Review of Benchmarks for Small Power Consumption in Office Buildings

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Abstract

There is significant evidence to suggest that buildings consume more energy than initially predicted during the design phase of building procurement. With increasing efforts to reduce the energy consumption associated with the operation of buildings, it is vital that these predictions be improved to represent the operation of buildings more realistically. One approach to bridge this gap would be to include energy consumption due to small power equipment in the energy models. Typically ignored, these end-uses usually represent between 13% and 44% of the total electricity consumption in an office building, according to Energy Consumption Guide 19.

Currently there is little data available related to the electricity consumption of small power equipment in the context of office buildings. Existing data published in CIBSE Guide F is over a decade old and the use of office equipment and its associated technologies has changed significantly over this period. This lack of up-to-date benchmarks makes it increasingly difficult for designers to include small power consumption accurately within in their energy models.

Following a detailed review of existing benchmarks for small power in office buildings, this paper presents a set of monitored data for a range of equipment commonly found in contemporary office buildings. Key metrics include details of power consumption and hours-in-use for both ICT equipment and kitchen appliances. In addition, a comparison of different laptops of varying specifications is provided and their subsequent impact on productivity is also discussed.

Keywords

Small power, appliances, offices, energy performance, performance gap

1.0 Introduction

The construction industry is currently faced with an increasing demand for more energy efficient buildings. However, previous research[i,ii,iii] demonstrates that energy efficiency levels predicted at design stage are rarely achieved in practice, with buildings typically consuming at least twice as much energy than anticipated. This so-called 'performance gap' can be attributed to numerous elements relating both to predictive models and building operation. One of the key factors is the exclusion of several sources of energy use from the compliance calculations for Part L of the Building Regulations. These end-uses are commonly referred to as 'unregulated loads' and include all small power equipment and plug loads, as well as external lighting, vertical transportation and servers.

In an office building, unregulated loads will typically represent a large proportion of the total energy consumption, with office equipment alone accounting for more than 20% of the total energy use[iv]. Supporting data from ECON 19[v] provides typical (TYP) and good practice (GP) values for office equipment and catering electricity loads. Figure 1 illustrates these values 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, Type 4 – air-conditioned prestige office.

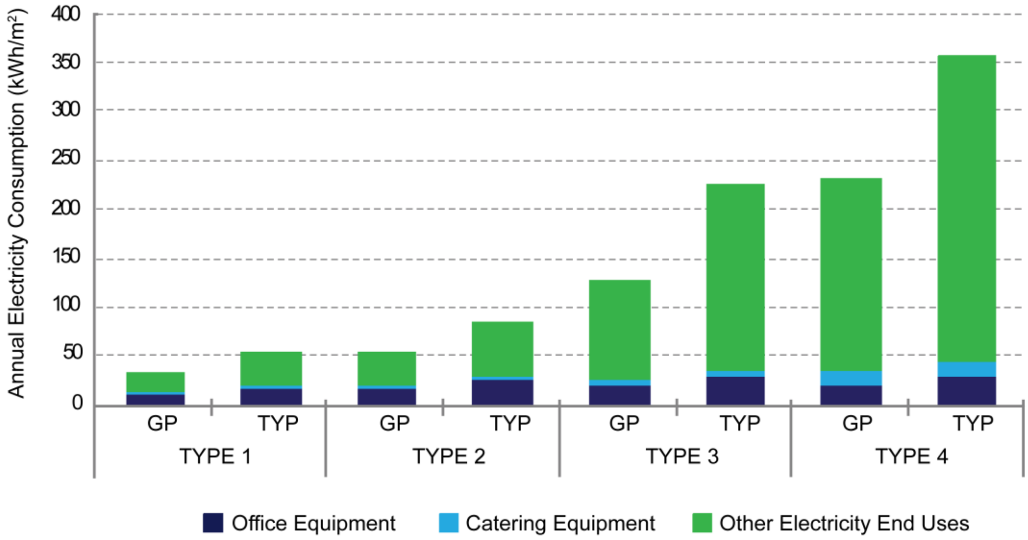

Figure 1: Typical and best practice electricity consumption for office equipment and catering equipment in office buildings [iv].

As seen, electricity consumption for office equipment will range from 12 kWh/m^2/year (for good practice Type 1 offices) to 32 kWh/m^2/year (in typical Type 4 offices). These values represent 36% and 9%, respectively, of the total electricity consumption of each office type. For catering equipment, annual electricity consumption will usually range from 2 kWh/m^2 per year (for good practice Type 1 offices) to 15 kWh/m^2 per year (in typical Type 4 offices), accounting for 6% to 4% of the total electricity consumption, respectively. Combined, both end-uses will usually represent between 13% and 44% of the total electricity consumption. These percentages are not trivial and should be given more attention if realistic predictions are to be achieved.

This paper focuses on small power consumption in office buildings, reviewing and assessing the accuracy of existing benchmarks using monitored data acquired as part of a case study. Many of these benchmarks were published over a decade ago, yet are commonly used for predictive calculations of energy use and internal heat gains. According to the British Council for Offices, there is significant difference between actual small power loads observed in occupied buildings and those assumed for design[vi]. The same report also claims that current benchmarks fail to account for diversity of use, highlighting a need for more detailed benchmarks that reflect current and realistic usage of small power equipment in office buildings. This paper aims to substantiate such claims by providing monitoring data regarding energy use for specific items of equipment commonly found in office buildings. A short discussion on the relationship between energy consumption of laptop computers and productivity is also provided.

2.0 Existing Benchmarks for Small Power in Office Buildings

One of the most widely recognised guidance documents on energy efficiency in buildings is CIBSE's Guide F[iv]. Section 12 of the publication deals exclusively with electrical power systems & office equipment, providing a compilation of data regarding power demand and energy consumption for small power equipment. More recently, in 2009, the BCO[vi] published a short document focused solely on small power use in offices. Tables 1-4 and Figures 2-4 illustrate the key benchmarks published in Section 12 of CIBSE's Guide F[iv] as well as monitoring data published by the BCO[vi].

Table 1 shows overall benchmarks for office equipment, originally published in ECON 19[v]. The data relates to the 4 office types from ECON 19 and provides typical (TYP) and good practice (GP) figures for installed capacity (in W/m^2), annual running hours and percentage ICT area in relation to the treated floor area. The combination of all these figures are used to calculate typical annual energy consumption data for office equipment (in kWh/m^2/year).

	Type 1		Type 2		Type 3		Type 4	
	GP	TYP	GP	TYP	GP	TYP	GP	TYP
Installed capacity for floor area with IT (W/m^2)	10	12	12	14	14	16	15	18
Annual running hours (h)	2000	2500	2500	3000	2750	3250	3000	3500
IT area as % of treated floor area (%)	60	60	65	65	60	60	50	50
Energy consumption by office equipment (kWh/m^2)	12	18	19.5	27.3	23.1	31.2	22.5	31.5

Table 1: Benchmarks for office equipment [iv, v]

According to CIBSE Guide F, allowances of 15 W/m^2 for installed loads are more than adequate for all but the most intensive users[iv]. The exact same value of 15 W/m^2 is also published by BSRIA in their 'Rules of Thumb' guide[vii] as a typical small power load in general offices. Actual energy consumption data published by the BCO suggests that higher installed loads can normally be found in typical office buildings[vi]. Figure 2 illustrates the monitored small power density of 15 office buildings in the UK. As seen, more than one third of the offices monitored had installed loads higher than 15 W/m^2 and a large variation in small power densities is also observed.

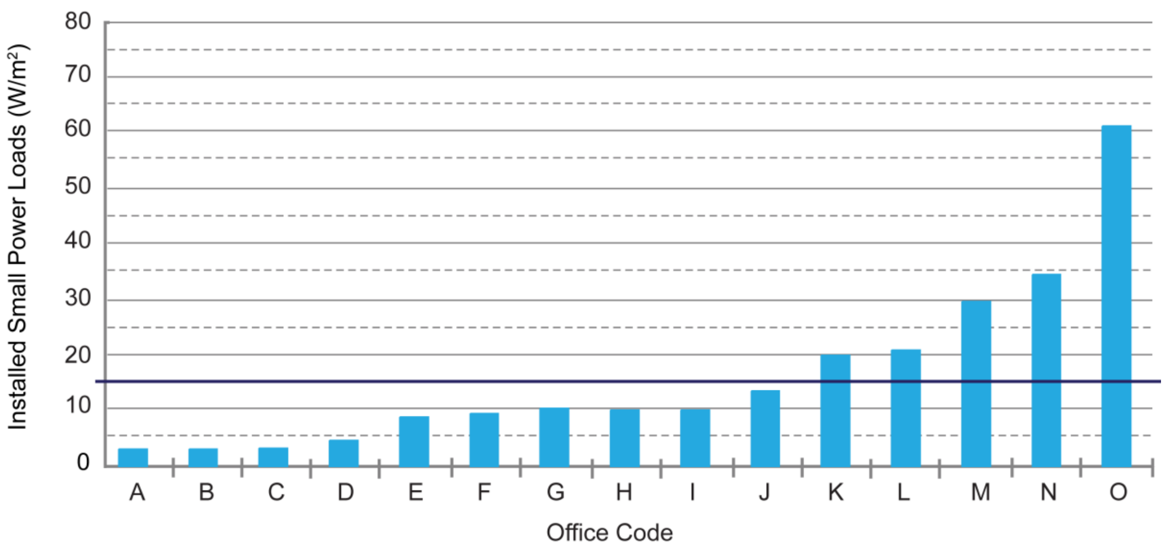

Figure 2: Monitored small power density in offices [vi]

In 2003, the Australian National Appliance and Equipment Energy Efficiency Program (NAEEEP) published a report on the operational energy use issues of office equipment [viii]. One of the main aims of the study was to investigate the impact of different power management settings on the overall energy consumption of desktop and laptop computers as well as screens. A model was developed for two desktop and two laptop computers accounting for the following 5 scenarios:

1. Power management features disabled – equipment on all the time
2. Power management features disabled – equipment off outside office hours
3. Power management features enabled – equipment on all the time
4. Power management features enabled – equipment off outside office hours
5. Aggressive power management (effective after 5 minutes of inactivity).

Table 2 provides the power levels assumed for each desktop and laptop computer modelled. The main difference between Desktop 1 and Desktop 2 is that the latter is compliant the 'One Watt' standard enforced by the Australian National Appliance Equipment Energy Efficiency Committee[ix]. This standard aims to limit standby energy consumption of small power equipment to 1 Watt. It is worth noting that the data for desktop computers includes the use of an LCD screen and for laptop computers is assumed that the device's own screen is used.

Mode	Desktop1 (non-compliant with 'One-Watt' standard)	Desktop 2 (compliant with 'One-Watt' standard)	Laptop (1.2 GHz Celeron Processor)	Laptop 2 (1.6 GHz Pentium 4 Processor)
In Use	85 W	85 W	20 W	45 W
Active Standby	80 W	80W	18 W	42 W
Sleep	30 W	2 W	4 W	4 W
Deep Sleep	23 W	2 W	2 W	2 W
Off	3 W	2 W	1 W	1 W

Table 2: Power levels of modelled computers in NAEEEP study[viii].

Figure 3 illustrates the results from the modelling study undertaken by the NAEEEP. This includes both laptops and both desktops under the five different power management scenarios.

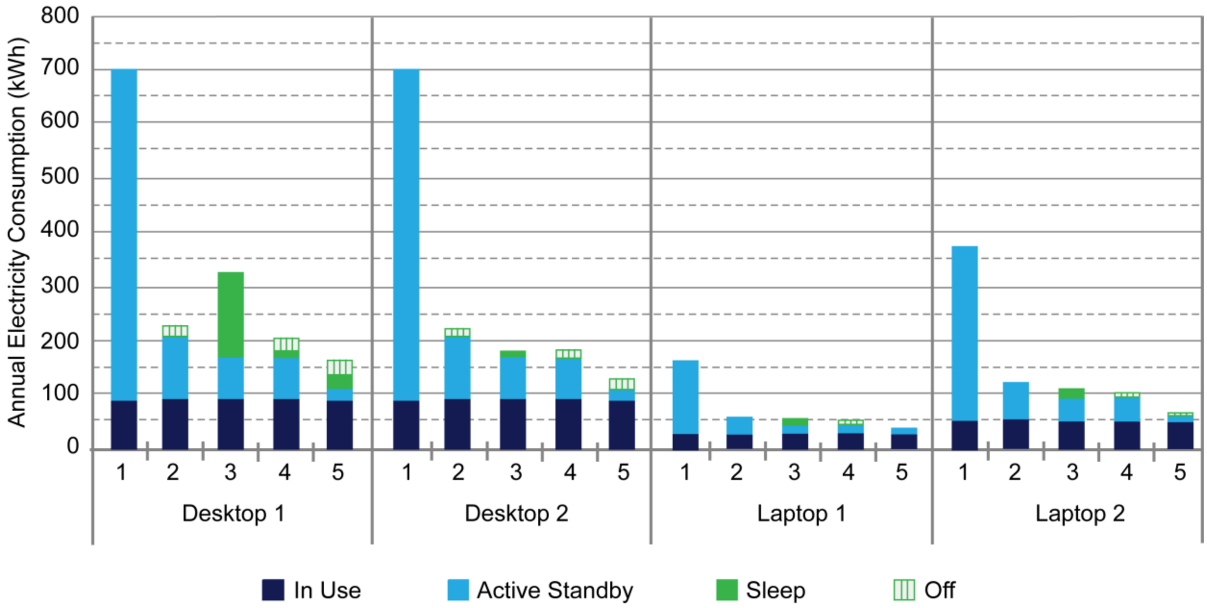

Figure 3: Annual energy consumption of various computers under different power management regimes[viii].

As seen, a significant variation in energy consumption can occur when implementing different power management settings to the same machine. When scenario 5 was implemented, all computers used approximately 75% less energy than they would have consumed if no power management setting were applied and the equipment were left on all the time (scenario 1). Figure 3 also demonstrates the difference in energy consumption by two different laptops with diverse processing powers, demonstrating that Laptop 2 will typically consume more than twice the energy necessary to run Laptop 1, no matter what power management setting is applied.

Such variations, highlighted by both the BCO guide and the NAEEEP study, highlight that care must be taken when using high-level benchmarks, as numerous parameters such as occupancy density, power management settings and type of activity can have a significant impact on overall energy consumption. CIBSE Guide F highlights this risk, providing as alternative methodology for calculating installed loads based on a “bottom-up” approach. This concept is illustrated in Figure 4 (published in CIBSE Guide F [iv] and adapted from Energy Consumption Guide 35 [x]).

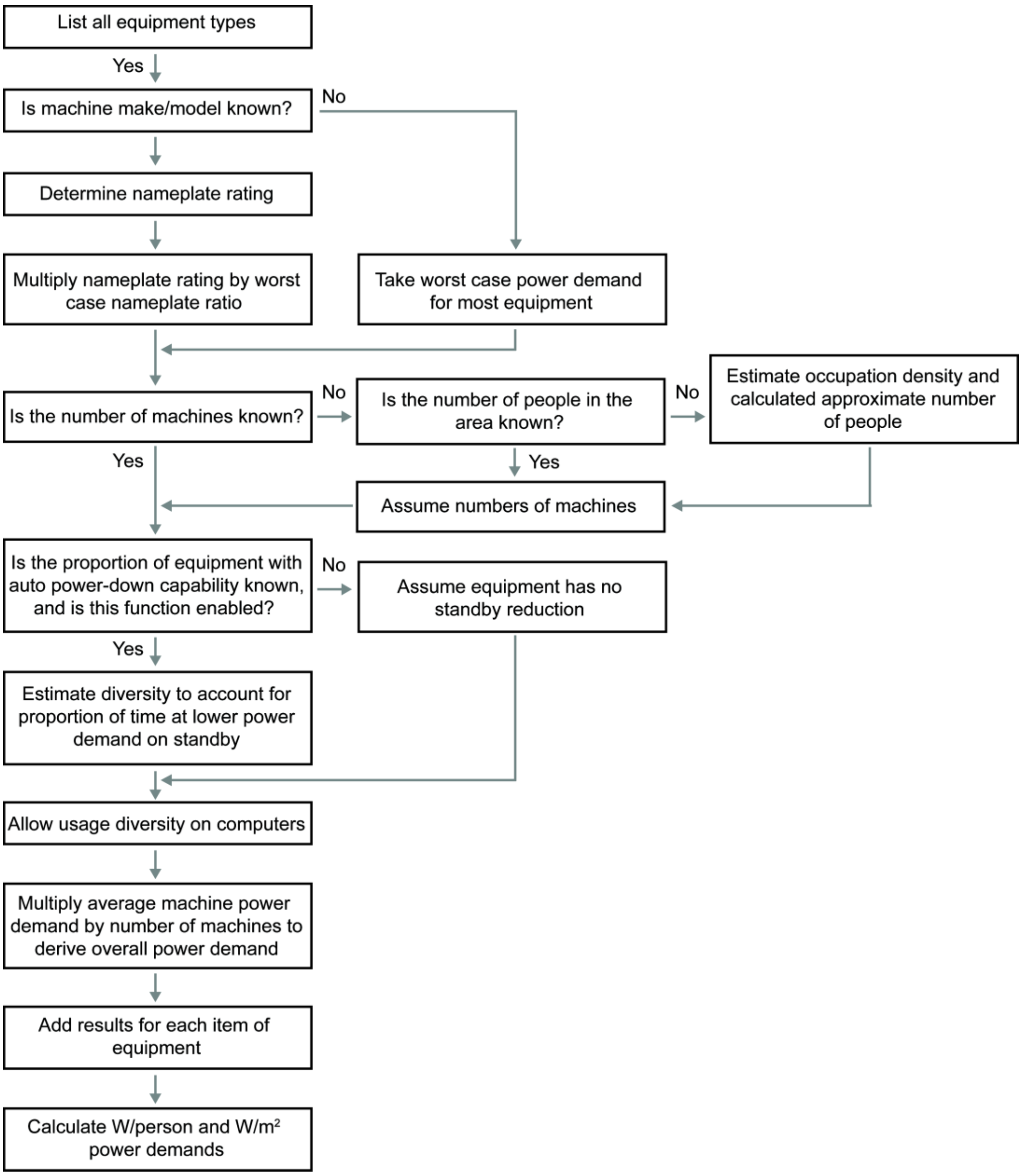

Figure 4: Decision guide for estimation of likely power demands [iv, x]

As seen, this methodology relies on numerous sources of information to account for diversity of use, including detailed benchmarks for individual pieces of equipment, hours of usage and quantity of equipment (per floor area or number of staff). Supporting data to undertake such a process are presented in Tables 3-5 and Figure 5, below.

Table 3 provides detailed benchmarks for power demand for individual office equipment. Originally published in Good Practice Guide 118 [xi], the data relates to peak, average and stand-by consumption, as well as typical recovery times.

Item		Peak rating (W)	Average consumption (W)	Stand-by energy consumption (W)	Typical recovery time
PC and monitor		300	120-175	30-100	almost immediate
Personal computer		100	40	20-30	almost immediate
Laptop computer		100	20	05-10	almost immediate
Monitors		200	80	10-15	almost immediate
Printer	Laser	1000	90-130	20-30	30 seconds
	Ink Jet	800	40-80	20-30	30 seconds
Printer/scanner/copier		50	20	08-10	30 seconds
Photocopiers		1600	120-1000	30-250	30 seconds
Fax machines		130	30-40	10	almost immediate
Vending machines		3000	350-700	300	almost immediate

Table 3: Typical levels of energy used by office equipment [iv, xi]

Figure 5 illustrates the typical average operational power demands for a number of different office equipment as well as their corresponding ratio to nameplate ratings. This ratio is of great importance seeing as most items of office equipment consume considerably less power than stated on their nameplates. It is worth noting that most items of equipment have power demands and nameplate ratios within the ranges shaded in dark blue.

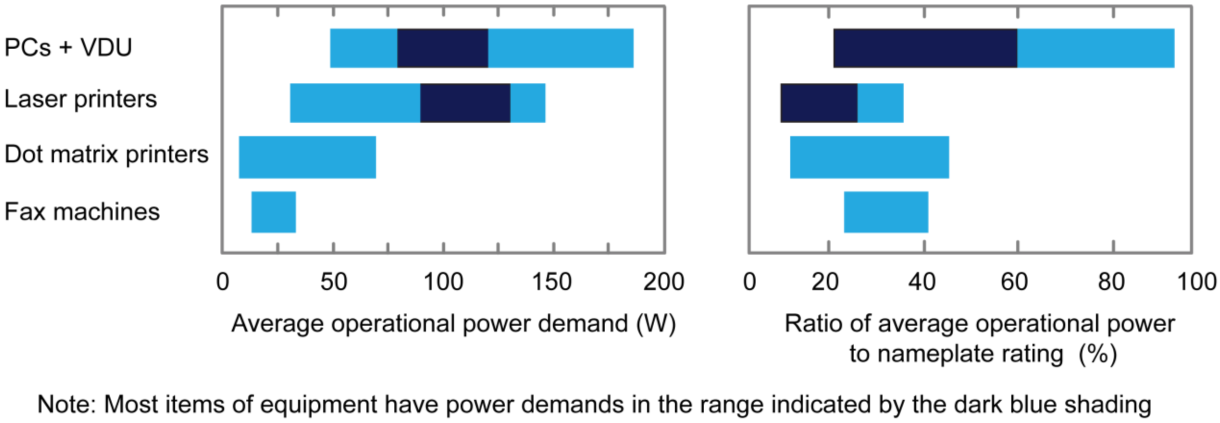

Figure 5: Average operational power demand and ratio to nameplate rating [iv, xi]

Table 4 provides information regarding typical daily use of office equipment. Such data is of great importance to account for the operating time for each equipment and is based on the percentage operating time for intermittent users, allowing for the time staff are absent from the office. Table 5 indicates the minimum likely staff numbers per machine in large offices.

	Time per day that equipment is in use
Personal Computers	4 hours
Printers	1-2 hours
Photocopiers	1-2 hours
Fax machines	20-30 minutes
Vending machines	8-10 hours

Table 4: Typical daily use of office equipment [iv]

	Persons per machine
Personal Computers	1
Laser printers	3
Photocopiers	20
Fax machines	20

Table 5: Minimum likely staff numbers per machine [iv]

Data compiled in this literature review has demonstrated significant variation in overall energy consumption due to small power in different office buildings. It has also highlighted the impact of different equipment and power management strategies on installed loads and annual energy consumption. An alternative approach to utilising high-level benchmarks was highlighted in the form of a bottom-up process and supporting data to undertake such a process was provided.

3.0 Methodology

Aiming to investigate the accuracy of current benchmarks for small power consumption in offices, actual energy consumption data for a variety of small power equipment commonly used was obtained. The monitoring process was undertaken using plug monitors with logging capabilities and in-built wireless transmitter enabling communication with a laptop computer. Such devices were used to measure the electricity demand in half hourly intervals over a period of at least one week for each individual appliance. A minimum of two different appliances were monitored for each equipment type, namely: laptops, desktops, computer monitors, printers, microwave ovens, fridges, coffee machines and vending machines. Typical days were chosen within the larger data set to represent normal daily profiles for both weekdays and weekends. For each, the maximum and minimum demand were calculated as well as average demand during working hours. The data was then used to extrapolate daily, weekly and annual consumption based on typical weekday and weekend profiles.

In order to assess the operational efficiency of 3 laptop computers of different specification, a program was run on three different machines whilst connected to plug monitors. Power demand was recorded every minute and the time taken to complete the given task was also recorded. The aim of this exercise was to assess the impact of higher specification laptops on the total electricity consumed to run a 'standard' program. With each laptop having different numbers of processors, their respective power demand should vary significantly, and so should time taken to complete the task. By correlating these two variables, conclusions can be drawn regarding the operational efficiency of each laptop computer.

4.0 Monitoring Results

Results from the monitoring study were compiled into graphs illustrating the typical weekday and weekend power demand for different equipment (Figures 6 -10). Supporting Tables 6 -10 highlight key power demand values as well as extrapolated daily, weekly and annual energy demands.

4.1 Laptop computers

Figure 6 illustrates the monitored power demand during a typical weekday and weekend for three laptop computers with distinctive processing power and age. Table 6 provides information about each laptop specification, the maximum and average in-use power demands as well as stand-by mode demand. These values were then used to calculate the expected daily, weekly and monthly electricity consumption based on a typical 8-hour working day for all laptops. Note that values for laptop power demand were obtained while external screens were being used (i.e. excluding the power demand for the in-built laptop screens). This allows for a fair comparison between laptops that have different sized screens.

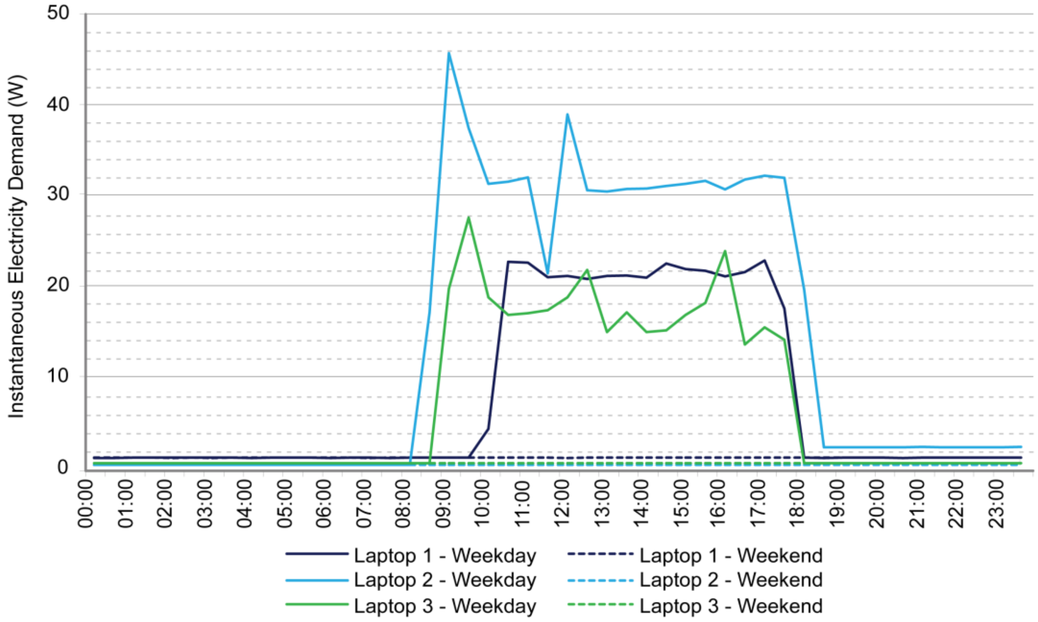

Figure 6: Monitored electricity demand for laptop computers

As seen, the newest laptop (Laptop 3) has the lowest overall power demand, despite its occasional peaks throughout the day, with an average in-use demand of 17.9W. This is followed closely by Laptop 1, with an average in-use demand of 20.3W, and a significantly 'smother' power consumption throughout the day, partly attributed to its single processor. Meanwhile, Laptop 2 has the highest power demand in-use, averaging 30.9W and peaking at 45.8W (more than twice the maximum demand of Laptop 1). With regards to stand-by power demand, Laptop 1 consumes the most energy when not in use at 1.1W, compared to Laptops 2 and 3 at 0.3W and 0.5W respectively. Annual electricity consumption figures suggest that Laptop 2 would consume the most energy at 66.4 kWh, whilst Laptops 1 and 3 would consume significantly less electricity at 49.7W and 40.8 kWh per year, respectively.

		Laptop 1		**Laptop 2**		**Laptop 3**	
		3 years old, 1.3 GHz Intel Centrino single processor		2 years old, 2.3 GHz Intel Core Duo processors		6 months old, 2.6 GHz Intel Core i5 processors	
		Weekday	Weekday	Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Stand-by mode	1.1	1.1	0.3	0.3	0.5	0.5
	Maximum Demand	22.9	1.1	45.8	0.3	27.6	0.5
	Average In-Use	20.3	-	30.9	-	17.9	-
Electricity Consumption (kWh)	Daily	0.2	0.0	0.3	0.0	0.2	0.0
	Weekly	1.0		1.3		0.8	
	Annual	49.7		66.4		40.8	

Table 6: Power demand and electricity consumption data for laptop computers

4.2 Desktop computers

Figure 7 illustrates the monitored power demand during a typical weekday and weekend for two desktop computers with distinctive processing power and age. Desktop 1 is a 3-year old computer with basic processing power, typically used to run basic programs such as word processors and spreadsheets. Meanwhile, Desktop 2 is a high performance computer with multi-core processors used to run 3D modelling software and complex programs requiring high processing power. There are only 6 of these desktops in the monitored office. Table 7 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each machine.

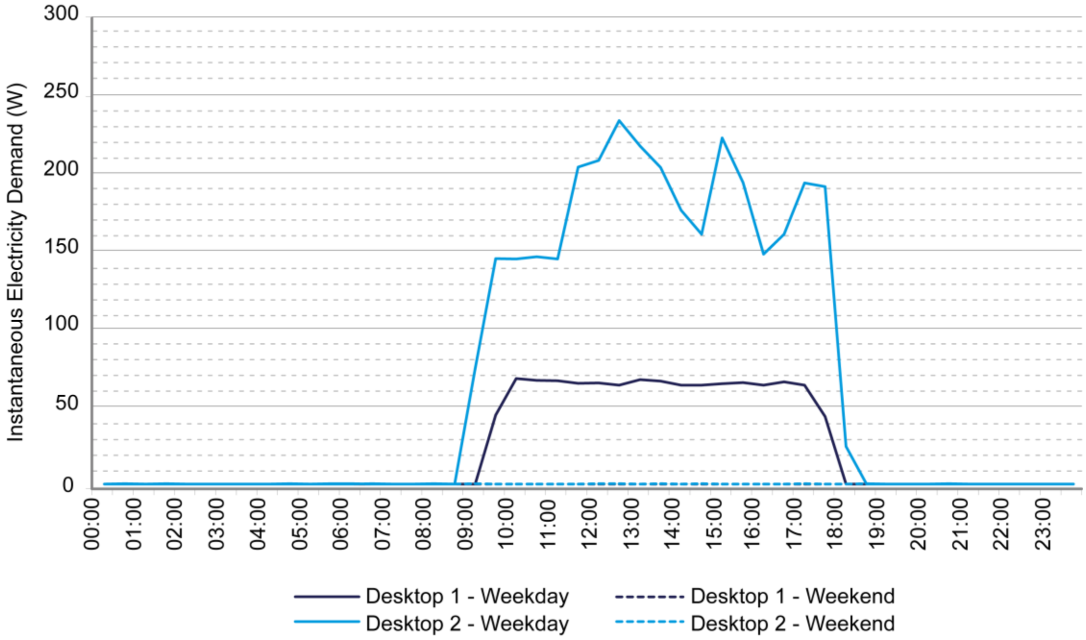

Figure 7: Monitored electricity demand for desktop computers

As seen, Desktop 1 consumes significantly less energy than Desktop 2 with an average in-use demand of 64.1W compared to 168.6W. Desktop 1 also presents a very stable energy demand throughout the day, unlike Desktop 2 whose power demand fluctuates between 140W - 230W at different times of the day. When considering stand-by mode, both desktops consume similar amounts at approximately1.9W. However, their respective annual consumptions vary significantly, with Desktop 2 consuming approximately three times more electricity than Desktop 1.

		Desktop 1 3 years old, 2.3 GHz Intel Core Duo processors (basic specification desktop)		Desktop 2 3 years old, 3.4 GHz Intel Xeon processors (high performance desktop)	
		Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Stand-by mode	1.9	1.9	2.0	1.9
	Maximum Demand	69.1	1.9	233.7	2.0
	Average In-Use	64.1	-	168.6	-
Electricity Consumption (kWh)	Daily	0.6	0.0	1.6	0.0
	Weekly	3.0		8.2	
	Annual	153.8		428.8	

Table 7: Power demand and electricity consumption data for desktop computers

4.3 Computer monitors

Figure 8 illustrates the monitored power demand during a typical weekday and weekend for three LCD computer monitors. Monitors 1 and 2 have 19-inch screens, whereas Monitor 3 has a 21-inch screen. All three monitors have power management settings activated, yet Monitors 1 and 3 switch to stand-by mode after 30 minutes of inactivity whereas Monitor 2 has a shorter ‘power-down’ time of 15 minutes. Table 8 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each monitor.

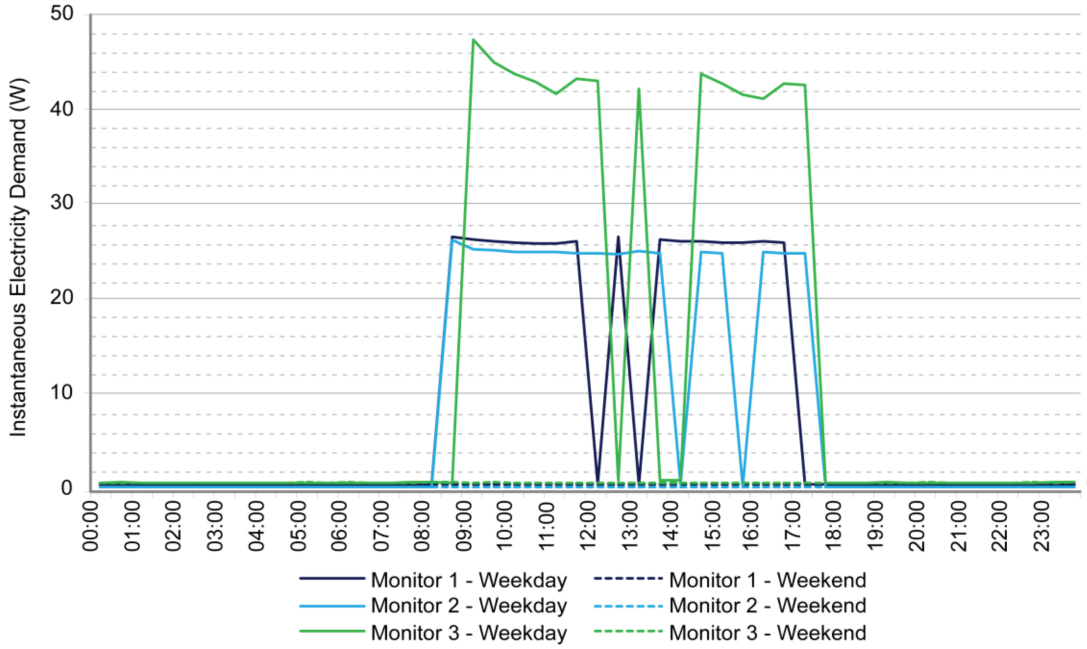

Figure 8: Monitored electricity demand for computer monitors

As seen, the larger monitor consumes almost twice as much energy than the two smaller ones, with a peak demand of 47.7W compared to 26.3W - 26.7W for the 19-inch screens. In stand-by mode, Monitor 2 has the lowest conusmption at 0.4W followed closely by Monitors 1 and 3 at 0.7W and 0.9W respectively. Monitor 2’s shorter ‘power-down’ time results in more frequent drops in energy consumption (to stand-by level) throughout the day, resulting in lower expected annual consumption than Monitor 1, despite their equal dimensions and almost identical average power demand. Meanwhile, Monitor 3 is expected to consume approximately 60% more electricity per year than Monitors 1 and 2, despite the relatively small increase in dimensions.

		Computer Monitor 1		**Computer Monitor 2**		**Computer Monitor 3**	
		19” LCD flat screen		19” LCD flat screen		21” LCD flat screen	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Stand-by mode	0.7	0.7	0.4	0.4	0.8	0.8
	Maximum Demand	26.7	0.7	26.3	0.4	47.7	0.9
	Average In-Use	23.2	-	22.4	-	35.7	-
Electricity Consumption (kWh)	Daily	0.2	0.0	0.19	0.0	0.3	0.0
	Weekly	1.02		0.95		1.54	
	Annual	53.1		49.3		79.8	

Table 8: Power demand and electricity consumption data for computer monitors

4.4 Printers

Table 9 illustrates the monitored power demand during a typical weekday and weekend for three printers/photocopiers. Printer 1 is a desktop ink-jet printer whereas Printers 2 and 3 are large-scale digital printer/scanner/photocopiers. Figure 9 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each printer.

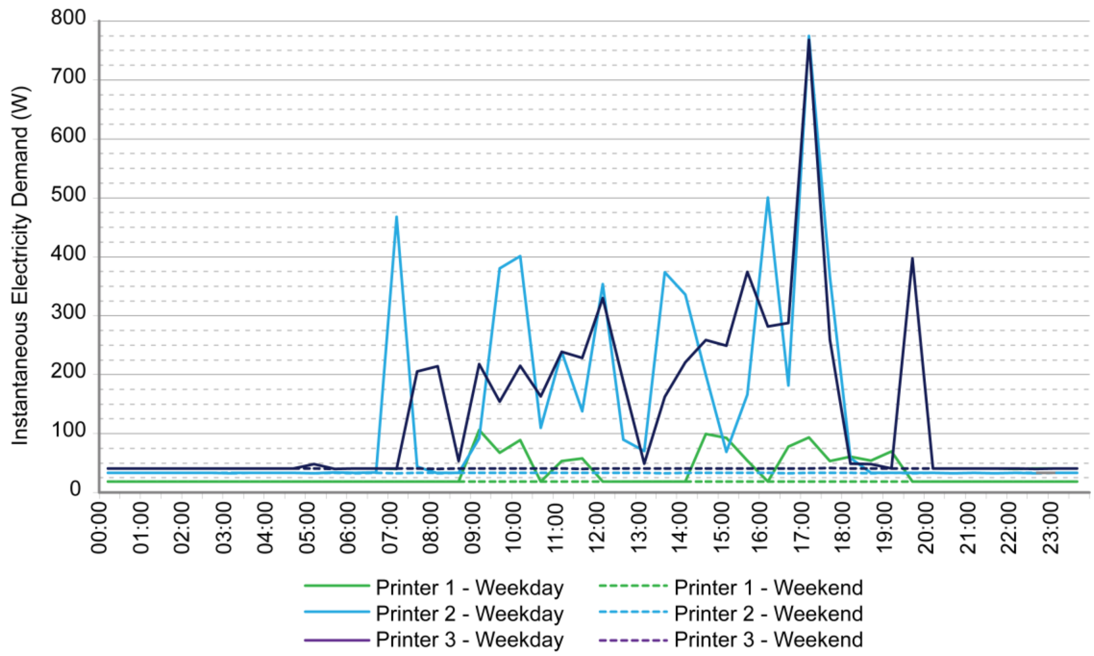

Figure 9: Monitored electricity demand for printers

As seen, the desktop printer (Printer 1) has a significantly lower power demand than both other printers, averaging at 49.1W and peaking at 103W. Meanwhile, Printers 2 and 3 have average demands around 230W (almost five times higher than Printer 1) and peak demands of approximately 770W (more than 7 times that of Printer 1). Such a discrepancy is to be expected seeing as Printer 1 is of a much lower specification than the large-scale photocopiers, having inferior printing capabilities with regards to speed and volume. It is also worth highlighting that Printer 1 is an ink-jet printer whereas Printers 2 and 3 are digital laser printer. When considering stand-by power demand, Printer 1 consumes the least amount of energy with a rating of 15.6W, whilst Printers 2 and 3 have stand-by demands of 29.9W and 37.2W respectively. Despite their similar specifications and operational power demands, Printer 3 is expected to consume more energy per year than Printer 2 (713.5W compared to 689W). This disparity can be attributed mainly to Printer 2's higher stand-by demand.

		Printer 1		Printer 2		Printer 3	
		Desktop ink-jet printer		Large photocopier		Large photocopier	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Stand-by mode	15.6	15.6	29.9	29.9	37.2	37.2
	Maximum Demand	103.0	15.8	771.6	30.7	765.1	38.4
	Average In-Use	49.1	-	235.1	-	223.2	-
Electricity Consumption (kWh)	Daily	0.64	0.38	13.25	0.73	2.38	0.91
	Weekly	3.69		13.25		13.72	
	Annual	206.1		689.0		713.5	

Table 9: Power demand and electricity consumption data for printers

4.5 Vending machines

Figure 10 illustrates the monitored power demand during a typical weekday and weekend for three vending machines. Vending Machine 1 sells snacks (such as crisps and sweets) and Vending Machine 2 sells cold drinks, both being refrigerated. Vending Machine 3 sells hot drinks, containing an internal heating element to boil water. Table 10 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each vending machine.

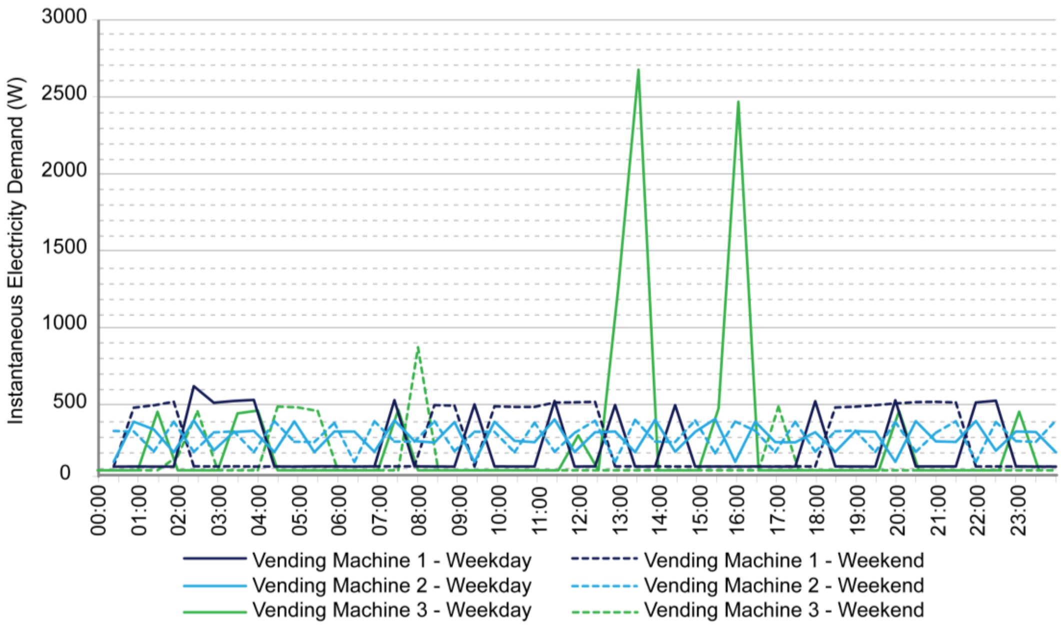

Figure 10: Monitored electricity demand for vending machines

As seen, Vending Machine 3 consumes significantly more energy than Vending Machines 1 and 2, with an average demand of 337.8W compared to demands of 158.8W and 262.1W, respectively. When considering peak demands, Vending Machine 3 consumes up to 2663.9 W, being approximately four times more energy intensive than Vending Machine 1 and almost seven times more energy intensive than Vending Machine 2. This disparity can be associated with the presence of a heating element in Vending Machine 3 used to boil water for hot drinks. Yet when considering minimum power demands, the roles are reversed, with Vending Machines 1 and 2 having somewhat higher demands to cope with their cooling functions, demanding at least 57W compared to Vending Machine 1's minimum demand of only 23.4W. Predicted annual consumptions suggest that the refrigerated vending machines (1 and 2) consume more energy than the hot drinks machine, with the cold drinks vending unit consuming a total of 2320.2W, compared to 1696.6W for the snacks vending unit and 1561.1W for the hot drinks vending machine.

		Vending Machine 1		**Vending Machine 2**		**Vending Machine 3**	
		Snacks (food)		Cold drinks		Hot drinks	
		Weekday	Weekday	Weekend	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Minimum Demand	89.0	56.9	88.9	57.4	23.4	23.6
	Maximum Demand	623.3	386.7	392.6	513.6	2663.9	835.1
	Average In-Use	158.8	271.4	262.1	254.4	337.8	84.9
Electricity Consumption (kWh)	Daily	4.4	6.4	6.2	5.3	5.2	2.0
	Weekly	32.6		44.6		30.0	
	Annual	1696.6		2320.2		1561.1	

Table 10: Power demand and electricity consumption data for vending machines

4.6 Microwave ovens

Figure 11 illustrates the monitored power demand during a typical weekday and weekend for two microwave ovens with different power ratings. Table 11 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each microwave oven.

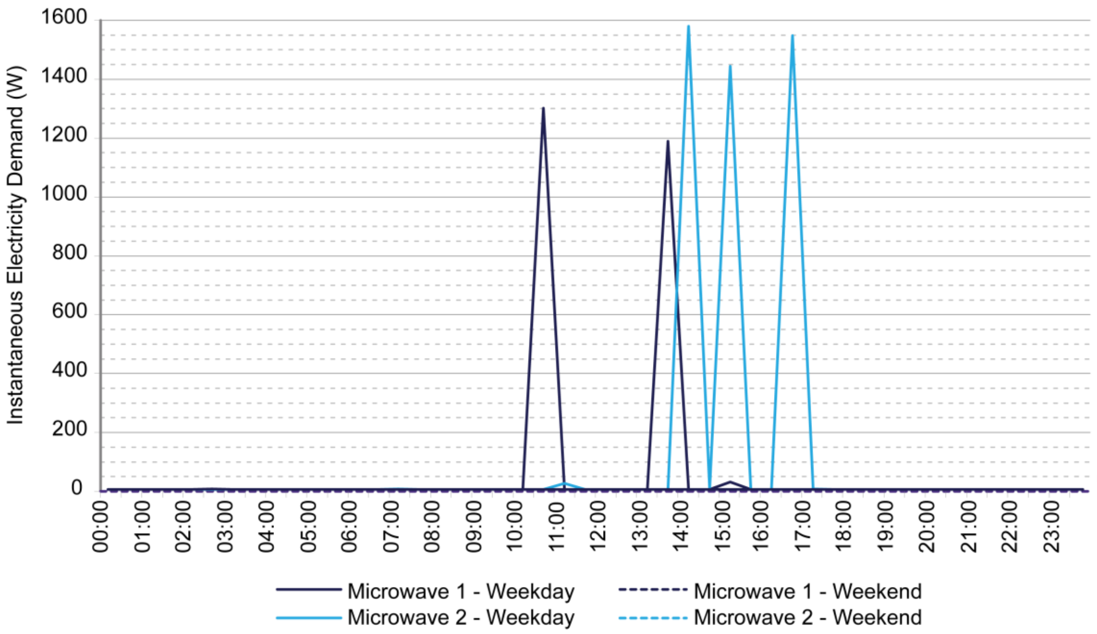

Figure 11: Monitored electricity demand for microwave ovens

As seen, both microwave ovens demonstrate similar energy demand profiles, with stand by consumptions of approximately 2W and peak demands of 1299.7W to 1578.9W when in use. Microwave 1's higher peaks can be associated with it's higher power rating at 900W compared to Microwave 2's 800W rating. It is worth mentioning that such ratings refer to the each oven's capacity to produce microwaves, and that typical energy demand is usually higher (as seen here) due to waste heat production and other inefficiencies. When considering each microwave oven's average energy demand, Microwave 2 demonstrates significantly higher values than Microwave 1, with 210.4W compared to 115.8W (respectively). This can be associated both with the increased power rating but also with the fact that Microwave 2 seems to have be used more frequently throughout a typical day than Microwave 1. As such, the discrepancies in the expected annual electricity consumption for both ovens can be somewhat misleading, with Microwave 2 consuming almost twice as much as Microwave 1, at 615W and 343.3W respectively.

		Microwave 1		Microwave 2	
		800W power rating		900W power rating	
		Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Stand-by mode	2.1	2.2	1.9	2.0
	Maximum Demand	1299.7	2.4	1578.9	2.3
	Average In-Use	115.8	-	210.4	-
Electricity Consumption (kWh)	Daily	1.3	0.1	2.3	0.1
	Weekly	6.6		11.8	
	Annual	343.3		615.0	

Table 11: Power demand and electricity consumption data for microwave ovens

4.7 Fridges

Figure 12 illustrates the monitored power demand during a typical weekday and weekend for two different fridge units. Fridge 1 is a large upright fridge with a 375-litre capacity, whereas Fridge 2 is a small upright fridge with a capacity of 150 litres. Table 12 provides key monitoring values including maximum and average in-use power demands as well as stand-by mode demand for each fridge.

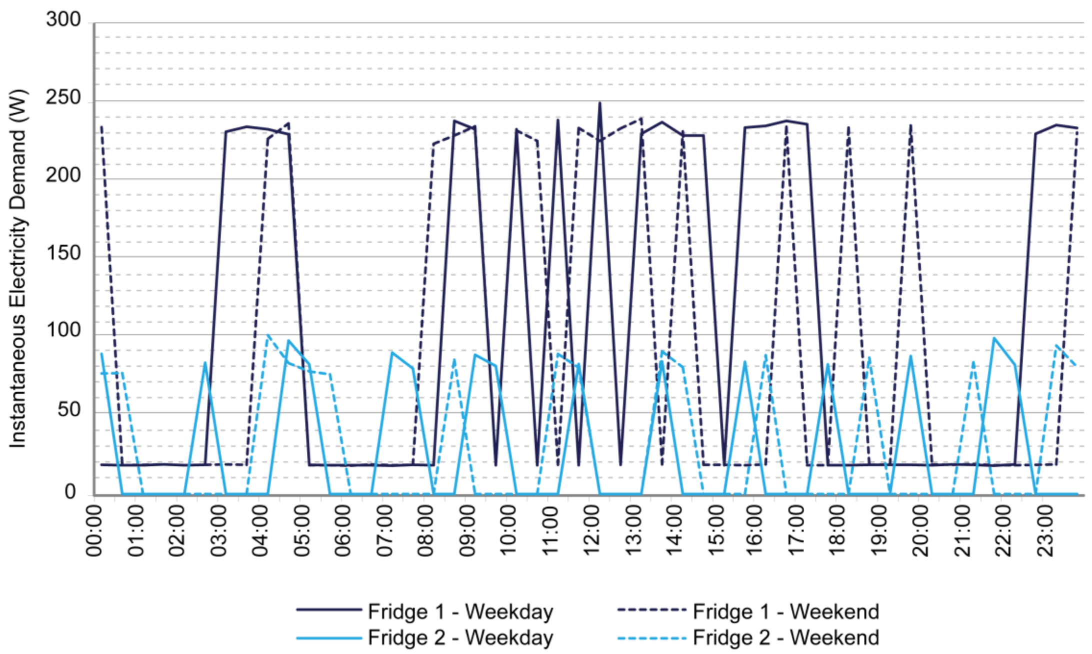

Figure 12: Monitored electricity demand for fridges

As seen, Fridge 1 has a consistently higher power demand than Fridge 2, with average and peak demands of approximately 140W and 240W, compared to 27W and 100W average and peak demands for Fridge 2. Such differences are to be expected considering that Fridge 1 has a capacity of more than twice that of Fridge 2. When considering the minimum demand, Fridge 2 has a negligible demand, typically 0W, whereas Fridge 1 has a minimum demand of 18W. This can be associated with the fact that Fridge 1 has a small freezer whereas Fridge 2 is a larder fridge (i.e. having no freezer compartment). As a result, Fridge 1 has a predicted annual electricity consumption of 851.3W compared to a significantly smaller consumption of 237.7W for Fridge 2.

		Fridge 1		Fridge 2	
		Full size fridge (375 L)		Small fridge (150 L)	
		Weekday	Weekend	Weekday	Weekend
Monitored Power Demand (W)	Minimum Demand	18.0	18.0	0.0	0.0
	Maximum Demand	237.8	247.7	98.8	100.5
	Average In-Use	133.6	145.5	26.4	27.2
Electricity Consumption (kWh)	Daily	2.2	2.6	0.6	0.7
	Weekly	16.4		4.6	
	Annual	851.3		237.7	

Table 12: Power demand and electricity consumption data for fridges

5.0 Comparison of monitored data against existing benchmarks

Table 13 displays both the existing benchmarks for small power equipment published in CIBSE Guide F and monitoring data discussed in Section 4 for the equivalent types of equipment. Unfortunately, benchmarks weren't available for fridges and microwave ovens.

Item	Peak demand (W)		Average demand (W)		Stand-by demand (W)	
	Benchmark	Monitored	Benchmark	Monitored	Benchmark	Monitored
Desktop computer	100	69 - 234	40	64 – 169	20 - 30	1.9 - 2
Laptop computer	100	23 - 46	20	18 - 31	5 - 10	0.3 - 1.1
Computer monitor	200	26 - 47	80	22 - 36	10 - 15	0.4 – 0.8
Desktop printer	800	103	40 - 80	49	20 - 30	15.6
Photocopiers	1600	765 - 772	120 - 1000	223 - 235	30 - 250	30 - 37
Vending machines	3000	513 - 2664	350 - 700	183 - 338	300	23 – 89
Fridges	n/a	98 - 248	n/a	26 - 146	n/a	0 – 18
Microwave ovens	n/a	1300 - 1580	n/a	115 - 210	n/a	1.9 – 2.2

Table 13: Benchmarks and monitored energy demand for small power equipment in offices

5.1 Desktop computers

A peak monitoring demand of 234W was observed as part of this study (for Desktop 2), being significantly higher than the peak rating benchmark of 100W. This could present significant problems if high specification desktop computers such as Desktop 2 were to be specified in an office building, resulting in significantly higher internal heat gains than anticipated if benchmarks were to be used. When considering the average power, both monitored desktop computers consumed more energy than the given benchmark, with the higher specification desktop consuming over four time the benchmark demand (of 40W). In stand-by mode however, both monitored computers had demands significantly lower than the benchmark, at approximately 2W (compared to the benchmark of 20-30W).

5.2 Laptop computers

Monitored peak demands for laptop computers were observed to be lower than the equivalent benchmarks, with the highest consuming laptop having a peak demand of approximately half the benchmark value. When considering average demand, both monitored laptops had consumptions within an acceptable range of the benchmark. Yet in stand-by mode, the monitored demands were significantly lower than the benchmark, at approximately 1W compared to a 5-10W benchmark. Such discrepancies could result in a significant overestimation of energy use for laptop computers.

5.3 Computer Monitors

For computer monitors, the peak, average and stand-by demands observed in the monitoring study were all significantly lower than the benchmarks provided in CIBSE Guide F. The highest demand monitored was less than 25% of the peak benchmark value, whereas average demands were also observed to be less than half the average benchmark value. In stand-by mode, all monitors consumed less than 0.8W, whereas the benchmark suggested demands of 10-15W. These sizeable discrepancies are probably related to the recent proliferation of LCD screens, which notoriously consume much less energy than older cathode ray tube (CRT) screens. When these benchmarks were originally published in the 1997 BRECSU guide[xi], CRT screens were the predominant technology for computer screens, resulting in significantly higher benchmark values.

5.4 Desktop printers

Monitoring data for the single desktop printer included in this study demonstrated significantly a lower peak demand than the benchmark value (at 103W compared to an 800W benchmark). However, the monitored average consumption of 49W was well within the range given in CIBSE Guide F (40-80W). Meanwhile, the stand-by consumption figure of 15.6W was somewhat lower than the benchmark range (i.e. 20-30W).

5.5 Photocopiers

The monitored peak demands for photocopiers (765-772W) were observed to be approximately half of the published benchmark. Average consumption however were seen to be within the range of 120-1000W, staying closer to the lower margin at approximately 230W. Similarly, monitored stand-by power was observed to be within the lower portion of the benchmark range (30-250W) at approximately 35W.

5.6 Vending Machines

Monitored peak demands for the vending machines demonstrated that the benchmark value of 3000W was applicable mainly to units selling hot drinks. The refrigerated vending machines only reached peaks of approximately 500-630W. With regards to average consumption, monitored demands for all vending machines were below the benchmark range of 350-700. The hot drinks machine had the highest average demand at 338W, yet still fell short of the benchmark. When considering the stand-by demand, once again all machines had significantly lower consumptions than the benchmark (300W), with the highest consuming machine having a demand of only 89W.

6.0 Assessing the efficiency of laptop computers

Data analysed in Section 4.1 demonstrated a significant variation in energy consumption for different laptop computers. In order to investigate the impact of their different processing powers on overall energy consumption, a short test was undertaken whereby an identical program was run simultaneously on all three laptops. The aim of the test was to determine whether a computer with lower peak demands (such as Laptop 1) would result in a lower overall consumption of energy to undertake the test, or whether a higher processing power (and consequently higher peak demands) could be counter-balanced by shorter running times, resulting in lower consumption of energy overall. The results from the test are shown in Figure 13 illustrating the energy demand for each laptop computer in 1-minute intervals. The time taken by each laptop to complete the test was also recorded, and once the test was complete, energy demand was no longer monitored. The total energy used by each laptop to complete the test was also calculated and is shown in Table 14.

	Laptop 1	Laptop 2	Laptop 3
Test duration	2h 20 min	1h 05 min	48 min
Electricity consumed	54.6 Wh	47.8 Wh	31.1 Wh

Table 14: Energy consumed and time taken to complete the test

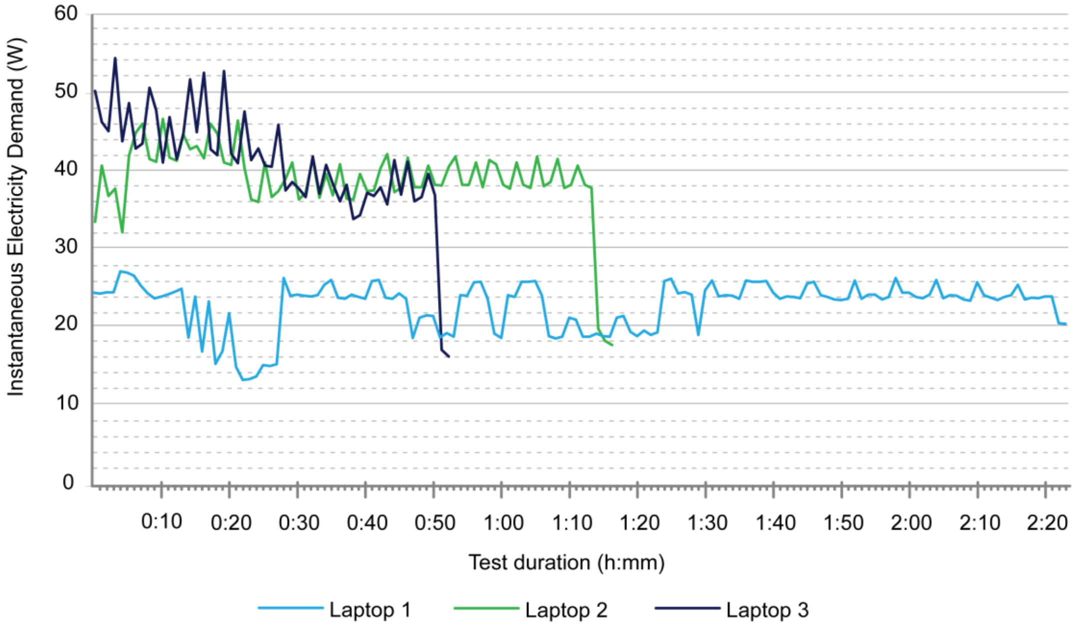

Figure 13: Energy demand in 1-minute intervals throughout the test

As seen, Laptop 3 completed the test in the quickest time (48 minutes) consuming the least amount of energy (31.1Wh) despite its significantly higher peak demands of up to 54W. Meanwhile, Laptop 1 took 2 hours and 20 minutes to complete the test, resulting in the highest total consumption (54.6Wh), despite its consistently lower energy demand. Laptop 2 had peak demands slightly lower than Laptop 3 yet consumed more energy overall due to a comparatively longer running time of 1 hour and 5 minutes.

These results would suggest that higher specification laptops with more processing power could contribute to lower energy consumption in office buildings. However, this would not necessarily be the case if the computers were switched on for the same amount of time regardless of their ability to complete tasks in a shorter timeframe. A clear advantage of specifying computers with higher processing power is that higher speed in running tasks could enable more work to be done over a given time. Yet, doing so would result in higher levels of energy consumption overall. A balance should be drawn between the need for higher processing power and energy consumption. Computers with multiple processors will usually have higher peak demands whilst also being more time efficient, yet they should only be specified when higher processing power and/or speed is indeed required. Otherwise, higher overall energy consumption can be expected at little or no advantage to the users.

7.0 Conclusion

This paper has highlighted that small power equipment can have a significant impact on the total energy consumption of typical office buildings. It has emphasized that small power consumption can vary significantly depending on the installed equipment, power management strategies, occupant behaviour and hours of occupancy. If realistic predictions for power demand and energy consumption are to be achieved, detailed benchmarks for individual appliances should be considered and accounted for using a bottom-up approach.

Having reviewed existing benchmarks for individual small power equipment, this study has compared these benchmarks to monitored data in order to assess their accuracy and applicability. Despite the small sample size of monitored equipment, a number of discrepancies were indentified, suggesting that published benchmarks might not be representative of small power equipment currently being used in office buildings.

Key findings demonstrated that typical desktop computers can have higher peak demands and average energy consumption than the published benchmarks. Meanwhile, the monitored laptop computers were observed to have lower peak demands than the benchmark values with average consumptions being fairly close to the published benchmarks. Stand-by power demand for both laptop and desktop computers were observed to be only a fraction of the benchmarks, highlighting the technological improvements that have occurred since their publication over a decade ago. Monitored data for printers and photocopiers were fairly representative, with only peak demands demonstrating significant variation from the benchmarks. Results from monitoring of vending machines demonstrated that different types of machines, such as refrigerated units and those that provide hot drinks, can have very different peak and stand-by demands. This highlighted the need for separate benchmarks if these are to be representative of operational demands of each type of unit.

A study into the impact of processing power of laptop computers on their overall energy consumption was undertaken. Results indicated that higher processing power, and consequently higher peak demands, can result in less overall energy consumption to complete a given task due to shorter running times. However, if different laptops were to be left on for the same amount of time, regardless of their ability to run tasks faster, laptops with less processing power would consume less energy overall. These findings highlight the importance of specifying appropriate computers for the particular tasks to be undertaken.

Overall, this paper has demonstrated that predicting energy consumption and power demand due to small power equipment might not be a straight forward process. Up-to-date benchmarks would be very beneficial to the industry as a whole, providing designers with reliable data to predict small power consumption in office buildings. This would enable more realistic predictions to be obtained, going some way towards reducing the performance gap.

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