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Estimating the energy consumption and power demand of small power equipment in office buildings

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ABSTRACT

Small power is a substantial energy end-use in office buildings in its own right, but also significantly contributes to internal heat gains. Technological advancements have allowed for higher efficiency computers, yet current working practices are demanding more out of digital equipment. Designers often rely on benchmarks to inform predictions of small power consumption, power demand and internal gains. These are often out of date and fail to account for the variability in equipment speciation and usage patterns in different offices. This paper details two models for estimating small power consumption in office buildings, alongside typical power demand profiles. The first model relies solely on the random sampling of monitored data, and the second relies on a 'bottom-up' approach to establish likely power demand and operational energy use. Both models were tested through a blind validation demonstrating a good correlation between metered data and monthly predictions of energy consumption. Prediction ranges for power demand profiles were also observed to be representative of metered data with minor exceptions. When compared to current practices, which often rely solely on the use of benchmarks, both proposed methods provide an improved approach to predicting the operational performance of small power equipment in offices.

1. Introduction

As buildings become more energy efficient, small power equipment such as computers are an increasingly significant source of energy end-use [1]. A study published by the New Buildings Institute suggest that plugs loads can represent up to 50% of the electricity use in buildings with high efficiency systems [2]. Office buildings are likely to have higher cooling demands in the future due to climate change, emphasising the need to better understand (and reduce) the impact of internal gains from IT equipment [3].

Predicting internal heat gains accurately is of great importance in order to ensure that building systems are designed and operated as efficiently as possible. The use of nameplate electrical power ratings significantly overestimates the internal heat gains, which results in the specification of chillers with a higher capacity than needed [4]. This can result in increased capital cost as well as higher operating costs through longer periods of inefficient part load operation [5]. Nevertheless, detailed estimates of small power consumption are rarely undertaken and designers often rely on published benchmarks in order to account for small power demand in office buildings [6]. A review of published benchmarks for small power demand and consumption undertaken by the authors revealed that these are sparse, often out of date and broadly unrepresentative of small power equipment currently being used in UK office buildings [7]. Overall, the approach of using benchmarks inherently fails to account for the variability of small power loads in different buildings, presenting an additional shortfall.

This paper presents two methods for estimating building specific small power energy consumption. The study also aims to evaluate the associated power demand profiles, which can be used to inform predictions of internal heat gains. Focus is mainly on the use of computers as these are often observed to be the single biggest source of energy use amongst small power equipment [8,9]. Both models also account for the energy consumption of other small power equipment commonly found in offices such as screens, printers, photocopiers and local catering equipment. The first model relies solely on the random sampling of detailed monitored data,

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Nomenclature

u	uncertainty
t	Student's t distribution using $n-1$ degrees of freedom
n	the number of samples
S	standard deviation
P	power (W)
T	time of day

minimising the need for assumptions regarding the operational characteristics of small power equipment. A second model was developed using a bottom-up approach, allowing for the expected power demand and usage profiles for different equipment types to be characterised.

2. Literature review

The widely referenced Energy Consumption Guide (ECG) 19 provides typical and good practice benchmarks for office and catering equipment electricity consumption (Table 1) [10]. Values are provided for four different types of office buildings: Type 1, naturally ventilated cellular office; Type 2, naturally ventilated open plan office; Type 3, air-conditioned standard office; and Type 4, air-conditioned prestige office (typically including large catering kitchen and/or regional server rooms). Given the broader scope of the guide, which deals with all end-uses in office buildings, the four building types provided relate mainly to the way in the building is conditioned. From a small power perspective however, such classifications are not necessarily adequate, as the energy consumption and power demand of small power equipment is not directly related to the way in which the building is conditioned. Nonetheless, these benchmarks highlight the variability in energy consumption for small power equipment amongst office buildings.

ECG 19 also provides benchmarks for power load density, varying from 10 to 18 W/m^2. These values can be used to estimate the electricity consumption when coupled with the number of run hours (daily, monthly, annually, etc.). More commonly, however, power load density is used to assess expected peak power demand, commonly being used to calculate internal heat gains, affecting the design of cooling systems. According to the Building Services Research and Information Association (BSRIA), a value of 15 W/m^2 can be used to represent typical small power load in general offices [11]. Conversely, a study conducted by the British Council for Offices (BCO) demonstrated that higher loads are found in typical office buildings, with one third of the offices monitored having installed loads higher than 15 W/m^2 [6]. The recently updated CIBSE Guide F suggests that a benchmark figure for building loads of 25 W/m^2 is adequate for most office buildings (with 15 W/m^2 when diversity is taken into account) [12]. The updated Guide F also suggests that when occupancy details are known, using a loading of approximately 140–150 W/desk might be a more appropriate approach.

High-level benchmarks are informative, but they need to be used with caution and in the right context as they fail to account for variations in diversity of use, workstation density, power management settings on ICT devices and the type of activity carried out in an office building. In an attempt to address such variations, CIBSE Guide F provides an alternative methodology for calculating installed loads based on a 'bottom-up' approach [12]. This method was adapted from Energy Consumption Guide 35 [13], and enables a more robust prediction of power demand and energy consumption. It relies on detailed information regarding the expected types and quantities of small power equipment, typical power consumption figures, power management settings, usage diversity and typical hours of operation for each equipment type. As a manual calculation however, this methodology is quite laborious and designers often resort to high level benchmarks instead. The new CIBSE TM54 proposes a simpler calculation based on the expected power demand and operating hours of individual desks/workstations, accounting for communal appliances separately [14]. This approach allows for variations in equipment specification and intensity of use to be accounted for, yet usage patterns are not dealt with in detail.

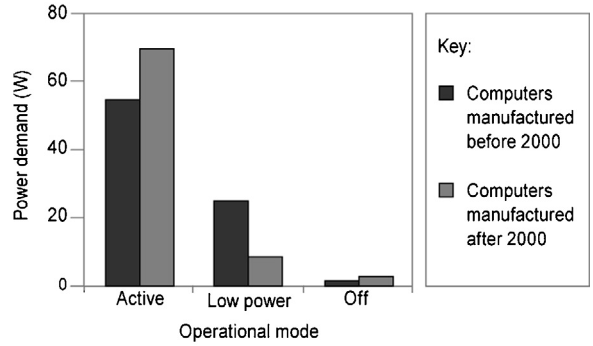

Fig. 1. Energy requirements of desktop computers manufactured before and after 2000.

Computers are commonly the single biggest source of energy use, and as such, contribute significantly to internal heat gains [8,9]. Moorefield et al. conducted a monitoring study of small power use in 25 offices in California over a 2-week period [15]. Power demand data for 470 plug load devices was collected at 1-min intervals through the use of plug monitors and the data were extrapolated based on an inventory of nearly 7000 devices. Results revealed that computers and screens were responsible for 66% of small power consumption in offices.

Significant improvements in the energy efficiencies of computers have been observed in the last few decades, resulting in reduced energy requirements [16]. This can be attributed in part to initiatives such as Energy Star, an international certification scheme for consumer products that defines performance criteria including maximum power demand levels at different operating modes [17]. Published data suggests that newer computers require less energy in 'low power' modes than older computers [18,19], however, the demand for computers with increased processing power has resulted in higher power demands when the computers are active, as illustrated in Fig. 1 (adapted from [18,19]).

More recently, a review of UK benchmarks for small power consumption against monitoring data for a small sample of in use office equipment revealed similar results, highlighting an increase in power demand in active modes and a further reduction in demand for low power modes [7]. The same study also revealed the challenge of keeping benchmarks up to date with fast paced development of computer technologies. Table 2 provides a summary of key published data regarding energy requirement of both laptops and desktops, highlighting the trends discussed above. Note that figures for laptop computers exclude the power demand for the in-built screens, as laptops are typically connected to a desktop screen when used in an office environment.

As observed in Table 2, laptop computers consume only a fraction of the energy of desktop computers, presenting a big opportunity for energy savings in office buildings [16]. Energy efficiency is a critical issue for laptops as it determines the length of time the machine will be able to run from its battery. As a result, laptops generally have lower power demands whilst also going into low power modes more quickly in order to preserve battery power. The recent proliferation of laptop computers will have a large impact on the