detailed understanding of a building's DSR potential, surveys have a time and cost impact and therefore are normally only undertaken once an initial desktop assessment has been completed. However, performing a desktop assessment to determine a building's potential is often difficult as detailed usage information (from sub-meters for example) about the individual electrical assets that are being assessed for DSR is normally unavailable [19]. Instead, the only information normally available is the building's overall electricity usage as recorded at half hourly (UK standard practice) or similar intervals by the building's utility supplier. Half hourly information will provide a usage profile that

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https://doi.org/10.1016/j.enbuild.2018.06.004
0378-7788/

can be used for estimating the building's DSR potential and suitability if all electricity demand from the grid is reduced by either using backup generators or turning off all assets. For buildings that can only turndown a limited subset of assets for DSR, a building level profile is unable to provide the individual assets' usage patterns needed to understand their suitability for DSR. To gain this necessary level of detail requires additional analysis to try and determine what proportion of the building's usage is represented by individual assets.

Research on understanding energy usage in buildings is extensive, with a review by Borgstein et al. [2] identified five categories (Engineering calculations, Simulation, Statistical, Machine Learning, and Other) that each contained multiple approaches. However, research on application of these approaches for DSR estimation is limited and is influenced by whether the estimation is for implicit or instead explicit DSR [26]. Implicit DSR covers price-based measures, whereby demand might be reduced based on users responding to electricity price signals (for example, temporarily high electricity prices that encourages reduction in usage to reduce costs). Explicit DSR covers incentive-driven measures, whereby demand reduction is specifically requested based on an external signal (for example, demand is reduced temporarily based on a site or its appliance receiving a signal in return for financial compensation for participation). As implicit DSR relies upon optional participation, research into estimating reduction potential focuses on how groups with similar DSR assets behave in response to different pricing signals, for the purposes of gaining an understanding of their combined potential. This is illustrated in research by Shen et al. [28] where a genetic algorithm is used to estimate the DSR potential for a group of buildings based on time of use and dynamic pricing signals. The authors showed that if each building responds independently to pricing signals, then this can cause higher peak demand usage and therefore recommended that responses are coordinated across similar groups of buildings to achieve the desired peak reduction. Similarly, Chassin and Rondeau [3] utilised the Random Utility Model to understand the potential provided by groups of fast-acting demand response loads under real-time pricing. In contrast to implicit DSR's reliance upon optional participation, explicit DSR participation is established by contract and the application of penalties where sites fail to respond to a specific reduction request or do not deliver pre-agreed levels of usage reduction. This means that estimation methods for explicit DSR focus on assessing the likely long-term potential of specific buildings to ensure that contractual commitments can be met. As 80% of DSR is currently provided by aggregators, who rely upon explicit DSR, this paper focuses on comparing only energy estimation methods used for explicit DSR [27].

The majority of contributions to the research field of explicit DSR have originated from the Lawrence Berkeley National Laboratory – Demand Response Research Center [10]. Their research into DSR has covered several areas including methods for assessing the DSR potential of buildings. To help improve the assessment process the DRRC developed the Demand Response Quick Assessment Tool (DRQAT) [32] which uses the EnergyPlus whole building energy simulation program [29] to predict DSR potential using predefined building models and a limited set of user selectable variables. While the DRQAT program helps to make the assessment process easier, it introduces other limitations, notably that it will only work for predefined building models which are currently offices and retail buildings based in California. They also recognise that are still many input uncertainties like operational behaviour and space loads that are hard to capture in the DRQAT model. To overcome these uncertainties, they use metrics of peak demand (kW), absolute demand savings (kW), and relative demand savings (%) to compensate for differences in actual and forecasted load shapes. The DRRC have also looked into understanding the factors that influence how well a building will perform when enabled for DSR [16,22]. This research showed that the level of turndown potential could be linked to temperature if the DSR assets demonstrate varying levels of usage based on external weather conditions with prediction uncertainty being approximated using the standard error. The limitation of using this approach for assessing a building is the need for the building to have already been involved in DSR to have access to event outcomes for analysis. Another assessment approach proposed by Panapakidis et al. [21] is to cluster electricity usage of a building into profiles that can then be used to ascertain DSR turndown opportunities based on variance between the profiles. They try to reduce uncertainty by testing a range of cluster lengths to find the optimal number to use that minimises the overall sum of squared errors. This method has the advantage of only needing the building's overall electricity usage records, yet is limited by the assumptions required when deciding what the differences between profiles mean in terms of individual asset usage. There are other proprietary commercially developed analysis methods that have not been published. One such method has been provided by an aggregator in association with this research. They have two approaches when performing building asset assessment for DSR. The first approach assumes that the asset will work at a set level all year. To help reduce the uncertainty of this estimation a second approach is used that analyses the building's overall electricity records for a year to create a baseload usage amount for 95% of the time. The aggregator then takes a proportion of this 95% to represent the asset usage. Using the baseload value reduces uncertainty by knowing that at least this amount of electricity is being used 95% of the time and therefore taking a proportion of it prevents over estimating the assets potential usage. The major limitation of both approaches is the assumed consistent usage of the asset across the year, which they recognise, but still use the method to provide an initial understanding of anticipated potential before deciding on further investigations.

The issue that faces aggregators and anyone trying to perform DSR estimations using these methods is knowing which one to use and how they compare in terms of uncertainty and cost to undertake. Therefore, the aim of this paper is to provide an understanding of uncertainty levels in current non-domestic DSR potential estimation methods based on the input requirements. By understanding the uncertainty levels and costs of DSR estimation methods this research hopes to increase usage of DSR from businesses that are currently excluded due to risk aversion resulting from not knowing the level of estimation uncertainty. The research is undertaken by examining and applying four DSR estimation methods to two UK hotels as described in Section 2. Section 3 sets out the research results and discusses these findings. Section 4 concludes by summarising the implications of this research.

2. Methods

Four DSR potential estimation methods were applied to two medium-sized UK hotels (∼200 rooms) to evaluate outcome uncertainty against the level of information required for estimation. The four methods are: asset assessment; baseline comparison; historical event analysis; and building energy modelling. Fig. 1 provides an overview of the explicit DSR estimation methods reviewed in this paper, including the primary data and parameter inputs and the analytical approaches used. The methods are to be used as part of an initial desktop assessment to determine the potential DSR of a building or business. The assessment provides a decision on whether further assessment or inclusion of the business in a DSR aggregation programme is valid. All methods estimate the half-hourly kW usage profile of electrical assets over a one-year period to assess if sufficient DSR potential exists. To explain how the methods were used and compared this section is divided