Energy and Buildings 159 (2018) 164–178

Contents lists available at ScienceDirect

Energy and Buildings

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

Towards critical performance considerations for using office buildings as a power flexibility resource-a survey

K.O. Aduda*, T. Labeodan, W. Zeiler

Building Services Group, Department of Built Environment, Technische Universiteit Eindhoven, De Groene Loper 6, 5612, AZ, Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form 27 October 2017
Accepted 30 October 2017

Keywords:
Office buildings
Power flexibility
Comfort
Performance characteristics

ABSTRACT

The continued growth in variable renewable energy sources (VRES) has created increased focus on the use of office buildings for power flexibility activities. Office buildings uniquely present opportunities for relatively easy control adaptation during power flexibility activities given their large thermal inertial and existing building automation. Though a number of studies have outlined the potentials of office buildings for power flexibility, however only few studies have clearly outlined associated critical performance characteristics as it relates to comfort. Subsequently, this paper uses structured literature survey to outline critical performance characteristics that should be considered when using office buildings as power flexibility resources. Understanding the performance characteristics that are critical for using office buildings as power flexibility resources is important not only for their effective control and coordination but also to avoid compromising the core role of office buildings which is the provision of a comfortable and productive environment for business transactions.

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1. Introduction

The last three decades have seen enormous increase in renewable energy installations as a result of the quest for greater sustainability and energy security in the built environment [1]. The growth of variable renewable energy resources (VRES) in form of wind and photovoltaic power generation plants has been particularly high with some European economics aiming for over 80% renewable energy integration in the power grid by 2050 [2]. Due to associated stochasticity, continued rise in VRES have likelihood of introducing frequent power grid imbalance if unchecked [3,4]. Subsequently, extra control burden is imposed on the power infrastructure as it tries to deal with the resulting imbalances [5]. Although, the current practice in power systems is to provide flexibility with power plant capacity, this results in tying up expensive capital investment, operating the generators at potentially lower efficiency, and increasing wear and tear from continually adjusting their output in response to the immediate balancing needs of the grid [6,7]. The result has been a greater need for alternative power flexibility resources (mainly from demand side installations) with office buildings identified as amongst the sectors with promising potential [8,9]. Distributed demand side assets such as buildings can provide these equivalent services potentially at a lower cost by adjusting load rather than power plant output. Buildings are considered to be capable of providing faster response than power

* Corresponding author.

https://doi.org/10.1016/j.enbuild.2017.10.096

Table 1
Flexibility sources and strategies in office buildings.

System	Strategy
HVAC	Precooling
	Global temperature set point adjustment
	Exhaust and inlet air fan speed reduction
	Chiller quantity reduction
Light	Turning off lighting in auxiliary spaces
	Turning off lighting in perimeter zones
	Dimming ballasts
Appliances and plug-loads	Turning off non-essential appliances

plants and can effectively reduce the need and lower the cost of regulation [8,7,10].

Flexibility in this context refers to the ability to continually balance of electricity supply and demand with negligible disruption to service for connected loads often in response to variability in renewable energy resources (RES) based generation [11]; sources of power flexibility have been identified as buildings (residential and non-residential, i.e., office buildings), industrial loads, storage systems, power curtailment, combined heat and power (CHP) plants and gas turbine plants [2]. In this paper, 'demand side flexibility (DSF) in office building' has been used to refer to deployment of office buildings for power flexibility activities.

Although the concept of harnessing energy flexibility of buildings is not entirely new [10,12,13], office buildings, both individually and collectively are nonetheless considered to hold the greatest potential for energy flexibility in the near term [8,14,15]. This is because in office buildings heating, ventilation and air-conditioning systems (HVAC) and other office plug load appliances such as printers, coffee machines and refrigerators can be used to provide grid support services at different timescales [16]. The supply air fan has fast dynamics, and is suitable for high frequency ancillary services, while heat pumps with variable speed drives are another potential resource. Chillers, even those without variable speed drives, can also be used to provide ancillary services by indirectly varying the load on them [6,17,14,15]. Office buildings also often have high thermal inertia [18] that can be utilized as energy reservoir for short periods of time during power flexibility activities [14]. Moreover, most office buildings are equipped with a building energy management system (BEMS) thus making the task of implementing additional control algorithms easy and inexpensive [14,19]. In office buildings, the common sources of flexibility are highlighted in Table 1 [20,21].

The use of office buildings as a power flexibility resource seem promising; however, associated use is hampered by uncertainties [22,23]. The mentioned uncertainties require adept risk management plan which is complicated by aggregation requirements as a result of involvement of large number of small loads [24] with multiple response characteristics [25] during delivery of power systems flexibility service. Furthermore, a comprehensive understanding of performance parameters of the office building when used as a power systems flexibility resource is needed for optimal value. As can be observed from Table 1, power flexibility in office buildings is often sourced from systems tasked with providing comfort in building. This includes visual, thermal and indoor air quality. The quality of life in buildings (comfort conditions) is determined by these three parameters [26]. Thermal comfort is determined by the index Predictive Mean Vote (PMV) [27]. Visual comfort is determined by the illumination level (measured in lux) [28]. Indoor air quality can be indicated by the carbon dioxide (CO_2) concentration in a building [29]. These systems are often operated based on given standards and recommendations [27–29] that ensure the indoor conditions are maintained at levels that guarantees a comfortable and healthy indoor environment for occupants.

Hence, in harnessing the energy flexibility of these systems for grid support, it is essential that occupants demand for energy for 'comfort' be satisfied while delivering a reliable resource to the power system when required [12,30]. This is particularly essential in office buildings where a strong link between occupants' comfort and productivity has been demonstrated [31,32]. Moreover, compared to residential buildings, the complexity of commercial buildings makes participation costly and challenging. This is because in addition to requiring occupants to actively participate, the capacity for error in manually executing load reductions can lead to even greater costs, due to facility operation problems, unexpected losses in productivity and occupant comfort degradation [33–36]. Consequently, clarity in understanding involved systems, processes and associated performance considerations for using office buildings as power flexibility resources is critical.

1.1. Contribution of this paper

Given that discussions on power flexibility activities by office buildings has mostly been examined from the perspective of power systems engineering, this paper provides a review of articles focused on office buildings as energy flexibility sources and the associated performance considerations that are critical when using office buildings as power flexibility resources. This is considered essential taken that the main function of office buildings is to provide productive and comfortable environment for occupants [37], occupants and business processes therein should take priority. The value of office buildings as a power flexibility resource should as such be inclusive of the traditionally core comfort related role, and occupants and associated activities on one hand [38–40], and power flexibility role on the other. The result is an urgent need for critical performance considerations that inclusively define the mentioned two roles of modern office buildings (that is, the traditional comfort related role and the power flexibility related role).

2. Literature survey methodology

The study used a structured approach in determination and analysis of existing relevant literature. Though there are quite a number of scientific literature databases available, the scope of this study was limited to only IEEE Xplore and Science Direct. This is because for power systems studies, IEEE Xplore provides the specialized focus with over four million articles archived on it [41] and Science Direct is arguably the largest multidisciplinary academic database hosting over 3800 journals [42]. The search was conducted using the key words 'demand power flexibility'. Inclusion criterion was that the articles were less than 6 years since publication; for IEEE Xplore it was required that the authors appear at least 4 times under the search criteria whereas for Science Direct only articles published in the following journals were selected: Applied Energy; Buildings and Environment; Energy and Buildings; Energy; Renewable and Sustainable Energy Reviews; Sustainable Cities and Society; and The Electricity Journal. The search in the Science Direct database was limited to these journals because of their dedicated focus on energy sustainability in the built environment.

Additional papers from journals outside of IEEE Xplore and Science Direct such as automation in construction, Procedia engineering, ASHRAE transactions, and publicly available technical and research reports were also included in the analysis based on snowballing from the papers considered to have milestone contributions. All the articles focusing solely on design, methodological discussions, renewable energy resources, policy issues and environmental sustainability were excluded from literature selection.

Analysis of selected literature followed a discursive approach along the themes of intended contributions. Discursive analyses