SMALL POWER USE AND WORKING PRACTICES IN OFFICE BUILDINGS

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Thesis submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Engineering (EngD)

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Declaration

I confirm that this is my own work and the use of all material from other sources have been properly and fully acknowledged.

Maroudia Pothitou

Abstract

This research aims to improve understanding of small power energy consumption in office buildings through an examination of the office work practices that give rise to it. Previous studies have mainly been based on quantitative approaches to show the contribution of small power use to total building energy consumption, and do not generally examine why small power energy is being used nor what it is used for. This deductive study takes a new approach, rooted in Social Practice Theory (SPT), by exploring how variations of small power use relate to the dynamic nature of office work practices. The research informs thinking about the nature and causes of small power energy use in offices and will ultimately be of interest to all those concerned with the design and operation of this building type.

A mixed-methods approach is used to understand office workers' work practices and how they give rise to electricity use in offices. Data were captured across three different office sites in Berkshire in the United Kingdom between September 2018 and April 2019. Each office worker participant in the study was observed and monitored over two different working days within a two-month period in each office site. The approach uses quantitative analysis of data from observations of activities performed and the devices and spaces used, as well as from monitoring of the energy consumption directly associated with them. This is combined with a qualitative exploration of office work through semi-structured interviews based on the elements of SPT.

The research contributes to knowledge in four main ways. First, it develops a new definition of small power energy use by interrelating the use of office equipment and electric plug-in devices with office workers' activities undertaken in different office spaces over a working day. Second, this study presents new data on small power energy use, showing its temporal distribution by different types of workers and suggests that variations in small power energy use in the office sites studied arise from the mobility of workers and their associated work practices. Further, the mobility of workers, determined mainly by their work role, is important in understanding small power energy use. The activities of 'mainly-static' workers account for more small power energy use than those of other types of worker ('mainly-mobile' workers).

Third, by exploring the working practices of office workers through the elements of SPT, an improved understanding of the work giving rise to small power energy consumption is developed. This highlights how the meanings that office workers ascribe to their work activities and the organizational rules under which they operate influence energy use through the type of devices they use and where work is carried out. Finally, the research develops a new categorisation of energy-consuming work activities performed by office workers that relates their mobility and the devices they use in different office spaces. This categorisation includes work activities (‘desk-based’ activities; ‘communication’ activities; ‘extracting/organizing document’ activities) and also other activities not related to work (e.g. preparing coffee in the kitchen) that have energy-consuming impacts.

This research develops an understanding of office work practices by considering what activities that involve energy-consuming devices and equipment are performed in different office spaces. Additionally, it identifies the nature of these activities, what are these devices and equipment, and their associated small power energy consumption to show how small power energy use can be explored and better understood through exploration of the work practices that give rise to it.

KEYWORDS:

Commercial buildings; Offices; Small power; Plug loads; Electricity use; Social Practice Theory; Work practices; Office spaces; Mobility; Activities; Static workers; Mobile workers.

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Dear Friends (from Greece, the UK, and any other country):

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Last but certainly not least, Mum, Dad, Brother, and Panagiotis Plastiras:

You give me strength to move on, no matters what. I am grateful for your patience, love, and emotional support.

Dedication

This doctorate is dedicated to everyone who fights to achieve more despite difficulties or adverse conditions that may face.

"Passion is energy. Feel the power that comes from focusing on what excites you"

Oprah Winfrey

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Abbreviations and Glossary

BCO	British Council for Offices
CIBSE	Chartered Institution of Building Services Engineers
DBEIS	Department for Business, Energy and Industrial Strategy
DCLG	Department for Communities and Local Government
DEC	Display Energy Certificate
DECC	Department of Energy and Climate Change
DETR	Department of the Environment, Transport and the Regions
EPBD	Energy Performance of Buildings Directive
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information Communication Technology
MEL	Miscellaneous Electric Loads
ONS	Office for National Statistics
SPT	Social Practice Theory

Working day A timeframe of 7am to 7pm, within which observation of work activities was carried out, depending on the time that the worker was present in the office building.

Preface

The Engineering Doctorate (EngD) programme is a four-year research study which is part-funded by the Engineering and Physical Sciences Research Council (ESPRC). An EngD degree is typically awarded for research conducted within an industrial context.

Unlike other EngD projects that have an industrial sponsor, this research instead took its direction from a project 'Negotiating needs and expectations in commercial buildings' that was part of the 'DEMAND' (Dynamics of Energy, Mobility and Demand) Energy Centre Programme funded by the ESRC/EPSRC with support from ECLEER (EDF R&D), Transport for London and the International Energy Agency. DEMAND is a collaborative research project led by Lancaster University and involving researchers from a number of UK-based universities, including the University of Reading and EDF Energy (www.demand.ac.uk).

Chapter 1: Introduction

1.1 Background to the Research

There is significant pressure from the UK Government to continue to reduce energy consumption of buildings in the UK. This is because much higher potential has been identified for cost-effective carbon mitigation in the built environment compared to any other sector (UK Green Building Council, 2011). The UK government has set legally binding targets towards reduction of national CO_2 emissions by 80% (on 1990 levels) by 2050 (DECC, 2013). Part L Building Regulations (BRegs) (DCLG, 2010a; 2013) is the main mechanism which is employed by the UK Government to regulate the energy performance – and associated emissions – of new buildings. At the same time, there is a gradual tightening of energy and emissions targets to stimulate emission reductions in both domestic and non-domestic new buildings (DECC, 2011).

The UK government has also applied initiatives to mitigate CO_2 emissions (under the law: SI 2007:991[1]) by measuring as-built and operational performance of buildings in energy performance certificates (EPCs) and by demanding the display of energy certificates (DECs) in public buildings, showing actual energy consumption (DCLG, 2015). While it is mandatory for public buildings with a size greater than 1000m2[2] to assess building energy use on a yearly basis and to display a DEC (DCLG, 2010b; 2015), private commercial buildings are not subject

[1] SI 2007:991: The Energy Performance of Buildings (Certificates and Inspections) (England and Wales) (2007). The Energy Performance of Buildings Regulations (EPBR) 2012 (England and Wales) came into effect in January 2013 and introduce further obligations in relation to Energy Performance Certificates, Display Energy Certificates and Air conditioning. The EPBR implements the requirements of the recast 2010 EU Directive on the energy performance of buildings (European Union Law (EUR-Lex), 2010), which aims to reduce the level of CO_2 from public buildings by 2018 and all new buildings by 2021 (CIBSE, 2015).
[2] The recast version (Article 13) of the Energy Performance of Buildings Directive (EPBD) indicates that total floor area has been reduced to 500 m^2 (Bull et al., 2012).

to this regulation. Consequently, there is no comprehensive data on energy usage of this type of building from this source. It is therefore challenging to obtain and compare benchmarking data for all commercial buildings, particularly given the wide variety of building types and space usage falling within the ‘commercial’ category (e.g. office, retail, industrial, health, hospitality). Detailed knowledge and understanding of energy use and building performance in the commercial building stock has been identified as an area requiring further investigation for at least a decade (Liddiard, Taylor and Rylatt, 2010) and DECC (2013) has recognised that “there is currently no representative data series measuring the energy efficiency of the non-domestic building stock” (p.18). Thus, there is considerable potential to improve current understanding of energy consumption in private commercial buildings.

Commercial sector buildings consist of different types of premises such as retail, warehousing, factories, and offices. These buildings account for 11% of the UK’s greenhouse gas emissions (Committee on Climate Change, 2018). Office buildings are responsible for the second highest energy consumption (17%) amongst the different types of commercial buildings (according to Department for Business, Energy & Industrial Strategy (DBEIS), 2016), accounting for 1.1% of total UK CO_2 emissions (Perez-Lombar, et al., 2008; Tetlow, et al., 2015). Part of the energy consumption in commercial office buildings is regulated through Government legislation (Building Regulations), which is designed to achieve reductions of CO_2 emissions from certain building end-uses such as Heating, Ventilation, Air-conditioning (HVAC), domestic hot water, and internal lighting. However, there are other energy end-uses in commercial office buildings which are not governed by Building Regulations and are often referred to as ‘unregulated’ end-uses (Menezes, et al., 2012a; Mulville, et al., 2017). These unregulated electrical end-uses include office ICT equipment, plug in devices (e.g. printers and ancillary desktop equipment), and other equipment (e.g. server rooms) which are generally categorized as ‘small power’ office equipment. Generally, small power is defined as the energy used by electrical equipment and appliances commonly plugged in to the electricity network in an office environment (Gunay et al., 2016). This is further elaborated in the literature review chapter (Section 2.6.1).

Small power use from ICT and other small power office equipment makes a significant contribution to the energy balance of commercial office buildings, accounting for 37% of their total electricity consumption (DBEIS, 2016). Small power use has a significant effect on office electricity usage and is found to vary significantly (Tetlow, et al., 2015; Mulville, et al., 2014; Lanzisera et al., 2013; Menezes, et al., 2011). This variability of small power energy use may reach up to 50% of the total electricity consumption in offices (NBI, 2012). This research takes the issue of variability in small power energy use as a starting point and seeks to understand what people actually do in offices that gives rise to small power energy consumption. This is approached by looking at the relationships between the work that office occupants undertake, and the devices/equipment they use in different office spaces over a working day (an intraday approach). Given the potential significance and variability of small power energy use in offices, it is important to understand their relationships in the first instance to develop an improved picture of the nature and extent of this form of energy consumption. In addition, an improved understanding of small power energy consumption can be expected to improve the design and operation of HVAC systems as their designed capacity considers internal heat gain from small power devices and equipment (Gunay, et al., 2016; Hafer, 2017). Further, it could also be used to inform the development of end-use strategies designed to reduce energy consumption and associated emissions associated with small power devices and office equipment.

1.2 Research Problem

The preliminary brief of this research was drawn from the DEMAND project (see Preface) and was related to a broad area of enquiry on ‘Negotiating needs and expectations in commercial buildings’ that sought to investigate the context around how energy is used in offices, and how the design of offices and office spaces affects energy use. Given that one of the significant energy end-uses in offices is small power energy use (as outlined in 1.1 above, and developed further in Chapters 2 below and further), relatively little is currently known about this end-use category and the key determinants of energy use within it. Therefore, this research focused specifically on developing an improved understanding of small power energy consumption.

The original goal of this research was to investigate the interaction between office workers and their use of energy in office buildings, taking the view that energy in offices – and small power energy in particular, which relates specifically to the use of electrical office equipment and devices – is not consumed for its own sake but for the accomplishment of office work. As shown in Figure 1-1, this goal has been progressively refined to focus on small power energy consumption and is intended to improve the understanding of the nature of office work and what people do in offices that gives rise to small power energy consumption.

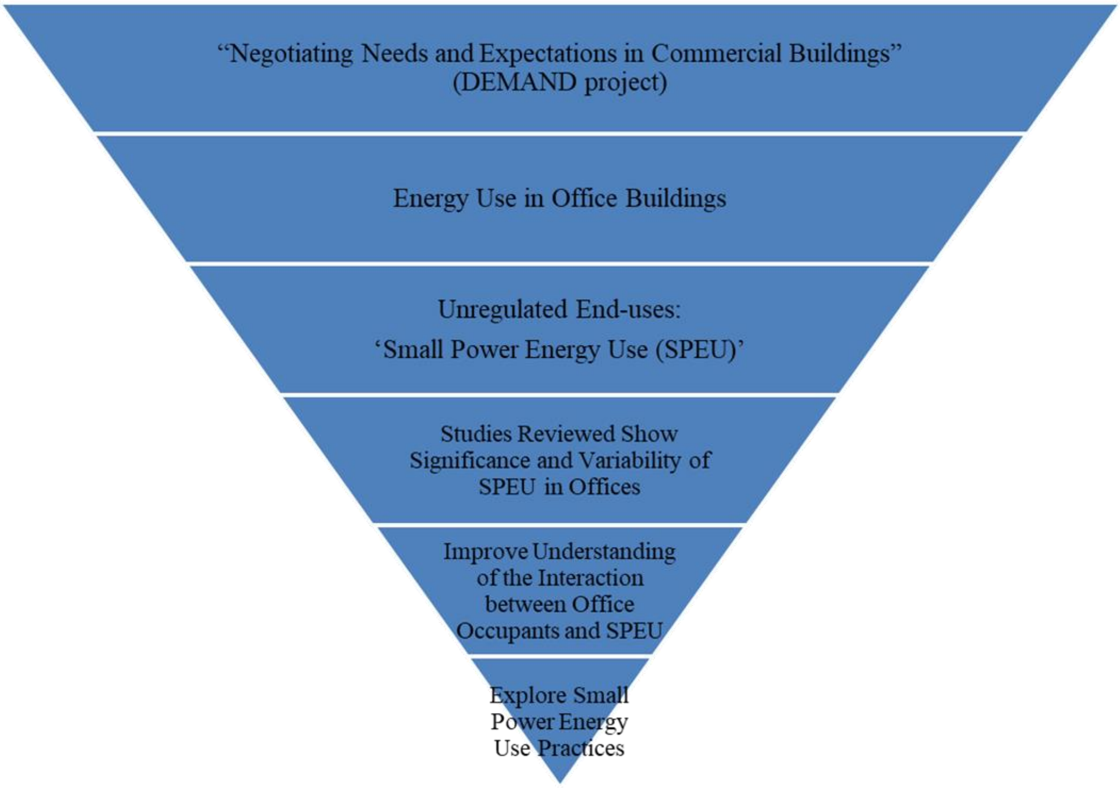

Figure 1-1. Development of research scope

This research focuses on understanding small power energy use through an examination of the office working practices that give rise to it. It explores the significance and variability of electricity consumption resulting from the use of small power devices and equipment in different office spaces, and the influence that office occupants have on small power energy usage.

1.3 Aims and Objectives

The aim of this research is to improve understanding on 'how small power energy is used and what it is used for' by demonstrating the factors that give rise to electricity consumption from small power devices and equipment in office buildings. This study addresses the following objectives:

1. To understand what office work and other activities are performed in different office spaces that use energy-consuming devices and equipment.
2. To understand what types and quantities of office devices and equipment are used to support the performance of these office work activities.
3. To measure what small power energy is consumed by these equipment/device-using activities in different office spaces.
4. To explore how small power energy use practices shape the usage of devices and the way that work and other activities are performed in an office environment?

1.4 Summary of Methods Used

To understand the interaction between office occupants and small power energy use in an office environment, this deductive research[3] adopts a mixed-methods approach, and draws on Social Practice Theory (SPT) to help provide insights into how day-to-day office work practices give rise to energy use – the theoretical basis, and the rationale for the approach adopted are discussed further in Chapter 4. Currently, studies on small power energy use are mainly focused on the quantitative estimation of electricity usage from devices and equipment. These include measurements of small power energy use in offices as part of the total building electricity consumption and are geared towards helping with future predictions of office energy use, but

[3] A deductive approach explores an existing theory or phenomenon and tests if that theory is valid in given circumstances by designing a research strategy to examine the research questions arising from that theory (Wilson, 2010).

few studies focus on what office occupants do in offices and the associated effect on small power energy use. This research uses quantitative methods (monitoring of electricity used by small power devices and equipment) in combination with qualitative methods (observational data and interviews) to understand what office occupants are doing and how that impacts small power energy use. This mixed-methods approach is currently not widely developed in the investigation of small power energy use in office buildings. It is used in this study to understand the nature of office work that give rise to small power energy use in offices, not only from the usage of small power devices and equipment, but also due to the working practices of office occupants while performing work in different office spaces.

1.5 Synopsis of the Thesis

The remainder of this thesis is organised into eight chapters. An overview of each chapter is provided below.

Chapter 2 – Review of Literature on Small Power Energy Use

Chapter 2 presents the importance of this research, presenting an overview of the electricity usage in commercial buildings. In addition, an overview of the work in relation to variability of small power energy use and factors which cause this variability are discussed. The chapter also provides a detailed discussion on the factors which cause variability of small power energy use in office buildings. These factors are related to definitions and scope of the studies, methods used, as well as building characteristics and use characteristics. This chapter identifies the research gaps and outlines that small power energy use in offices can be better understood by looking at the relationship of energy-related work activities with office occupants, office spaces, and office equipment over a working day.

Chapter 3 – Theoretical Basis

Chapter 3 considers the relationship identified in Chapter 2 which associates energy-related work activities with office occupants, office spaces, and office equipment over a working day and develops the theoretical approach to understand work practices and associated small power energy use. The elements of the SPT – habits/routines, meanings, knowledge, technologies/infrastructure – are discussed, showing how each element has been explored to understand small power energy use practices.

Chapter 4 – Research Methods

Chapter 4 outlines the mixed method approach used, introduces the case office sites, and discusses sampling characteristics. Data gathering techniques include monitoring of electricity usage from office devices/equipment (quantitative method) as well as observations of work activities and device usage in different office spaces, and semi-structured interviews (qualitative methods) to support this study and address the research questions.

Chapter 5 – Quantitative Findings on Office Small Power Energy Use

Chapter 5 presents the analysis of quantitative data. This includes descriptive analysis which combines observational data on activities performed and device used in different office spaces, with measurements of small power energy use from monitoring of devices and equipment in different case office sites. Observational data and monitoring data were also combined to conduct statistical analysis on small power energy use of the office sites examined.

Chapter 6 – Relating Small Power Energy Use Data to Working Practices

Chapter 6 considers the quantitative analysis conducted and uses elements of SPT to analyse interview data and to interpret the key quantitative findings of this study. The elements of SPT – knowledge, meanings, habits/routines, and technologies/infrastructure – were used to explore small power energy use practices in order to improve understanding of 'what small power is used for' in office buildings.

Chapter 7 – Discussion

Chapter 7 discusses the quantitative findings from Chapter 6 and the qualitative exploration of the practices behind these findings (Chapter 6) in the context of key literature. It also discusses the contribution of this study.

Chapter 8 – Conclusions

The final chapter outlines the key findings from the research and highlights the contributions and implications of this study. In summary, the main contributions to the theory and practice resulting from this research cover: (1) detailed observational data on activities performed and device used in different office spaces and monitored data on electricity used by small power devices and equipment in different case office sites; (2) a mixed method approach combining qualitative and quantitative analysis to understand what are the factors which cause variability on small power energy use in different case office sites; (3) development of a categorisation of energy-consuming activities (including work and other activities) performed by different work roles in different office spaces. Supporting these contributions, a critical evaluation of the research project is drawn and additional recommendations for further research are made, considering both theoretical and industrial contexts.

Chapter 2: Review of Literature on Small Power Energy Use

2.1 Overview on Energy Consumption in Building

This chapter discusses the literature in relation to energy consumption in the commercial buildings sector and shows the importance of energy use in office buildings. It provides a brief overview of the development of the UK Building Regulations (BRegs) to help put the prime focus of this study – on unregulated (so called 'small power') energy uses – in context. An analysis and discussion of secondary data from the literature on unregulated energy use is presented to focus attention on the central concern of this study, and the importance of unregulated energy usage on total building energy consumption.

2.2 Energy Consumption in the UK Commercial Sector and the Importance of Electricity Use in Office Buildings

Commercial sector buildings account for 11% of the UK's greenhouse gas emissions (Committee on Climate Change, 2018). The commercial sector consists of different types of premises such as retail, warehousing, factories, and offices. According to the British Property Federation (2016) office buildings make up the largest proportion (31%) of properties, after retail (e.g. shopping centres, retail warehouses, supermarkets) (41%), followed by industrial (19%) and other commercial property (e.g. hotels, leisure) (8%).

Office buildings[4] are classified within the commercial sector as one of the most energy intensive and consequently CO_2 emitting building type after retail, representing about 1.1% of total UK CO_2 emissions (Perez-Lombar, et al., 2008; Tetlow, et al., 2015). A recent study estimated that the energy consumption of UK office buildings can be responsible for up to 17% of total non-domestic energy use (DBEIS, 2016). The Building Energy Efficiency Survey (BEES) by the Department for Business, Energy & Industrial Strategy (DBEIS) (2016) considered data from a sample of 1.57 million commercial premises in England and Wales and identified that office and retail account for an equal proportion of energy use within the commercial sector, followed by industrial, health and hospitality (see Figure 2-1).

Energy consumption in the commercial sector is mainly divided into electrical and non-electrical end-uses[5]. According to the study from the Department for Business, Energy & Industrial Strategy (DBEIS) (2016), the electrical and non-electrical end-uses comprise 53% and 47% respectively. Non-electrical energy is used substantially for space heating while the most common electrical end-uses are lighting, cooled storage (for storage of food and drink), information communication technology (ICT) equipment (data centres and server rooms) and other, so-called ‘small power’ office equipment (comprising computers, printers and ancillary desktop equipment). In the UK commercial building sector, office buildings use a high proportion of electrical energy (68%) and of this total electricity consumption, a high

[4] Kamarulzaman, et al. (2011, p.263) defines an office building as encompassing a workplace that involves “information and knowledge processing activities of an organization, including filing, planning, designing, supervising, analysing, deciding and communicating”. Office buildings “range from small, single story multi-occupied buildings to the skyscrapers that form the skylines of all major cities” and “tend to be newer than other buildings” (WBCSD, 2009, p. 40).

[5] End-uses are described as those which comprise the primary energy use in commercial office building. The most common end-uses in office buildings consist of space heating, cooling and ventilation, water heating, lighting, catering, computing/electronics (including servers), and other miscellaneous such as office devices/equipment (i.e. small power use) (DECC, 2013b).

percentage (37%) is attributed to ICT and other small power office equipment (DBEIS, 2016) (see Figure 2-1).

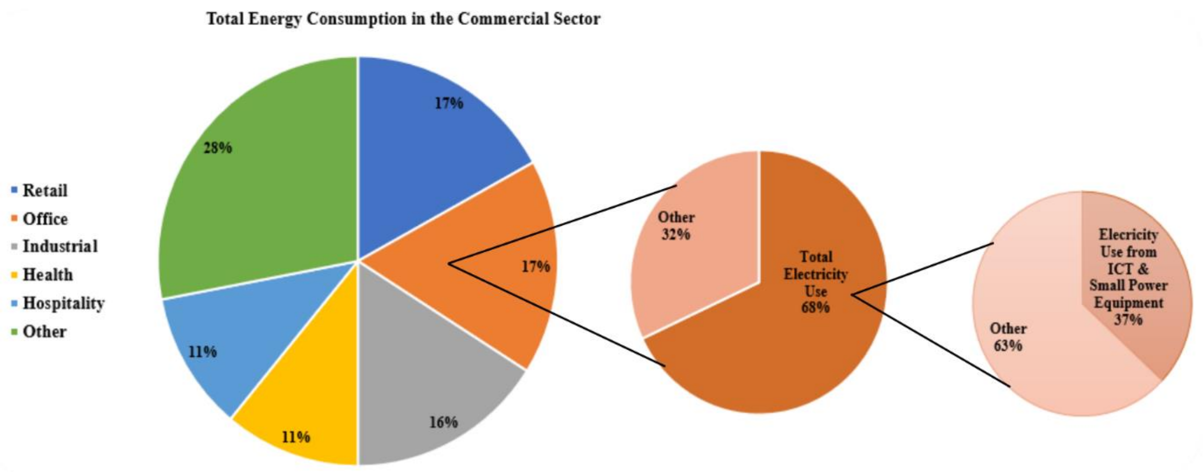

Figure 2-1. Proportion of energy consumption in the commercial sector (data were obtained from DBEIS (2016) - BEES)

This electricity usage from office ICT equipment and other electrical end-uses is not regulated through Government legislation (Building Regulations), which is designed to achieve reductions of CO_2 emissions from certain building end-uses such as HVAC, domestic hot water, internal lighting. The different types of energy use within regulated and unregulated end-uses are explored in the following sections.

2.3 Regulated Energy End-uses: Overview of Part L Building Regulations

Although BRegs are not the focus of the present study, this section discusses the development of the BRegs in order to distinguish unregulated energy uses more clearly from uses covered by Regulations, and to help identify the significance of the former. This is presented through an overview of the progressive development of BRegs during the last 30 years to reduce CO_2 emissions and their more recent focus (during the last decade) on the efficient performance of specific energy end-uses (e.g. HVAC, internal lighting, domestic hot water).

BRegs relating to energy efficiency were focused initially on specifying the thermal properties of a building's materials and components but have subsequently been extended to the assessment of the performance of whole buildings in terms of their CO_2 emissions.

In particular, 'Part L' was first introduced in 1985 under the 1984 Building Act provision and focused on regulated heating systems and insulation of services (BRE, 2006). Part L was revised in 1990 (in response to an oil crisis) (BRE, 2006) and then again in 1995. The latter revision was aimed at regulating the "conservation of fuel and power" but the regulations were limited to the compliance of certain elements of the building envelope (such as fabric insulation). In an initiative to bring considerations of carbon emissions reduction into the regulatory framework, in 2002 the Carbon Index was introduced and Part L "conservation of fuel and power" was divided to L1 (Dwellings) and L2 (Non-Dwellings). This change included introducing methods for assuring compliance, such as the Carbon Emissions Calculation Method, which assesses the annual carbon emissions of a building. In 2006 Part L was amended in response to the European Union's Energy Performance of Buildings Directive (EPBD), which aimed to shift building energy regulations in European countries from 'a prescriptive to a performance basis'

(Kolokotroni, 2008; Cohen and Bordass, 2015, p.4). This amendment differentiated between New Dwellings (L1A), Existing Dwellings (L1B), New Buildings other than dwellings (L2A) and Existing Buildings other than dwellings (L2B). The assessment of Part L 2006 was based on activities for different commercial building types, including occupancy hours and required performance standards. This is achieved by using a National Calculation Methodology to calculate the building's CO_2 emissions in comparison to a defined 'notional' building. This methodology, which considers energy use mainly from HVAC and lighting, sets limitations on the CO_2 emission rates of commercial buildings. However, there are other energy end-uses in commercial buildings (e.g. office plug in devices and other equipment generally categorized as 'small power') which are not governed by BRegs and are often referred to as 'unregulated' (Menezes, et al., 2012a; Mulville, et al., 2017). The following sections will explore those unregulated end-uses and their impact on building energy consumption.

2.4 Unregulated Energy End-uses: Analysis of Secondary Data on Small Power Use in Office Buildings

This section discusses unregulated energy end-uses in office buildings based on a review of studies from different countries (the US, UK, Malaysia and South Africa) that explores the effect of small power energy use on overall building energy consumption.

It was difficult to compare the findings of the studies reviewed due to lack of consistency in relation to measurement approaches and metrics on small power use. In order to address the issue of comparability between the results of these studies, a review of the data across various studies around the world was carried out to normalise the findings of each study. This analysis covers 25 empirical studies that used quantitative methods to examine small power energy consumption in offices.

2.4.1 Comparing Data on Small Power Use in Offices

Different studies which have reviewed small power usage in offices have presented the results of small power energy consumption using a range of different metrics, amongst other different factors. These differences include the scope and methodology used by each study, as well as the building and use characteristics considered for each study (e.g. building type examined, quantity of devices assessed). In order to compare the results of these different studies and to demonstrate the importance of unregulated end-uses on the assessment of office buildings' energy performance, an analysis was undertaken to compare these results. To achieve comparability between results the process entailed:

- Converting all different measurement and reporting units (e.g. kilowatt-hour per square foot per year, expressed as kWh/SF/year) to a common metric which is commonly used, i.e. kilowatt-hour per square meter per year (kWh/m^2/year);
- Where parameters for comparison were missing in the reviewed studies, the following assumptions were made based on data from relevant studies, including:
    - using recognized metrics for office occupancy density of 10m^2/person (BCO, 2014; Tetlow, et al., 2015)

- using data on average working days[6] during a year in different countries in order to convert a metric of kilowatt-hour per day (kWh/day) or kilowatt-hour per desk per day (kWh/desk/day) to kilowatt-hour per square meter per year (kWh/m^2/year)
- estimating working hours during a day, using an average of 9 hours (Dunn and Knight, 2005; Tetlow, et al., 2015; Gandhi and Brager, 2016) in combination with the formula 'E(kWh)=P(W)*t(h)/1000'[7], which calculates energy (E) in kilowatt-hours (kWh), in order to estimate daily kilowatt-hours per square meter and by considering working days across a year (which varies for each country) to convert a metric of Watt per square meter (W/m^2) to kilowatt-hour per square meter per year (kWh/m^2/year).

While this process allowed data from 15 of the 25 studies providing energy use data identified to be compared, seven of the 25 studies only provided results on energy use for office devices, noting the quantity of devices or presenting their findings in MWh/year without including information (such as area of offices) that would assist in converting results to more common metrics such as kWh/m^2/year. The results of these seven studies have therefore been excluded from the comparison of the data. However, the remaining three of the 25 studies which reported the proportion of small power energy use in relation to the total office electricity use – rather than per square metre of floor area or per office worker – were also considered. Therefore, the normalised data have been extracted from 18 out of 25 studies considered and are presented and discussed in the following section. As an initial point, the comparison of the normalised

[6] Statistics on working hours considered from 'Bureau of Labor Statistics, 2011' for U.S., 'GOV.UK, 2014' for the UK, as well as, 'International Labor Organisation, 2011' and 'World at Work, 2010' (A survey of WorldatWork Members) for other countries (e.g. Malaysia and South Africa).
[7] The energy E in kilowatt-hours (kWh) is equal to the power P in watts (W), times the time period t in hours (hr) divided by 1000.

data revealed two issues: i) great variability of small power energy consumption in office buildings; and ii) unregulated end-uses can affect significantly the total electricity consumption in offices. These issues are further discussed in the following section.

2.4.2 Significance and Variability of Small Power Use in Offices

Study findings, which are presented in Figure 2-2, suggest that energy consumed for small power purposes is significant but also highly variable. The findings on small power use range from 4.7kWh/m^2/year to 63kWh/m^2/year, which can be responsible for up to 27% of total electricity consumption in the offices studied.

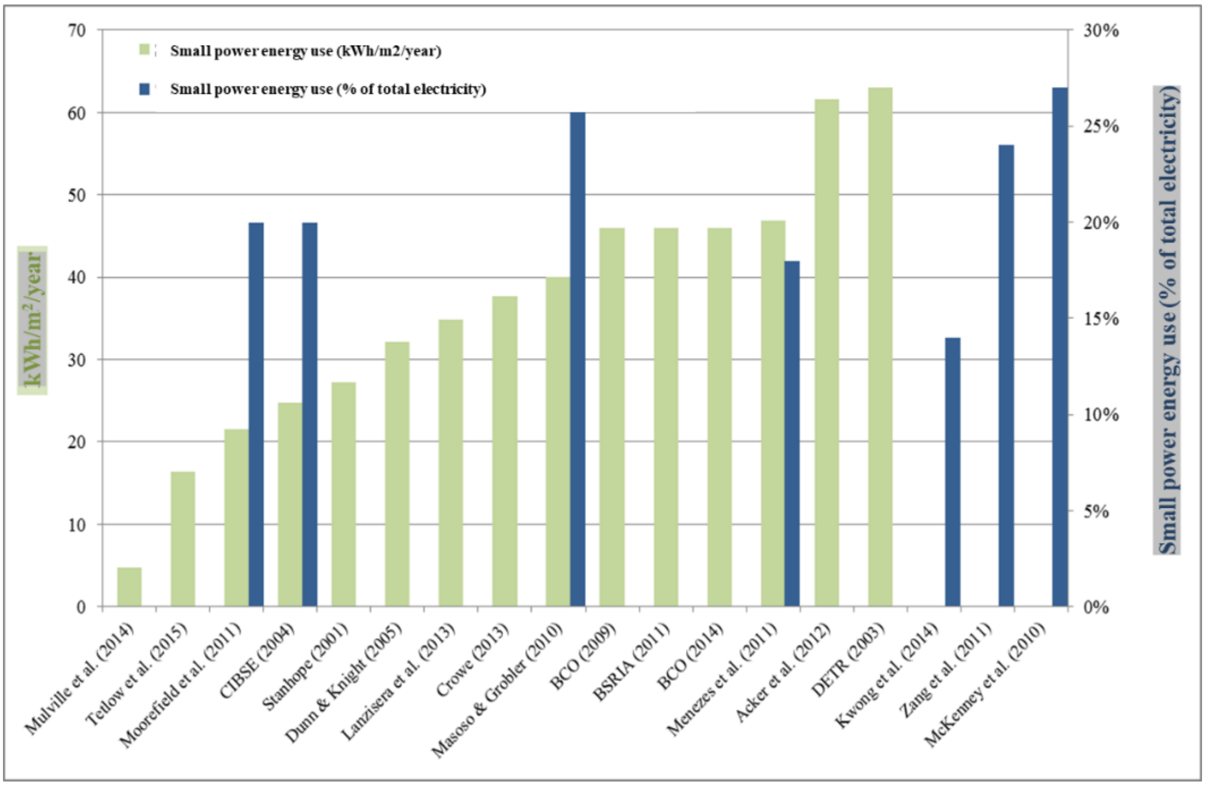

Figure 2-2. Quantitative assessment of small power energy use from a range of studies

In support of the above results, a best practice guide on plug loads developed by the New Building Institute (NBI) (2012) argues that even in office buildings that have improved the efficiency of lighting, heating and cooling, small power may account for up to 50% of the total electricity use[8].

Beyond the significant effect of small power use on electricity consumption of offices, there is also an indirect effect of small power use on the overall building energy consumption. Several studies highlight how expected small power use affects the design and operation of HVAC systems, thus contributing further to the overall energy usage in offices (Jenkins, et al., 2008; Menezes, et al., 2013; Menezes, et al., 2014). This is because small power use from office equipment not only increases electricity use, but also gives rise to internal heat gains from plug-in equipment that need to be taken account of in the design of heating and cooling systems (Menezes, et al., 2012a; Gunay, et al., 2016; Hafer, 2017). The comparative analysis of studies above (presented in Figure 2-2) supports the assertion that small power use makes a significant contribution to the energy balance of commercial buildings and needs to be further examined and understood.

[8] This guide considered mainly U.S. office buildings and revealed results based on Energy Information Agency (EIA) and NBI measured data which estimates that electricity use from plug loads increased as much as 35% in relation to the total office electricity consumption between 2003 and 2012.

2.5 Overview of Small Power Use in Office Buildings

Having identified the significance and variability of unregulated energy end-uses in office buildings (i.e. small power use), the following sections presents a more detailed review of the relevant literature. The review synthesises several studies to identify factors which are believed to contribute to the variability and importance of small power use in offices.

Over the last two decades, small power use in office buildings has been investigated using mainly quantitative methods (measuring and estimating energy consumption from the use of a range of office equipment and devices). Several factors have been highlighted as making a significant contribution to variations in small power use. For example Gandhi and Brager (2016), in an examination of small power use to assess the effect of a behaviour-based intervention for reducing energy use from office devices, found that density of occupancy (i.e. internal area allocated per person) has a strong influence on small power use. Menezes, et al. (2012b) studied the impact of occupant behaviour on electricity consumption for small power and lighting in an office building in central London, UK, to help improve the accuracy of design stage predictions. They found that, in addition to density and hours of occupancy, variations on small power can also be strongly related to the nature of occupancy (i.e. roles of occupants and associated work activities involved), as well as the range and energy efficiency of appliances and building energy management systems. Further factors are identified across other studies, including size of building (Dunn and Knight, 2005; Acker, et al., 2012; Moorefield, et al., 2012), extent of HVAC servicing (Dunn and Knight, 2005; Masoso and Grobler, 2010; Menezes, et al., 2011; Tetlow, et al., 2015), occupant behaviour (Webber, et al., 2006; Crowe, 2013; Reddy, et al., 2014; Tetlow, et al., 2015) and a range of other factors.

In order to understand the possible factors which cause variations on small power energy consumption, the empirical studies introduced in Section 2.4 above and other relevant studies were reviewed further to identify possible explanations for the differences in normalised small power energy between them. This further review identified a number of factors that could be argued to influence the levels of small power energy consumption reported. These factors feature prominently in the studies examined but there is variation in how they are used across the studies. To help in the further review and analysis of the potential influence of these factors, they are grouped into four categories, as follows:

- Category A. Definitions and scope
- Category B. Methods
- Category C. Building characteristics
- Category D. Use characteristics

Table 2-1 maps the studies examined in terms of the extent to which these factors might help explain the levels of small power energy use reported in each of them. Examples of studies covering each category are discussed below in order to develop an understanding of the influence of these factors on the variation of small power energy use.

Table 2-1. Possible key factors influencing reported small power energy use

Factor (category)	Number of studies	Country	Literature	Rational for grouping
A. Definitions and scope				
Definition of small power	8	UK S. Africa USA USA UK UK UK UK	Dunn and Knight, 2005; Masoso and Grobler, 2010; Moorefield, et al., 2011; Acker, et al., 2012; CIBSE, 2012; Menezes, et al., 2013; Mulville, et al., 2014; Tetlow, et al., 2015	Definitions of small power use and scope of studies are interrelated, as the definitions of small power used in each study depended on the study scope and the research purpose. Different definitions were used for studies that focus, for example, on examining the relationship between worker behaviour and small power use, compared to those examining small power use in different office spaces.
Scope of studies on small power use	6	Ireland UK USA USA Malaysia India	Schoofs, et al., 2011; Zhang, et al., 2011; Crowe, 2013; Lanzisera, et al., 2013; Kwong, et al., 2014; Reddy, et al., 2014	
B. Methods				
Methods to assess small power use Measurement units used to present findings from small power use	14	UK S. Africa USA Ireland UK UK USA USA	Dunn and Knight, 2005; Masoso and Grobler, 2010; Moorefield, et al., 2011; Schoofs, et al., 2011; Zhang, et al., 2011; Menezes, et al., 2012a; Crowe, 2013; Lanzisera, et al., 2013;	Methods and measurement units are not consistent in the studies reviewed, which gives rise to issues of incomparability.

		Malaysia UK India UK UK Austria	Kwong, et al., 2014; Mulville, et al., 2014; Reddy, et al., 2014; Tetlow, et al., 2015; Menezes, et al., 2014; Mahdavi, Tahmasebi and Kayalar, 2016	
C. Building characteristics				
Physical characteristics of buildings: size of office buildings	3	UK USA USA	Dunn and Knight, 2005; Moorefield, et al., 2011; Acker, et al., 2012	These two factors, the size of buildings and HVAC servicing, form part of the physical characteristics of the building envelope and systems. Both characteristics cause variations on small power use due to the differences in the designed occupancy density for different building sizes and small power allowance, as well as the designed capacity of energy systems in the buildings.
Physical characteristics of buildings: type and extent of HVAC servicing	6	UK UK S. Africa UK UK UK	BRECSU, 2000; Dunn and Knight, 2005; Masoso and Grobler, 2010; Menezes, et al., 2011; Mulville, et al., 2014; Tetlow, et al., 2015	
D. Use characteristics				
Type and quantity of office devices	6	UK S. Africa USA UK USA Malaysia	CIBSE, 2004; Masoso and Grobler, 2010; McKenney, et al., 2010; Menezes, et al., 2011; Moorefield, et al., 2011; Kwong, et al., 2014	These three factors, type and quantity of devices, occupancy density, and behaviour of occupants, are all related to the utilisation of the buildings and are influenced by the occupant presence and what people are doing, which affects small power use.

D. Use characteristics (continue)			
Occupancy density	3	UK UK UK	Stanhope, 2001; Dunn and Knight, 2005; BCO, 2014
Occupancy behaviour	3	USA USA India	Webber, et al., 2006; Crowe, 2013; Reddy, et al., 2014

Category A: Definitions and Scope. Differences in definitions of small power appear across several studies. In general terms, studies of small power use focus either on office 'unregulated' loads, i.e. those end-uses not covered by the UK Building Regulations (e.g. Moorefield, et al., 2011; Acker, et al., 2012; Menezes, et al., 2013), or on plug-in devices only (e.g. CIBSE, 2004; Dunn and Knight, 2005; Masoso and Grobler, 2010; Mulville, et al., 2014; Tetlow, et al., 2015). However, within these categories definitions of what constitutes small power vary considerably. In addition, the scope of the studies undertaken also varies, mainly in terms of the different types of commercial building studied (e.g. office buildings, industrial buildings, medical centres, hotels, retail stores) or different type of office buildings, (e.g. serviced offices, call centres). The scope of the studies reviewed also varies in terms of the number of buildings included in studies of small power use (e.g. single or multiple office buildings). Section 3.3.1 examine these factors further to see if they can help explain differences in small power use reported across the studies included.

Category B: Methods. This includes differences in study methods and in measurement and reporting units. Study methods range from monitoring energy use (Menezes, et al., 2011; Crowe, 2013; Mulville, et al., 2014; Tetlow, et al., 2015), energy audits (Masoso and Grobler, 2010; Kwong, et al., 2014), and walk-through surveys (Dunn and Knight, 2005; Moorefield, et al., 2011) to modelling approaches (Schoofs, et al., 2011; Zang, et al., 2011; Menezes, et al., 2014; Mahdavi, Tahmasebi and Kayalar, 2016). Further, different measurement and reporting units (e.g. MWh/year, W/m^2, kWh/desk/year) are used. These differences in study methods and measurement affect the comparability of reported results and this is discussed further in Section 3.3.2.

Category C: Building Characteristics. This includes size of buildings as well as the type and extent of HVAC services in the different buildings studied. Differences identified in the physical characteristics of buildings such as office size (Moorefield, et al., 2011; Acker, et al., 2012) and the type and extent of HVAC servicing (e.g. Masoso and Grobler, 2010; Crowe, 2013) are discussed further in Section 3.3.3. below.

Category D: Use Characteristics. Office buildings in the studies examined also differ by occupancy density, the type and quantity of energy-consuming office devices used, and occupant behaviour, and there have been identified from the studies reviewed. Some studies (e.g. Stanhope, 2001; Dunn and Knight, 2005; BCO, 2014) focused on occupancy density (m^2/person) and rate of occupation (% of use across the working day). Other studies have covered considerable differences in use characteristics including, for example, variations in the type and quantity of office devices used for office work (Menezes, et al., 2011; Acker, et al., 2012; Lanzisera, et al., 2013) as well as differences in user behaviour, including turn-off rates of office devices (e.g. Zhang, et al., 2011; Mulville, et al., 2014; Reddy, et al., 2014). The type and use of buildings (Zang, et al., 2011; Lanzisera, et al., 2013) were also identified to differ between the studies reviewed. These differences are examined in more detail in Sections 3.3.4.

The categories above are not mutually exclusive. Empirical studies of small power in office buildings exhibit some prominent differences in key categories, e.g. in terms of definitions and/or scope, and also reveal further differences in other areas that might potentially offer more compelling explanations for the changes in small power energy use recorded. These are now discussed.

2.6 Small Power Use: Understanding and Assessing Small Power Use in Offices

2.6.1 Category A: Definitions and Scope

2.6.1.1 Definitions of Small Power Use

This section examines the first factor from Category A discussed in Section 3.2 on the variability in how small power use is defined. The various definitions used within the literature show that there is no standardized definition of 'small power' to examine its use. This complicates the assessment of small power use across a range of studies, and comparisons between them to understand potential differences and likely influences on small power levels. The key differences between definitions adopted are discussed below.

Definitions can broadly be divided into two groups:

i) definitions of 'unregulated loads', mainly applying to UK studies (with reference to energy use that is not regulated under the Building Regulations), or 'plug loads' mainly in U.S. studies

ii) device-use definitions

'Small power' is the term that is mainly used in UK studies for the assessment of office energy use associated with unregulated energy (i.e. not for the purposes of HVAC, internal lighting, domestic hot water that are regulated under the Building Regulations – see Section 2.3), including that for office devices and equipment (Menezes, et al., 2011; Tetlow, et al., 2015). In the U.S. and other countries (e.g. Malaysia and South Africa) small power typically covers the energy used by office equipment and electrical devices, and is referred to as 'plug load' electricity or Miscellaneous Electric Loads (MELs) (Masoso and Grobler, 2010; Lanzisera, et al., 2013; Kalimaris, et al., 2014; Kwong, et al., 2014). As will be seen, while there is some common ground between these definitions, there are also significant differences between them. Indeed, even within each broad definition (small power, plug loads or MEL) there are variations in the range of energy uses that are covered under each and therefore some inconsistency in how they are applied.

Starting with small power defined as unregulated load or plug loads compared to that defined in terms of electrical devices, a study conducted in the UK by Menezes, et al. (2013) includes equipment and associated plug loads, as well as external lighting, vertical transportation (i.e. elevators and escalators) and computer servers. In some U.S. studies, by contrast, small power mainly covers office plug loads (e.g. Moorefield, et al., 2011; Acker, et al., 2012) and in some cases includes computer servers (e.g. McKenney, et al., 2010; Crowe, 2013) but excludes vertical transportation and external lighting. The definition of small power from these US studies refers to plug loads as any electric device which plugs into sockets that are distributed throughout a building (Komor, 1997; Lobato, et al., 2011). Other studies use a rather broader approach without specifying the inclusion of particular end-uses such as vertical transportation or computer servers. For instance, McKenney, et al. (2010) and Kalimaris, et al. (2014) defined plug loads as all electric loads except for those related to main systems for heating, ventilation, cooling, water heating and lighting (however, these studies have also not included vertical transportation and servers). Gandhi and Brager (2016, p.1) argue that “plug loads are considered to be devices plugged into an electrical outlet in a commercial office building, primarily including, but not limited to, IT equipment”. Another approach used for assessing small power use is to describe office plug loads as MELs. Energy used by MELs is similarly defined as the energy which is distributed across many electric devices and equipment but primarily comes from plug-loads in buildings (Lanzisera, et al., 2013). McKenny, et al. (2010, p.16) define MELs as “electricity-consuming loads that do not fall under the conventional end use categories of lighting, heating, ventilation air conditioning, and water heating”. To add to the variability of definitions, in a small number of cases, MELs are sometimes considered to include elevators and medical, cooking, and refrigeration equipment (McKenney, et al., 2010; Lanzisera, et al., 2013), whereas other studies focus more on office devices/equipment only (e.g. Moorefield, et al., 2011; Acker, et al., 2012; Crowe, 2013).

Many studies using device-based definitions of small power energy (generally in terms of plug loads or MELs) also group devices and equipment into further categories, e.g. general office equipment, computing equipment, miscellaneous equipment. A summary of how different devices are included in different categories of equipment or small power uses across the different studies examined is shown in Table 2-2 below.

Table 2-2. Office devices and how they are categorised in the literature

Device	Categories included in	References
Computer (desktops/ laptops)	Computing equipment; Small power equipment; Office plug loads; Office equipment.	Webber, et al., 2001; Roberson, et al., 2004; Dunn and Knight, 2005; BCO, 2009; Kaneda, et al., 2010; Masoso and Grobler, 2010; Menezes, et al., 2011; Moorefield, et al., 2011; Zhang, et al., 2011; Menezes, et al., 2012a; CIBSE, 2012; BCO, 2014; Kwong, et al., 2014; Menezes, et al., 2014; Reddy, et al., 2014; Tetlow, et al., 2015; Gunay, et al., 2016.
Monitors/ Screens	Computing equipment; Computing peripherals; Small power equipment; Office plug loads; Office equipment.	Webber, et al., 2001; Roberson, et al., 2004; BCO, 2009; Kaneda, et al., 2010; Moorefield, et al., 2011; Acker, et al., 2012; CIBSE, 2012; Menezes, et al., 2012a; BCO, 2014; Kwong, et al., 2014; Menezes, et al., 2014; Reddy, et al., 2014; Tetlow, et al., 2015; Gunay, et al., 2016.

Device	Categories included in	References
Printers/ Photocopiers	Computing peripherals; Network shared equipment; Small power equipment; Office plug loads; Office equipment.	Webber, et al., 2001; Roberson, et al., 2004; Dunn and Knight, 2005; BCO, 2009; Kaneda, et al., 2010; Menezes, et al., 2011; Moorefield, et al., 2011; Zhang, et al., 2011; Acker, et al., 2012; CIBSE, 2012; Menezes, et al., 2012a; BCO, 2014; Kwong, et al., 2014; Menezes, et al., 2014; Reddy, et al., 2014; Tetlow, et al., 2015; Gunay, et al., 2016.
Scanners/ Fax machines	Computing peripherals; Network shared equipment; Small power equipment; Office plug loads; Office equipment.	Webber, et al., 2001; Roberson, et al., 2004; Dunn and Knight, 2005; BCO, 2009; Kaneda, et al., 2010; Masoso and Grobler, 2010; Moorefield, et al., 2011; Acker, et al., 2012; BCO, 2014; Kwong, et al., 2014; Reddy, et al., 2014.
Multifunction Devices (MFDs)	Computing peripherals; Office equipment.	Webber, et al.,2001; Roberson, et al., 2004; BCO, 2009; Moorefield, et al., 2011; Acker, et al., 2012.
Desk lamps	Miscellaneous equipment; Small power equipment; Office equipment.	Menezes, et al., 2011; Acker, et al., 2012; CIBSE, 2012; Tetlow, et al., 2015.
Microwave	Miscellaneous equipment; Small power equipment; Office plug loads; Office equipment; Kitchen equipment.	Kaneda, et al., 2010; Menezes, et al., 2011; Menezes, et al., 2012a; CIBSE, 2012; Reddy, et al., 2014.
Refrigerator	Miscellaneous equipment; Small power equipment; Office plug loads; Office equipment Kitchen equipment.	Kaneda, et al., 2010; Masoso and Grobler, 2010; McKenney, et al., 2010; Menezes, et al., 2011; Zhang, et al., 2011; Acker, et al., 2012; CIBSE, 2012; Menezes, et al., 2012a; Lanzisera, et al., 2013; Menezes, et al., 2014; Reddy, et al., 2014.

As presented in Table 2-2, across the studies reviewed there is no consistency in the range of devices which have been considered in the study of small power use, nor in the sub-categories used to group these office devices. For instance, some studies include specific devices (e.g.

desktop and laptop computers, monitors, printers, copiers, multi-functional devices (MFDs), scanners, fax machines) in a particular group such as ‘office equipment’ (Webber, et al., 2001; Roberson, et al., 2004; BCO, 2009; BCO, 2014; Kwong, et al., 2014; Gunay, et al., 2016); others include the same devices as office plug loads (Kaneda, et al., 2010; Moorefield, et al., 2011) or small power equipment (Dunn and Knight, 2005; Menezes, et al., 2011; Tetlow, et al., 2015). Yet other studies sub-divide types of devices into different sub-groups (e.g. computing equipment, computing peripherals, miscellaneous equipment and kitchen equipment) (Acker, et al., 2012; Reddy, et al., 2014). While several studies assessed mainly those devices that are commonly used in offices (e.g. computers, monitors, printers/scanners, multifunction devices, microwave, refrigerator; Masoso and Grobler, 2010; CIBSE, 2012; Menezes, et al., 2012a; Menezes, et al., 2014; Mulville, et al., 2014), other studies examine the device usage based on the different spaces within offices at which devices are located (Zhang, et al., 2011; Crowe, 2013) and focus more on the nature of these spaces, e.g. private offices, meeting rooms, kitchens, server rooms, rather than the type and quantity of device used.

This review of the definition on small power use shows that there are differences in the definitions used with respect to the unregulated loads and in what is included in several defined groups of office devices. These differences in definition impact the comparability between studies. Even studies that applied some similar concepts of small power (e.g. covering common office devices) show differences in how small power definition has been applied and this leads to variations in their findings on small power energy use. The variation within the findings of these studies is explained by what was measured in each study (related to small power, plug loads or MELs) and what was excluded from each study in terms of office devices and equipment (e.g. servers or vertical transportation).

2.6.1.2 Scope Differences in Studies of Small Power Use in Offices

Apart from differences in the definitions of small power use across the studies examined, there are also considerable differences in the scope of these studies (Category A). This review highlights that studies vary in terms of the number and variety of offices examined and consider either single buildings or multiple office buildings across a considerable range. The buildings studied also have further inherent differences such as in the type and use of buildings, reflecting considerable variety in office building design and construction.

Of the studies covered, those which examined a single building were mainly focused on small power energy consumption in academic buildings. Zhang, et al. (2011) studied small power energy use during working and non-working hours from different devices and equipment (e.g. computers, monitors, printers, information displays) in a purpose-designed academic office building which hosts a school of computing science. Schoofs, et al. (2011) examined small power use in an academic building which hosts a school of computer science and informatics, by focusing only on the electricity use of computers during working and non-working hours. In addition, Reddy, et al. (2014) assessed computers, monitors and imaging devices (e.g. printers, scanners, copiers, projectors) in an academic building to identify electricity used when devices are in use or standby/sleep mode. Kwong, et al. (2014) examined four different offices within the same academic building – administrative office, lecturers' office, classrooms and computer laboratory - by auditing the energy usage of different office devices (e.g. computers, monitors, printers, projectors). Whilst these studies provide details on the effect of small power use in relation to overall building electricity usage, their findings are specific to the individual buildings studied and their particular contexts (as well as use characteristics, – see 3.3.5 below – and are not directly comparable). For example, Kwong, et al. (2014) and Zhang, et al. (2011) reveal that small power use affects overall building electricity usage from 14% to between 15%

and 33%, respectively. Reddy, et al. (2014) reveal findings of small power in kWh per year which varies from 24kWh to 339kWh depending on the type of devices assessed (e.g. computers, imaging, networks, and other appliances such as refrigerators, water coolers).

Other studies of single office buildings go beyond assessing a specific type of office (e.g. academic buildings) and cover more general, unspecified office uses. For example, Lanzisera, et al. (2013) assessed electricity used from a variety of plug loads devices (e.g. computers, displays, imaging and network equipment, space heaters and fans) in a single building which is used as a 'traditional office', though without specifying what this is. The findings show that information technology equipment consumes over 75% of the annual energy used from plug loads although IT devices are less than half of the total number of devices recorded. In addition, Crowe (2013) examined three floors of a single building used as an office headquarters, considering plug loads devices from different office spaces (e.g. workstations, conference/meeting rooms, kitchen) and revealed that a significant proportion (33%) of electricity used from plug loads is consumed after working hours, from desktop computers, laptops, monitors, conference room equipment, and printers. While both these studies examined small power use in single office buildings, their scope differs. The first study is focused on electricity usage of IT equipment, while the second focuses on out of hours energy consumption of general office devices. In addition, Lanzisera, et al. (2013) acknowledge that the examination of a single building may not be representative of the diversity present in office buildings, covering building type and occupancy characteristics. So even within studies of single buildings, variation is evident due to the scope of studies and the individual circumstances of the buildings examined.

While there is a considerable range of studies examining small power energy across multiple office buildings, there are also considerable differences between them in terms of the nature and range of buildings covered. For instance, one study considered a wide range of 'commercial' buildings, including office, retail, education, warehouse, and healthcare buildings (e.g. McKenney, et al., 2010). Other studies examined small power use in different types of office buildings, e.g. serviced offices and call centres, as well as offices used for computer services, management consulting, architecture services, land records, insurance, and financial services (e.g. Stanhope, 2001; Webber et al., 2001; Acker et al., 2012). With respect to these studies, their scope differs not only in terms of the number of buildings examined but also in terms of the building characteristics (e.g. size and/or type).

For example, most of the multi-building studies have been conducted consider only a small number of buildings ranging from a minimum of 2 buildings (e.g. Menezes, et al., 2011; Mulville, et al., 2014; Tetlow, et al., 2015) to a maximum of 220 (e.g. Dunn & Knight, 2005; Webber et al., 2006; Moorefield et al., 2011; Acker et al., 2012; Gunay et al., 2016; Hafer, 2016). Acker, et al. (2012) examined 6 office buildings of different size and type and reveals that small power energy use ranges between 2.18kWh/SF/year and 10.5kWh/SF/year (Acker et al., 2012). Moorefield, et al. (2011) examined 47 offices of different type and size and show that small power office (from office electronics and miscellaneous plug loads) is responsible for 2.97 kWh/SF/year mainly for small offices (<30,000 square feet). Webber, et al. (2006) evaluated 16 buildings, including education buildings and office buildings, and estimated that plug loads comprised 18% and 11% of the electricity consumed at these office buildings respectively. Hafer (2016) examined plug loads in 220 buildings on a university campus, which were categorized as laboratories, offices, classrooms, public space, recreation facility, and service facility, estimating that plug loads comprised 32% of the total energy consumption of the assessed buildings.

One exception to studies which examined only a small number of buildings is the study conducted by McKenney, et al. (2010)[9], which considered data from 824,000 office buildings from U.S. Commercial Building Energy Consumption Survey. This study also considered many other types of commercial buildings such as retail and services, e.g. non-food, education, health care, warehouse, food services. This study shows that energy consumed for small power purposes can be responsible for up to 26% of the total office electricity consumption. The results of this study also show that MELs account for a variation between 10% and 60% of total electricity consumption across the range of building types examined such as retail and services: non-food, office, education, health care, warehouse, food services, food sales. Office buildings are shown to be the second highest electricity consumer after retail and services: non-food (McKenney, et al., 2010).

In addition to the variations in the scope of studies already discussed, these studies also reveal other factors (e.g. methods used to examine small power use and also physical and use characteristics of buildings examined) which may affect small power use. Investigation of these additional factors will be examined in the following section to gain a more detailed understanding on small power use in offices.

[9] This study estimates small power use using data from 824,000 office buildings of various office types (e.g. administrative/professional offices; bank/financial; government offices, e.g. non-profit and social services; medical offices; research and development offices; sale office, and call centres).

2.6.2 Category B: Methods, Measurement Approaches, and Reporting Units on Small Power Use

Section 2.5 identified variability in examining methods, measurement approaches and reporting units (Category B) from empirical studies reviewed on small power use. This section explores these factors in order to improve understanding of the effect of the different methods and measurement approaches used to examine small power use. Quantitative methods (i.e. involving data on the quantity of devices used and/or measurement of small power energy use) tend to predominate in studies of small power use. Quantitative methods are mainly concerned with on-site energy monitoring and metering (i.e. quantifying actual small power use), though some studies adopt modelling approaches (using empirical data on small power use to calibrate estimation models) to estimate the proportion of small power in relation to the total building electricity usage and/or predict future small power requirements.

Energy monitoring and time-series metering have been extensively applied in studies of small power energy consumption in offices. The focus of these studies is on the electricity usage of office devices and equipment in use, typically obtaining data of relatively high interval frequency (from a few seconds to hourly intervals) within a specific time frame (ranging from few days to several months) to show the proportion of small power use in relation to the total building electricity consumption. For example, Crowe (2013) obtained hourly use data through monitoring 250 plug loads within different office spaces for 56 days, while Mulville, et al. (2014) collected hourly monitoring data on 90 workstations alone for 100 days. Lanzisera, et al. (2013) monitored 455 plug loads in high interval frequency (10 seconds) for a period between 6 and 16 months to assess small power use in an office building while Reddy, et al. (2014) monitored the energy used from 93 plug loads within an office building at a 10-minute interval for a period of 4 months. Monitoring approaches are useful in the assessment of small power use in offices, but the differences between studies in respect of what devices are included in monitoring lead to variations in findings which makes difficult to compare the studies. For example, Mulville, et al. (2014) examine small power use at desk level of two office buildings during working hours and non-working hours (including weekdays and weekends) and show that up to 23% of the overall small power consumption at desk level can be attributed to non-working hours. However, Crowe (2013) assessed small power use from devices within different office spaces of an office building during working hours and non-working hours and revealed that different type of office devices (e.g. desktop PCs, laptops, monitors, conference room equipment, and printers) constitute 33% of electricity consumption during non-working hours.

Several other studies use post-hoc energy auditing (Masoso and Grobler, 2010; Kwong, et al., 2014) and walk-through surveys (Dunn and Knight, 2005) to determine the quantity of electricity used by small power use, considering office devices and equipment on site over a given period. The assessment of electricity used by office devices and equipment based on energy audits, which record data from a circuit or electrical panel (periodic, manual readings of meters), may not achieve as high interval frequency of data as achieved by other methods (e.g. monitoring of a single plug load device) and therefore limit the detail and level of data collected. Walk-through surveys typically record details (e.g. device power and mode as well as nameplate-ratio) on the type and quantity of office devices/equipment used by office workers, as well as on the number of workers and treated floor area (i.e. usable internal floor area) of office buildings. This approach differs significantly from other methods which identify actual device energy consumption (e.g. monitoring of individual device energy use). This approach gives useful insights into the number and types of devices used per office worker but tends to be based on design consumption rate rather than measured energy use.

Modelling approaches have also been used to improve understanding of small power use. These approaches vary from baseline models (e.g. bottom-up model, stochastic model) (Menezes, et al., 2014; Mahdavi, Tahmasebi and Kayalar, 2016) to agent-based models (Zhang, et al., 2011). These different modelling approaches either estimate electricity used by office devices (baseline-models) or predict future electricity use for small power purposes by sizing the small power energy supply and considering the implications for heating and cooling provision (agent-based models). For instance, one modelling study (Mahdavi, Tahmasebi and Kayalar, 2016) focuses mainly on predicted estimates of electricity usage from plug loads based on workstation devices (e.g. computers, peripherals, and telephones) and occupancy of a small number of staff members in an academic building, but excludes other devices which affect small power use, such as projectors, kettles, microwaves. Another study, which also examined an academic building, developed a different model which integrates (among other important elements) a variety of electric appliances and equipment to simulate the electricity consumption of the building (Zhang, et al., 2011). This latter study, while it considers an extensive sample of different type of devices, also focuses only on a single building type, which reflects the specific characteristics (type of building) of the building examined, and thus limits the comparison of results with other office buildings.

It is notable that, with some exceptions, qualitative approaches (using methods including surveys, observations, user-interviews) have not been used so widely in the examination of small power energy consumption nor, indeed, to examine why people are using the devices and equipment that give rise to small power use in offices. This paucity of qualitative studies may reflect the challenges of developing meaningful parameters for measurement. In a small number of cases, surveys and observations are applied to assess the behavioural effect of occupants on small power use by identifying individuals' attitudes, norms, perceived behavioural control and habits in relation to small power energy consumption (e.g. Menezes, et al., 2012b; Tetlow, et al., 2015). The qualitative methods used from these studies are combined with measurements of small power use to assess the device use that gives rise to electricity consumption and the contribution that individual users make to this.

To sum up, methods and measurement approaches that are used to examine small power energy consumption in offices vary considerably. For instance, monitoring individual device energy use, which reveals actual device energy consumption, differs significantly from other methods used such as walk-through surveys, which calculate small power use based on the number of devices in use, device power and nameplate-ratio and office treated floor area. Quantitative methods may provide insight on small power use in offices, however they are mainly focused on the assessment of devices and equipment used without further considering the ‘how’ and from ‘whom’ these devices are used that in turn affect small power energy consumption. There is a considerable lack of qualitative methods in the assessment of small power that might help understand the nature of office work and occupant activity that is giving rise to small power use. A mixed method approach, involving both quantitative and qualitative methods, could allow the capture of measurements on small power use whilst also helping to develop an understanding of the reasons behind the use of electricity for small power purposes. This type of combined analytical approach may help to develop a better understanding of the dynamics of small power use in office buildings.

2.6.3 Category C: Building Characteristics and their Effect on Small Power Use

Having identified variations in several factors which might help explain small power use (such as definitions and the scope of studies, as well as the methods used to examine small power in offices), this section explores additional factors that are present in the studies reviewed. The physical characteristics of office buildings (Category C) such as the building size and energy systems (HVAC) servicing have been considered in several studies which show that there is no clear relationship between small power use and these characteristics. These physical characteristics and their effect on variations of small power use are reviewed below.

2.6.3.1 The Effect of Office Size on Small Power Use

A small number of cases across the studies of small power explored in this review examined office buildings of different sizes. Data is presented on the number of occupants, office area and business type or space type (e.g. open plan offices, cellular offices or mixed type offices). The findings of these studies show that the relationship between office size and small power energy use varies.

Acker, et al. (2012) examined office buildings of different sizes and their small power use. This study revealed that office buildings of different sizes consumed similar relative small power energy per square meter. This study considered six office buildings and grouped them into different sizes, based on number of building occupants. Sizing ranged from what they authors defined as small (≤10 office workers), medium (≤50 office workers) and large (≤100 office workers) offices, with floor areas ranging between 1,288SF (120m^2) and 13,688SF (1,270m^2).

The findings based on a survey of occupants and metered energy use data are presented in Table 2-3 below.

Table 2-3. Small power energy in offices of different sizes

Buildings	Number of occupants	Size (m^2)	Type/use of office	Small power use ($kWh/m^2/year$)
Small offices	6	120	Architecture	54.46
	7	144	Elections office	23.46
Medium offices	31	422	Land Records	55.43
	49	1,214	Regulatory Agency	23.46
Large offices	90-97	1,270	World-wide logistics	23.46
	100	1,270	Investment Analytics	113.02

Adapted from Acker, et al. (2012)

The data in Table 2-3 suggests variations between the different size of offices and small power use. For instance, one medium-size office (regulatory agency) with 49 occupants was measured to have very low energy usage despite its high computer intensity, in comparison with another medium-size office (land records), despite the latter office accommodating a smaller number of occupants (31). It is also noticeable that a small Architects' office accounted for double the amount of small power (kWh/m^2/year) compared to a small elections office, despite their similar size. Comparing two large offices of the same building size (1,270m^2), it was found that one office consumed the lowest and the other accounted for the highest rate of energy for small power purposes, indicating that other more important factors (e.g. nature and density of occupancy, as well as number and type of devices used) may be affecting small power energy use than office size.

Similarly, a study by Moorfield, et al. (2011) of a large number of different office buildings (47 office buildings of varying occupancy with almost half of the offices ranging in size from 10 to 275 workers, and the remainder having fewer than 10 workers), with a range of floor space from 350 to 38,000 SF (32.52m^2 to 3,530m^2), found no clear relationship between plug load energy use and floor area. The main office uses represented in the sample of this study are: legal, accounting, and tax services; architectural and engineering services; and computer systems design. However, and somewhat in contrast to the study by Acker, et al. (2012), architectural and engineering business was found to consume the lowest small power energy use per square foot while the occupants with the highest energy use per square foot were a computer systems design business (Moorefield, et al., 2011).

On the other hand, Dunn and Knight (2005) revealed a strong correlation between small power energy use and occupancy density in terms of treated floor area per person. This study examined small power energy consumption in 30 office buildings of different size and occupancy density, ranging from 17m^2 to 1,195m^2 of sample floor area (m^2), with a range of between 3 and 178 office workers respectively. The occupancy density of the offices examined varied from 4.3m^2/person to 22.8m^2/person. The findings of this study show that the higher the occupancy density, the lower the small power use (W) per person (comparing the calculated small power equipment loads (W/m^2) with occupancy density in terms of treated floor area per person (m^2 TFA/person) as indicated in Figure 3, p.90).

Whilst recognising the small number of cases covered by these studies, they nonetheless suggest no clear relationship between size of office buildings and small power energy use. Rather, they suggest that the nature and intensity of occupancy may be more important, and this is examined further below in Section 2.6.4.1.

2.6.3.2 Air-Conditioning Versus Natural Ventilated Offices and The Effect on Small Power

HVAC servicing in offices may cause variations on small power energy use. Small power provision is associated with the design of HVAC systems in air-conditioned offices, as allowances for heat gains from small power devices together with assumptions about occupancy density are considered during the design of HVAC systems.

Several studies in this review explore the extent of HVAC servicing in offices and compare it with non-air-conditioned offices to identify the potential impact on small power energy. These studies cover air-conditioned offices (e.g. BRECSU, 2000; Dunn and Knight, 2005; Masoso and Grobler, 2010; Mulville et al., 2014) and, in a few cases, office buildings with more of a 'mixed mode' approach (i.e. air-conditioning and natural ventilation, e.g. Menezes, et al., 2011; Tetlow, et al., 2015). The comparison of these studies, which assessed small power use considering HVAC servicing, show that the relationship between HVAC servicing and small power energy use varies as discussed below.

Interestingly, findings on small power energy consumption in air-conditioned offices vary considerably, revealing results which range between 4.7kWh/m^2/year and 63kWh/m^2/year (e.g. BRECSU, 2000; Masoso and Grobler, 2010; Mulville, et al., 2014). However, the results of these studies cannot easily be compared due to other inherent differences (e.g. number and size of offices examined, quantity of devices/equipment assessed etc.) between the buildings considered. For example, Masoso and Grobler (2010) identified that the effect of small power use for six office buildings (e.g. academic buildings, customer service centre, headquarters, public buildings) accounts for 26% of total building energy use. Mulville, et al. (2014) examined small power use at desk level in two office buildings (typical serviced offices) and revealed that up to 23% of the overall energy consumption at desk level can be attributed to non-working hours. Consequently, the variability and intensity of small power use in both types of offices (i.e. air-conditioned and natural ventilated offices) may be attributed to other factors than HVAC servicing (e.g. differences in scope of each study and, in turn, of what is being measured to assess small power).

In addition, a small number of studies that examined both air-conditioned and natural ventilated offices revealed considerable variations in small power use, ranging from 18kWh/m^2/year (Tetlow, et al., 2015) to 45kWh/m^2/year (Menezes, et al., 2011). This variation may be associated more with the different quantity and type of office devices and equipment used, rather than with the different HVAC servicing of these offices.

From this evidence, the extent to which the presence of HVAC systems in offices may help to explain variations in small power use is not clear. Other factors, such as occupancy density, the type and quantity of office devices/equipment used, turn-off rates, etc. would appear to offer greater potential to help explain small power use, given their direct relationship to devices and equipment that consume small power. These factors will now be considered.

2.6.4 Category D: Use Characteristics and the Effect on Small Power Use

Beyond the physical characteristics of office buildings included in studies of small power energy use, which vary considerably, the studies reviewed reveal that building use characteristics (Category D) are also considered to have an important effect on small power use. These characteristics are mainly related to the office measured (actual) occupancy density (i.e. m^2/person) and the number of devices used, as well as the way that office workers use them (i.e. the energy-consuming behaviour of office workers). Each of these characteristics is examined in terms of their contribution to improving understanding of small power use in offices and further discussed in the following sections.

2.6.4.1 The Effect of Building Occupancy Density on Small Power Use

Several studies of small power use in offices show that the ratio of occupants to floor area (m^2/person, i.e. occupancy density) may contribute significantly to electricity use (e.g. Dunn and Knight, 2005; BCO, 2014). Others, by contrast, suggest that occupancy density may not be directly associated with small power use to the same extent (e.g. Stanhope, 2001).

Stanhope (2001) examines small power use in 17 office buildings (involving both full air-conditioned and natural ventilated offices) and found no significant correlation between actual occupancy density and small power use, supporting that “higher density does not mean higher usage” (p.10). This study covers a range of office environments, used for call centre services, lawyers’ offices, computer services, investment banking, and insurance company headquarters. Findings show that high measured occupancy densities (e.g. 6.7 and 8.6m^2/person) are associated with relatively low electricity usage for small power purposes (e.g. 11 and 14W/m^2

of small power use, respectively). On the other hand, low measured occupancy densities (e.g. 20.4 and 14.6m^2/person) were estimated to consume relative high small power energy (e.g. 24 and 21W/m^2 of small power use, respectively). This pattern is suggested in most of the case studies examined by Stanhope (2001, p.11), revealing that there is not an [expected] correlation between occupancy density and small power (i.e. the higher the density, the higher the small power use). This resulting correlation between occupancy density and small power use may be associated with two factors identified by British Council for Offices (BCO) (2013) in relation to the designed occupancy density. These are firstly the utilisation of the building (the proportion of employees present at any time in the office) and second the diversity (the proportion of workforce absence). These two factors can reduce the actual occupation of office buildings (referred to as ‘effective density’) below the design predictions of densities and in turn reduce the heating and cooling loads as well as small power requirements. Higher designed occupancy densities than recorded occupancy densities, and in turn higher than necessary small power allowances, may have been assumed at the design stage of the offices examined by Stanhope (2001), as the author clearly indicated that small power actual consumption was lower than small power design capacities. This was evident by one case study having 80W/m^2 design capacity, with a recorded minimum and maximum small power energy use from 30W/m^2 to 35W/m^2 respectively. This consideration of higher occupancy densities and small power allowances during the design stage can lead to over-specification of air-conditioning systems, causing additional capital cost as well as inefficient operation in use as equipment runs below capacity (Stanhope, 2001, p.12).

In contrast, Dunn and Knight (2005) identified a relationship between small power use and occupancy density. This study examined the level of small power use from a variety of recorded occupancy densities, the latter ranging from 4.3m^2/person to 22.8m^2/person (average density of

11.1m^2/person), and examined 30 fully air-conditioned UK offices (with a range of treated floor area from 17m2 to 1,494m^2). The findings on small power energy use, considering different actual occupancy levels, range between 6W/m^2 and 34W/m^2 (average small power of 17.5W/m^2). Taking into account their results on average actual occupancy density and average small power use, the authors suggested a reduction on the average UK office small power load design estimate from approximately 40W/m^2 to between 12 and 25W/m^2 (Dunn and Knight, 2005, p.91).

In support of this latter argument on small power load design, a more recent study by the British Council for Offices (BCO) (2014) suggests that different designed occupation levels can be supported by different small power use allowances (and further allowances for HVAC design). That study examined typical occupancy scenarios in offices considering high, medium and low intensity of small power energy use and different occupancy densities, revealing findings which show that small power use is directly proportional to office occupancy density. In particular, BCO (2014) suggests that for the design of HVAC systems (i.e. the capacity of HVAC systems in relation to small power requirements), small power design allowance of 20W/m^2 should be provided for an occupancy density of 8m^2/person; 16W/m^2 for an occupancy density of 10m^2/person; and 14W/m^2 for an occupancy density of 12m^2/person.

Considering the studies above, actual occupancy density could be argued to influence small power use; however, the relationship seems somewhat complex due to the variation of the findings from different studies. In particular, the diversity of office utilisation (i.e. actual occupation) and the energy intensity of different occupants directly affect the levels of electricity use for small power purposes (i.e. the capacity of offices to accommodate people at a high occupancy density does not necessarily imply high small power use). Further, the requirements of occupancy densities, and in turn small power provision, are assumed for the design of other building systems' capacity (i.e. HVAC), suggesting that knowledge of occupant activities and the office equipment used to support these activities – as well as the density, diversity and intensity of occupation – are all important factors in developing an understanding of small power energy use. These are explored further below.

2.6.4.2 Small Power and the Use of Office Devices (Type/Quantity)

The type and quantity of electrically powered office devices has been identified as another factor which may contribute to small power use in offices and several studies focus primarily on this factor. Consideration of different equipment densities and types of devices in use in offices from the studies reviewed shows variations in small power energy use in relation to the total electricity consumption between 14% (Kwong, et al., 2014), 18% (Menezes, et al., 2011); 20% (CIBSE, 2004; Moorefield, et al., 2011) and 26% (Masoso and Grobler, 2010; McKenney, et al., 2010). An initial observation indicates that computers (desktops/laptops) and monitors feature prominently in these studies and are believed to consume a high proportion of small power energy (Masoso and Grobler, 2010; McKenney, et al., 2010; Menezes, et al., 2011; Wang and Ding, 2015).

With respect to the different type of devices used in offices, a study of 47 office buildings in California (Moorefield, et al., 2011) shows that small power accounts for an average of 20% of the total building annual electricity consumption. This study applied time series metering across the office studied, revealing that computers and monitors account for up to 66% of small power use. They consider other 'miscellaneous' devices to include items such as portable lighting, telephones, and small kitchen appliances (e.g. coffee makers), noting that these are responsible for up to 18% of small power use, with a further 16% of small power use from other office electronic equipment (e.g. imaging equipment such as printers, faxes, multifunction devices, and computer peripherals such as computer speakers, external drives). CIBSE (2004) also present a similar picture relating to device energy use in the UK, finding that 66% of the energy consumed for small power purposes (20% of total office annual electricity use) is attributed to desktop computers. Another more recent study (Lanzisera, et al., 2013) found that information technology equipment consumes over 75% of the annual MELs energy, with computers using the highest proportion of MEL energy consumption (about half of the plug-load energy), followed by displays, imaging and network equipment (e.g. network switches and routers), and miscellaneous (e.g. task lighting). In addition, McKenney, et al. (2010) found than MELs account for 26% of office building energy, largely attributed to PCs, monitors, and other office equipment such as servers, fax machines, printers, and multi-function devices. Crowe (2013) further found that desktop and laptop computers alone are respectively responsible for 17% and 7% of total small power energy use. This study included 250 plug loads from different office spaces on 3 floors of an office building in the U.S.

A small number of studies include computer servers and show that servers contribute significantly to small power use (Masoso and Grobler, 2010). Servers have been shown to consume the highest proportion of small power use, accounting for 28% of total building electricity consumption (Menezes, et al., 2011) in comparison with other office equipment related to small power (e.g. small power devices and equipment) which is responsible for 18%.

The number of devices used by office workers has a clear impact on small power use. In terms of the quantity of office devices used, Moorefield, et al. (2011) found that on average some 30 plug load devices are used per 1,000 Square Foot (SF) (92.90m^2), with each office worker typically using an average of seven devices. Similarly, Acker, et al. (2012) identified a range between seven and ten office devices being used per office worker (e.g. computers, monitors and miscellaneous equipment), based on survey and metered data extracted from six different office buildings of 1000SF (92.90m^2). An average of around 9 items of office equipment per occupant in 1000SF (92.90m^2) was found likewise by Webber, et al. (2006) who conducted after-hours audits in 16 office buildings, with computer density to range between 0.53 and 2.18 units per office worker. Hafer (2016) also found that on average approximately 13 plug load devices are used per 1,000 Square Foot (SF) (92.90m^2), based on an inventory of devices and occupancy density data from 220 office buildings. In this analysis, each office worker uses an average of seven devices, three of which are computing and networking devices.

Energy used by computers and monitors accounts for a generally high proportion of small power use in most of the studies reviewed while server installations (when these are included) also have a significant effect on small power energy consumption. A significant consideration for server rooms is that servers often have their own dedicated air conditioning, and the associated energy consumption is sometimes included in assessments of small power energy. Leaving aside the question of whether server installations are included, however, the review suggests strongly that the number of office occupants using a range of powered equipment and devices for the performance of office work tasks has a direct influence on small power energy, i.e. small power energy use is closely related to the nature and intensity of occupancy.

2.6.4.3 User Behaviour and Small Power Use: Assessing wasted electricity and Turn-off Rates of Small Power Devices and Equipment

Finally, office occupant behaviour in relation to devices (i.e. when devices are not in use but may be remain connected to the small power supply, i.e. ‘on’) and small power use during unoccupied hours is a further factor examined in order to improve understanding of small power use in offices. The final group of studies to be reviewed adopts more of a behavioural approach and examines how small power use is affected by the 'energy habits' of office workers in relation to the office devices/equipment during and outside of working hours. As will be seen, considerable variations are revealed in small power energy consumption in offices across these studies. This is partly due to the different approaches used to assess the energy behaviour of office occupants.

For instance, Webber, et al. (2006) applied a series of after-hours audits of office equipment (e.g. computers, monitors, printers, fax machines, copiers, scanners, multifunction devices) in 16 businesses across three regions in the US. They found that occupants' behaviour, such as turning off devices at night or enabling power management, significantly influences energy use, especially as turn-off rates for most equipment types assessed were estimated to be less than 50% (p.20 – specifically 40% of the computers and 30% of the monitors were not switched off after occupants left the buildings examined). Reddy, et al. (2014) applied a different approach - using metering data - to assess device level energy usage and energy consumption profiles over a period of four months. This study revealed that most computers, displays, and imaging devices consumed energy in an ON state and/or Idle/sleep mode as they were typically not turned off (60% of computers were in an ON state during peak hours and 40% in an ON state during off peak hours). Mulville, et al. (2014) applied monitoring and field surveys to assess the small power use of 90 workstations within two UK offices, identifying that up to 23% of the overall small power energy consumption at desk level (i.e. energy used from office devices typically located in workstations) can be attributed to non-working hours. Similarly, Gunay, et al. (2016) conducted an office equipment survey on turn off rates and monitoring of devices (gathering concurrent plug load from computers and monitors, photocopier, printers, and network equipment, as well as motion sensor data) in ten private offices, identifying that about

75% of the electricity consumed from plug-in office equipment (479 kWh per occupant or 32 kWh/m^2/year) was used during unoccupied hours. Crowe (2013) also used device level monitoring and considered workstation devices, but further included conference room equipment, indicating unnecessary energy use by desktop PCs, laptops, monitors, conference room equipment, and printers during unoccupied hours (from 6pm to 6am), which constituted 33% of overall small power use.

Masoso and Grobler (2010) in addition to office equipment considered also lighting and temperature control to examine energy wasted during unoccupied hours. The findings of that study, based on energy audits, show that "more electricity is used during non-working hours (56%) than during working hours (44%)" (p. 176), mainly because office devices and lighting remain turned on for a longer period. According to the same study, which assessed 48 offices in three office buildings, most devices/equipment as well as lighting remain turned on throughout the day even though occupants on average "spend more than 50% of the time away from their workstation" (Masoso and Grobler, 2010, p. 173). The results of this latter study are in line with de Wilde & Tian (2010), revealing likewise that "around one half of the electrical load occurs when the building is unoccupied, due to lights and equipment being left on" (de Wilde and Tian, 2010, p. 1679). The findings of that study however were based on a probabilistic approach used to simulate building performance in a theoretical office building.

While the previous studies used a variety of different approaches to measure the proportion of electricity used for small power purposes during working hours and out of working hours, a small number of cases focused mainly on an examination of office workers instead of office devices/equipment. For instance, Zhang, et al. (2011) by assessing 'energy habits' in an academic building based on an agent-based model, revealed that 60% of occupants do not power down office devices (e.g. computers, printers) and lights at night time, with 31% powering down just occasionally and only 9% powering down regularly.

Turn-off rates of office devices and equipment revealed by these studies also have a significant effect on small power energy use. Recent advances in computing technology aim to address this by automatically placing desktop PCs and other equipment into 'idle/sleep' mode following periods of inactivity. Newer types of computers consume less energy in 'low power' modes (i.e. in idle and sleep mode) than older types of computers (Kawamoto, et al., 2001; Roberson, et al., 2002). This is in line with recent data by the DBEIS (2016) which shows that electricity used by advanced computers (desktop and laptop computers) has dropped by approximately 30% between 2008 and 2015[10], despite an increase of around 30% in the quantity of computers (desktop and laptop computers) owned in UK offices during the same time period[11]. However, measurements of electricity use for computers may exclude considerable small power energy that is consumed by the connection of laptops to desktop monitors when used in an office environment (Menezes, et al., 2014, p. 200).

Further studies are more concerned with reducing electricity consumption from office devices in the workplace and are therefore focused on the effectiveness of interventions (e.g. 'instructional interventions' aiming to change occupants' attitudes, and environmental beliefs and 'supportive interventions' influencing self-efficacy and commitment). These studies identify small power use from different office devices during working and non-working hours (or during workdays and non-workdays) and interventions to reduce electricity usage. These interventions includes suggestions on energy savings, comparative or real-time feedback on occupants' small power use, and graphical display on resulted savings via emails or game

[10] Data from Energy Consumption in the UK (ECUK) 2012, National Statistics, Table 5.09 (DECC, 2013c).
[11] Data from Energy Consumption in the UK (ECUK) 2011, National Statistics, Table 5.10 (DECC, 2013c).

applications, and also via information technology and tools such as social media (Bull et al., 2015; Katzeff, et al., 2013; Murtagh, et al., 2013; Orland, et al., 2014; Yun, 2014; Kalimaris, 2015; Lokhorst, et al., 2015; Nilsson, et al., 2015). In addition, interventions to reduce small power energy consumption in the workplace were applied using combined approaches such as feedback and peer education (Carrico and Riemer, 2011) or feedback, goal setting and information (Mulville, et al., 2016). However, Boomsma, et al. (2016) stresses that feedback may not automatically increase energy saving behaviour, specifically when the relevance of feedback design is not considered. In addition, according to Kalimaris, et al. (2015), these approaches may be affected by a lack of post-intervention observations to evaluate long-term changes in small power use, or changing conditions between pre- and post-intervention. Kalimaris (2015) ascribes the contribution of these interventions to differences in the times of the year, occupancy and working patterns (e.g. holidays and variations in workload) when interventions are made.

Given the inconsistency of the effect of interventions on reducing electricity use and the continuing increase of small power consumption from office device usage, it is important to consider how office devices/equipment are used to carry out work activities and tasks. Office occupants use a range of other office devices apart from desktop computers and laptops to perform several work tasks and other activities at different times. It is therefore important to understand the inter-dependency of work activities and device/equipment use over a working day in order to improve understanding of small power use in office buildings.

This inter-dependency of work activities (considering what occupants are doing during a working day) and use of device/equipment (considering the way that technology is used based on the technological adoption by organisations) is further highlighted by Janda (2014). Janda supports the idea that energy use and conservation opportunities in offices are to be better understood by taking matters that go beyond organisational factors (such as norms, culture, rules and policies) into account, as well as the behaviour of occupants and the adoption and use of technology (2014, p.49).

2.7 Key Findings and Implications of The Literature Review, and Research Objectives

The foregoing review suggests that considerable variations in small power energy consumption are due to a range of factors. These are grouped for discussion into four categories, including: i) definitions and scope of studies, ii) methods and measurement approaches, iii) the physical characteristics of the buildings studied (e.g. size of office buildings and type of office building in terms of HVAC servicing) and iv) use characteristics (e.g. occupancy density, quantity and type of office devices used and occupants' behaviour) of the buildings studied. Given the relatively limited range of studies, the range of these factors, the extent to which they are present across the various studies examined and how they interrelate with each other, it is difficult to isolate the effects of each of them in relation to small power energy use in office buildings, as discussed below.

Definitions used in the reviewed empirical studies to describe small power use vary. A number of definitions were related to unregulated loads but are not consistent in what they include, while other definitions were related to office devices resulting in a degree of overlap between them. The assessment of the definitions, which show inconsistency and challenge the comparability of the studies reviewed, was taken into account so that a synthesized definition could be developed for this research study, which is discussed below.

The review of studies on small power use revealed considerable variations in scope. These were either to single building cases (i.e. examining one office building) or to the examination of multiple buildings. Beyond the number of buildings that were studied, other inherent differences were identified such as the type/nature of buildings (e.g. type of commercial buildings or type of office buildings), the building size and the use of building (e.g. academic or government public building). This variability suggests that it is difficult to compare the findings of these studies and to build up a consistent picture by aggregating them. Also, the small number of office buildings considered for the examination of small power use in these studies does not reflect the diversity of office buildings and their usage. However, they provide insight on other factors which can further be examined to improve understanding of small power use (e.g. physical and use characteristics of office buildings).

Differences in methods and measurement approaches to the assessment of small power use were identified across the studies reviewed. These suggested that while quantitative methods predominate in the assessment of small power use, qualitative methods have been used, albeit to a lesser extent, and have contributed further insight in terms of the behaviour of occupants when they use office devices and how this affects small power energy consumption. It is clear that methods which support the evaluation of the relationship between occupants' work activities and their interdependency with device usage have potential to develop a better understanding of the effect of office work on small power energy consumption. In that sense, a mixture of quantitative methods for recording energy consumption, and more qualitative methods to help understand what office workers are doing when this energy is being consumed, may provide further opportunities for improving understanding. This point is returned to below.

Key office building parameters likely to affect small power use were examined across the studies reviewed. These parameters were mainly focused on building (e.g. building size and the extent of HVAC servicing) and use characteristics (e.g. type and quantity of office devices/equipment, occupancy density and occupants' behaviour) of office buildings. With respect to the former characteristics, the size of offices did not appear to be significantly linked to small power use, as offices of different sizes were not found to consume significantly different proportions of energy for small power purposes and, when differences were identified, these did not appear strongly linked to size differences. Similarly, no apparent link is evident between small power use in offices and different levels of HVAC servicing 'intensity' (i.e. specifically between air-conditioned and naturally ventilated offices). Given that the physical characteristics cannot be supported as being significant factors to determine consistent measurements on small power use, this review suggests that variations might have occurred due to other factors, which indicate a closer relationship between the nature and intensity of occupancy and small power energy consumption in offices.

Considering the use characteristics identified, occupancy density (i.e. m^2/person) suggests that the diversity of office utilisation (i.e. actual occupation) and the energy intensity of the work of different occupants directly affect the levels of electricity use for small power purposes. Further, while certain type of office devices that are extensively used (e.g. desktop computers and monitors) are found to affect small power significantly, followed by other office electronics (such as multifunction devices), the contribution of other office equipment such as servers may also be significant, especially when additional energy for dedicated air conditioning within server rooms is included. In addition, the average number of devices used per office worker (estimated to range between seven and ten devices in the studies examined) and their 'energy habits' with respect to device usage both during and outside of working hours, are also important. These suggest that the 'nature' of occupation, in terms of the office work undertaken and its reliance on electrical devices and equipment, as well as the density and intensity of occupation, are key factors in understanding small power energy consumption.

More specifically, office occupants use a range of devices to perform different work tasks and activities at different times in different office spaces within office buildings. Developing a detailed understanding of what gives rise to small power energy consumption in offices is therefore heavily reliant on understanding the inter-dependency between office spaces, work and other activities that are performed within different spaces, and the device/equipment used over a working day.

Considering the implications of the preceding review, it is difficult to draw any consistent learning from the various studies examining small power use due to the presence of a wide range of highly variable study parameters. However, an important missing element revealed from the studies reviewed is the explicit consideration of the nature of office work and related activities which involve the use of office devices/equipment and thereby give rise to small power energy consumption.

Given the central focus on office work activities as a key element in developing an improved understanding of small power energy use, a clear working definition of small power for the purposes of this study would help maintain a focus on the interrelationships between work activities, office workers and the work environments in which activities are performed. Thus, a new working definition of small power can be synthesised from the different studies reviewed as:

> the electricity that is used from office equipment and electric plug-in devices distributed across different spaces within office buildings to support office workers' activities and tasks which are performed over a working day.

The inter-dependency between spaces, occupants' activities and devices usage in offices, noted above, is illustrated in Figure 2-3 and reflects the main lines of enquiry for this study.

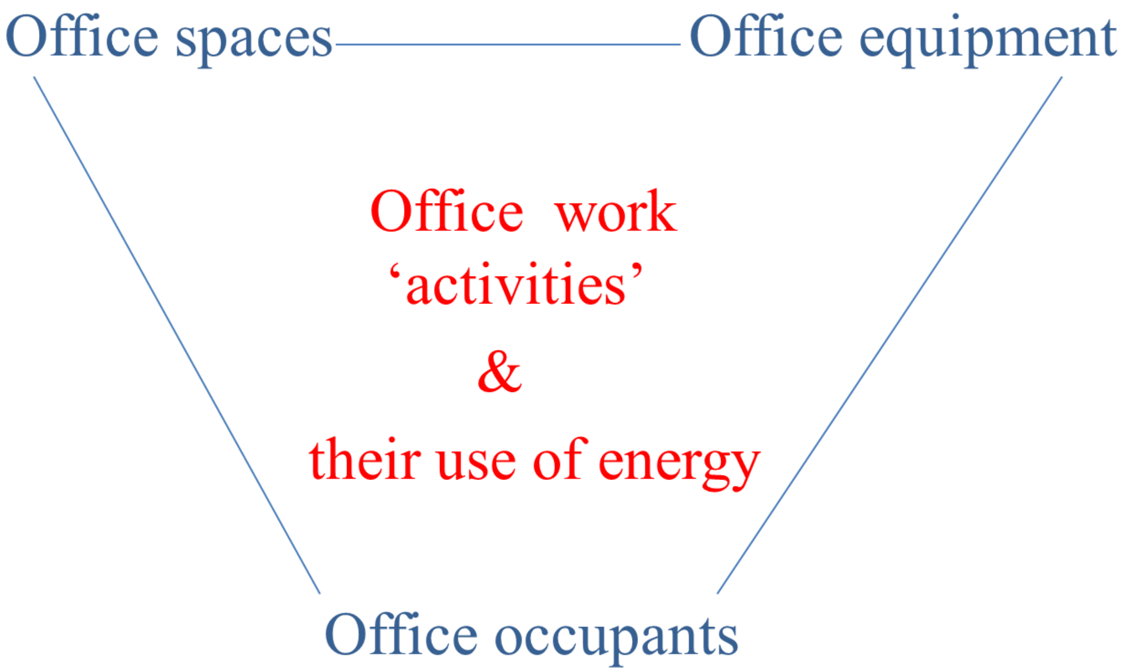

Figure 2-3. Key elements of this study

Figure 2-3 illustrates the central role of office work activities for understanding small power energy consumption. More specifically, these activities are performed within different functional spaces (e.g. private offices, open plan workstations, meeting rooms, common/kitchen spaces, photocopy rooms, etc) of an office environment, and require energy consuming devices for their performance by office workers/occupants). Such performance connects spaces, workers/occupants and devices/equipment so that the key features of small power use over a working day may be better understood. As the review of small power use revealed that variations on small power use might primarily be related to different kinds of office work, this study examines the link between occupants' patterns of work/tasks (i.e. work activities, the spaces in which they are undertaken, and the associated equipment required) and small power use over a working day of office occupants.

In summary, this study aims to address the following objectives:

1. To understand what office work and other activities are performed in different office spaces that use energy-consuming devices and equipment.
2. To understand what types and quantities of office devices and equipment are used to support the performance of these office work activities.
3. To measure what small power energy is consumed by these equipment/device-using activities in different office spaces.
4. To explore how small power energy use practices shape the usage of devices and the way that work and other activities are performed in an office environment?

The examination of the interrelationships between office workers and their work activities, functional office spaces and device usage is necessary to develop an improved understanding of small power use in offices. The concept of 'office work' (work activities) is key to understanding what people are doing in an office and how this affects small power use, and this is elaborated further in Chapter 3 in terms of a theoretical frame drawing on work in the 'practice' area of social science.

Chapter 3: Theoretical Basis

3.1 Summary of theoretical approaches

Previous studies have used different theoretical and empirical approaches to identify factors influencing small power use in the workplace. Small power use has mainly been approached from an empirical perspective (e.g. using modelling and data driven methods) and a behavioural perspective (applying behavioural theories, e.g. Theory of Planned Behaviour). A social practice perspective has been used to a lesser extent (by exploring routine practices to understand patterns of consumption) but mainly for other end-uses than small power use (e.g. heating consumption).

Empirical and data driven approaches (monitoring and quantifying actual small power use) tend to predominate in studies of small power use (Crowe, 2013; Lanzisera, et al., 2013; Mulville, et al., 2014; Reddy, et al., 2014). In some cases, studies adopt modelling approaches (using empirical data on small power use) to estimate the proportion of small power in relation to the total building electricity usage and/or predict future small power requirements (see Section 2.6.2).

Other studies on small power use in offices have mobilised behavioural theories to understand the effect of individual behaviour on device and equipment usage in office buildings. The Theory of Planned Behaviour developed by Ajzen (1991) and exploration of elements of pro-environmental behaviour – attitude, subjective norms and perceived behavioural control (PBC) – was featured in studies on small power energy use in offices (e.g. Menezes et al., 2012b; Staddon, et al. 2016; Tetlow et al., 2015). A common aim of these studies was to quantify the elements of pro-environmental behaviour for an individual and assess possible changes in behaviour by adjusting these elements (through behavioural interventions). Specifically, these studies have identified how daily actions of office occupants (e.g. switching lighting and appliances off when not in-use, Menezes et al., 2012b) influence the use of small power energy in the workplace. While findings of these studies show how attitudes, norms, and PBC (e.g. turn-off of small power equipment after leaving an office space) influence small power energy use, their focus is mainly on the pro-environmental behavioural elements of individuals. In contrast, this study examines the influence of office work on small power energy use though the exploration of the inter-relationship of daily work activities and associated equipment used in different offices. The need to understand the interrelationships between different aspects of daily work activities, including equipment use and the spatial and temporal distribution of work involves the understanding of work practices and this leads to the adoption of a different theoretical approach – Social Practice Theory – in order to address the main focus of this study as referenced in the next sections (see Section 3.2 and 3.3).

A recent growing trend on the examination of domestic and non-domestic building energy use is focused on social practices (e.g. Gram-Hanssen, 2010; Palm and Darby, 2014; Shove and Pantzar, 2005). In contrast to the behavioural approaches that focus on individual values and attitudes, from a social practice perspective, ‘behaviour’ is the observable performance of social practices (Spurling et al., 2013). Therefore, practices become the central focus of examination rather than individuals and their attitudes or preferences, norms, and values (Welch, 2017). The approach of small power energy use from a social practice perspective is elaborated in the following sections.

3.2 Framing

The central focus of this research is on the energy implications of office work activities which are performed in different office spaces over a working day. In particular, this study seeks to improve understanding of small power energy use in offices by examining the office work activities that gives rise to it, essentially developing a picture of what energy is used for. To provide a conceptual scheme to help do this, the study is framed using Social Practice Theory (SPT) (Gram-Hanssen, 2010; Shove, et al., 2012). This will help to examine the practices of office work by exploring the interrelationships between technological equipment (materials and artefacts), activities (involving habits and routine activities, bodily and mental actions), and the institutional context (including the physical environment and local norms about its operation and use). With respect to the purpose of this study, the choice of SPT is strongly associated with the idea that the use of electricity is contingent on the social environment in which it occurs and the different work and other practices for which it is used. This has been articulated by Shove and Walker (2014), who suggest that "energy is used not for its own sake but as part of, and in the course of, accomplishing social practices, examples of which might include cooking, commuting to work, watching TV or conducting meetings" (Shove and Walker, 2014, p.47).

3.3 Social Practice Theory

SPT suggests that practices are not shaped by independent actions of individuals but consist of 'interconnected sets of social norms, infrastructure, embodied habits and understandings' (Dantsiou and Sunnika-Blank, 2015, p.2228). This is in contrast to the focus of environmental psychology, which is associated with individual behaviours and tends to emphasise either the context in which individual behaviours are enacted or the cognitive processes that lead to particular behaviours (Kurz, et al., 2015).

SPT explains how practices are developed, maintained and reconfigured by exploring the interrelationships between several interconnected elements. There are many interpretations of these elements and understandings of their interconnections. According to Reckwitz (2002a, p.249) these elements are "forms of bodily activities, forms of mental activities, 'things' and their uses, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge". Practices thus can be considered as a "coordinated relationship of doings and sayings that are held together by different linkages" (Marechal and Holzemer, 2015, p.229). Those linkages can be thought of as enabling the "active integration undertaken by practitioners when practices are performed" (Røpke, 2009, p.2492). Schatzki (2010) considers practices as 'timespace' where actions are constituted by bringing together the dimensions of time and space.

While SPT has been used in the examination of energy use in domestic settings (Gram-Hanssen, 2010; Shove, et al., 2012), it has rarely been applied to energy use in non-domestic environments. Exceptions to this are studies by Palm and Darby (2014) who used SPT to compare energy use in domestic and office settings, and Hargreaves (2011) who focused on pro-environmental behaviour change in non-domestic environments through a case study using an ethnographic interpretation of SPT. The authors of these studies argue that analysis of practices offers a promising tool for understanding patterns of consumption. From a sociotechnical perspective, Palm and Darby (2014) emphasized that the ways in which a building is used can greatly affect its energy performance. Technical building management processes (e.g. management of energy systems, devices, and equipment) are only part of building performance and need to be complemented by a consideration of other practice elements relating to what people are doing in buildings, such as meanings, explicit knowledge and rules, routines, and the objects and materials involved (i.e. technologies) to understand how building are operated (Palm and Darby, 2014). Both studies consider that individuals themselves are not central in the analysis but may be viewed as ‘carriers’ of social practices, carrying out the various activities and tasks that the practice requires. Both studies show the importance of studying practice itself in the performance of collective routine activities performed in non-domestic environments, rather than focusing on the individuals who perform these practices or the social structures that surround them. By exploring the main elements of SPT - knowledge and skills; meanings and images; routines and habits; technologies and materials - and the linkage between them, these studies have been able to unpack what have been seen previously as environmental behaviours and aspects of consumption (Hargreaves, 2011; Palm and Darby, 2014).

Gram-Hanssen (2010) and Shove and Pantzar (2005) have mobilized SPT to make important contributions in the study of energy use practices in domestic environments. In these studies, they identified and used similar elements that hold practices together. These elements are technologies (also referred to as ‘stuff’ and materials), knowledge (also referred to as skills), routines, and meanings (also referred to as images). Using SPT, researchers have been able to understand different levels of energy consumption as the result of collectively shared practice taking into account the different socio-material configurations of different households. Although similar, the Gram-Hanssen model of SPT differs from that of Shove and Pantzar (2005) by maintaining a distinction between knowledge and habits/routines. Table 3-1 lists the different key elements developed by various authors to understand practices (Gram-Hanssen, 2010b), showing also the different elements considered between Shove and Pantzar (2005) and Gram-Hanssen (2010).

Table 3-1. Key elements in the understanding of social practices

Schatzki (2002)	Reckwitz (2002b)	Warde (2005)	Shove and Pantzar (2005)	Gram-Hanssen (2010)
Practical understanding	Body Mind The agent Structure / Process	Understandings	Competences (skill)	Habits / Routines
Rules	Knowledge; Discourse / Language	Procedures		Knowledge
Teloaffective structures		Engagement	Meanings / Conventions (image)	Meanings
	Things	Items of consumption	Products / Material artefacts (stuff)	Technologies/ Infrastructure

Adapted from Gram-Hanssen (2010)

For the purposes of this study, ideas about knowledge and routines are potentially important in developing an understanding of the effect of office activities and tasks on device usage and in turn on small power energy use. For example, knowledge about the energy consumption of office devices may influence the way that certain activities that use these devices are performed (e.g. work on drafting reports may be altered to reduce the number of versions that are printed for review, to save on electricity and other consumables). Gram-Hanssens's four elements of practice theory which hold practices together – knowledge; meanings; routines; and technologies – provide a potentially useful means of examining the relationship between office work and small power energy consumption. This may be done by recognising the meanings that workers attach to their work, the institutional and physical contexts within which work is carried out, and the technologies used to support it. These elements will now be explored further.

3.4 Elements of Social Practice Theory

3.4.1 Knowledge

Different sociologists have used differing approaches to understand the concept of knowledge in practices. Schatzki's view is that knowledge involves explicit rules of how to do things, what is allowed and what is not (Schatzki, 1996). Schatzki's 'rules' have been translated by Warde (2005) into 'procedures', which according to Gram-Hanssen (2010) may be confusing and difficult to separate from practical understandings. Reckwitz (2002a) refers to knowledge involving further language/discourse. This difference in the definitions of the concept of knowledge illustrates the dynamic nature of SPT and the multiplicity of interpretations of its elements. Shove and Pantzar (2005) refer to knowledge as 'competences', without differentiating the different forms of knowledge as used by Gram-Hanssen (verbal/theoretical knowledge, tacit knowledge or cultural myths). Gram-Hanssen rejects this conflation and holds that not differentiating between different types of knowledge, and their associated routines/bodily and mental activities which hold practices together, may lead to an incomplete picture of the issues surrounding energy consumption (Gram-Hanssen, 2010).

For the purpose of the present study, it is relevant to distinguish between different forms of knowledge of device electricity consumption – detailed technical understanding, more generic understanding, and organizational rules. Technical understanding involves more in micro-level, in-depth and nuanced understanding of device electricity consumption, including differences between the characteristics of individual devices, for example how a small printer affects electricity use compared to a multifunction device. Generic understanding involves more generalised, macro-level understanding of the impact of device usage on electricity consumption. For example, workers' understanding of different aspects of the energy consumption such as differences of energy consumption when devices are ‘on’ versus ‘idle’ mode. Organizational rules are imposed by the organisation on the worker in relation to how office equipment is managed. This can be exemplified in the case of the management of office devices/equipment by building managers. Building managers play a key role in operating buildings and their energy consuming systems, and they may require particular building systems and equipment to be provided that satisfy occupants’ needs rather than to improve energy efficiency (Bordass, et al., 2001). For example, they might provide device/equipment (such as a water boiler which continuously consumes electricity to maintain water at a consistently high temperature) for the convenience of office users rather than providing alternative, less energy intensive device/equipment (e.g. a single kettle which has a switch and consumes electricity only when it is used). Even when they are aware of the implications of this choice of equipment on small power energy use, they may still give priority to office worker convenience and satisfaction rather than energy use optimization. The reasons behind this seemingly irrational choice of equipment would only become apparent once considerations of the background and technical knowledge related to the operation and electricity usage of these devices were taken into account, as well as an understanding of user priorities and preferences (including those of both the organisation and individual office users). Having explored knowledge as an element of social practices, the second element of SPT, that of meanings (Gram-Hanssen, 2010) will now be explored to understand the interlinking of meanings with other elements which hold practices together.

3.4.2 Meanings

The terms meanings or engagements were largely introduced and used by Warde (2005) and Shove and Pantzar (2005). The concept of meanings in this context is derived from the idea that practitioners are continually engaged in some form of communication (formally or informally), and that this engagement gives rise to 'meaning' which accumulates through their actions (Gram-Hanssen, 2008). Meaning is considered an important element of holding practices together (Gram-Hanssen, 2008).

In the case of energy practices in office environments, meanings can be interlinked and be associated with workers' engagement, their performed activities (i.e. the meaning behind the things workers do), and the energy used to enable the building to function and for office activities to be performed. Specifically, meanings of formality and informality in office environments can be understood from the way that certain activities such as meetings are performed as part of work practices. Also, interaction between colleagues can take place in an informal or formal way and this may depend on the perceived hierarchy or importance of the meeting. Choices about the way that the interaction will take place may further involve the use of a specific place for the meeting (e.g. meeting room) and the use of technology/materials which may not normally be used.

The third element of SPT to be explored is 'habits / routines' which is closely related to the concept of routinization.

3.4.3 Habits, Routinization and the Importance of Temporality in the Development of Practices

Reckwitz (2002a, p.249) defines practices as “a routinized type of behavior”. Practices can be considered as a combination of elements that are reproduced at particular moments in time (temporal) and in particular environments or spaces (spatial; Strengers, 2010). Practices shape time by developing routines, or ‘practices make time’ by connecting activities and performance (Shove, 2009). For a practice to be recognised across space and time, it needs a certain level of reproduction, i.e. the repeated enactment by performing agents (Marechal and Holzemer, 2015). This social reproduction or routinization of practices implies a certain degree of social stability since most individuals understand, know and accept, to some extent, the way practices must be performed in order to be socially appropriate and acceptable.

Linking the interpretation of practices to this study, office work activities can be related to routines (Tukker, 2008) of workers associated with the use of energy from small power. The routinization (i.e. the repeated enactment) emerges from the repeated performance of activities by office workers in different office spaces across time (i.e. over a working day) as a means to explore work practices.

The temporality dimension has been expanded by Shove, et al. (2007) and Warde (2005), who summarized routine practices as: i) practice-as-entity; and ii) practice-as-performance. The practice-as-entity conceptualizes practices as the structured organisation of elements and linkages (Schatzki 2001, p.101, cited in Kuijer, 2014). Practice-as-performance refers to activities of people who integrate elements in specific situations (i.e. the ‘doing’ of practices through which practices-as-entities are changed or maintained) and therefore they are different every time (e.g. the way that practitioners ‘do’ things such as cooking, eating, driving etc.). In contrast to practices-as-performance, practices-as-entities are relatively consistent over space and time because they refer to a nexus of doings and sayings (which consist of the elements that hold practices together: socially shared ideas and meanings, knowledge and skills, routines, materials/technology and infrastructures). The practice-as-entity and practice-as-performance are in fact closely intertwined, as the practice-as-entity depends on repeated performances (Shove, et al., 2012, p.8). At any given time, a practice-as-entity is composed of a previous sequence of performances (Shove and Pantzar, 2005) that facilitates a continuity of performances over space and time. Practices are thus “coordinated entities but also require performance for their existence. A performance presupposes a practice, and practice presupposes performances” (Warde, 2004, p.4). According to Shove, et al. (2012), it is within the relation between entity and performance that the dynamics of change need to be sought, since practitioners do not always reproduce practices faithfully. The development of this relationship between entity and performance in practices undertaken in domestic environments has been shown to contribute to understanding different patterns of user/energy behaviour (i.e. how patterns of individual practices emerge, are performed and persist or disappear). This has been illustrated by Shove’s study on the ‘Dynamics of Social Practice: Everyday life and how it changes’, exploring the practices of driving and the maintenance of personal cleanliness (considering aspects such as laundry, bathing and so on). This study (Shove, 2012) shows that changes may occur by reducing the resource intensity of existing practices through changing the elements that make up those practices. This relationship between entity and performance in practices is helpful for the examination of non-domestic energy use in order to explore patterns or variability of small power use through contemporary work practices that lead to small power energy consumption. The final element to be explored is related to materials/technologies as an important linking component of practices.

3.4.4 Technology, Artefacts and Materiality

Practice theory has been used to understand and explain the complexity of unsustainable consumption. It has been used in studies of ecological economics and environmental aspects of domestic energy consumption (Røpke, 2009), mobility practices (Shove, 2002), cycling practices (Spurling, et al., 2013), domestic heating practices (Gram-Hanssen, et al., 2008), thermal comfort and domestic cleanliness practices (e.g. shower/bathing, laundry; Shove, 2003). These studies acknowledge that materiality (i.e. artefacts or things in Reckwitz's (2002b) view[12]) plays a central role in practices. For example, Gram-Hanssen, et al. (2008) focus on how routines of domestic heating consumption exist in close association with the physical structures and technologies that are part of the practices.

Following Reckwitz's view that artefacts or things are equal contributors to practices as humans (2002a, p.212), artefacts thus are treated as 'active, constitutive elements in the reproduction of daily life and social order' (Watson, 2008, cited in Kuijer 2014, p.31) and are considered as equally important as people. Artefacts (such as computers in office environments) can be thought of as enablers of practice, which 'materialize' or 'incorporate' knowledge specific to those particular practices. Thus, materiality is a key concept of SPT. Schatzki (2010) framed materiality as material arrangements that are linked to, but conceptually distinct from, practices. Practices and material arrangements each provide a context for the other and are accordingly bundled together, persisting over time in interlinked patterns. This concept of materiality is potentially useful for the present study in helping to examine the involvement of office equipment as material 'artefacts' in energy-consuming office practices.

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[12] Reckwitz argues that the material world 'should be understood as "artefacts" or "things" that necessarily participate in social practices just as humans do', i.e. humans and non-humans are treated in a similar way as contributors to practices (Reckwitz, 2002b, p.202).

Materials and technologies are highly significant for how practices develop and change over time (Wilhite, 2008; Morley, 2016; Strengers and Maller, 2019). From the beginning of the twentieth century, mass production and consumption has contributed to a materialization of everyday life (Wilhite, 2008). Today, domestic practices are intertwined with numerous technologies such as heating, lighting, refrigerators, televisions, and cars while household practices are dependent on these technologies to exist.

From a practice perspective, interaction between people and technologies/materials is perceived to develop in the 'emergent doing of practice', while varying from one situation to another (Watson, 2008, p.7). For instance, cooking is a process which involves the use of materials or things (i.e. food), devices (i.e. refrigerator, oven etc.) and infrastructure (i.e. electricity/energy supply). Materials or things (in the form of products, for instance) can influence and be influenced by the environments and contexts they are used in (Ingram, et al. 2007). A computer or tablet thus can be used for undertaking work in an office environment, while in a domestic environment it might be used for social interaction and entertainment (Lord, et al., 2016).

Considering the elements which comprise practices, an interaction between technology (i.e. office devices) and practices is encompassed in this study as available devices/equipment in the office may influence the adoption of certain activities (i.e. enable the performance of practices) or obstruct certain activities being performed. Thus, practices that are embedded in and constitute office work activities are explored in this study. A possible starting point for developing an understanding of what 'small power' energy in offices is used for – i.e. what activities and practices require energy for their accomplishment, and in what way – would be to identify recognized and routine office activities and examine their impact on energy use. This is explored further below and in the next chapters, where routine office activities are considered in more detail.

3.4.5 Energy Use as Practice in Gram-hanssen's Scheme

Gram-Hanssen (2010) has developed a conceptual framework which takes into account the issues raised in the preceding sections and uses this framework to examine practices that require energy use. This framework (Figure 3-1) considers four elements: knowledge, meanings, routines, and technologies.

Gram-Hanssen's framework has been applied in domestic (Gram-Hanssen, 2010) and non-domestic environments (Palm and Darby, 2014) to understand energy use practices. In this framework (Gram-Hanssen, 2010), technologies are related to artefacts/materials which contribute to practices. For instance, the diffusion of Information and Communication Technology (ICT) equipment contributes to new practices related to the way that people communicate and work.

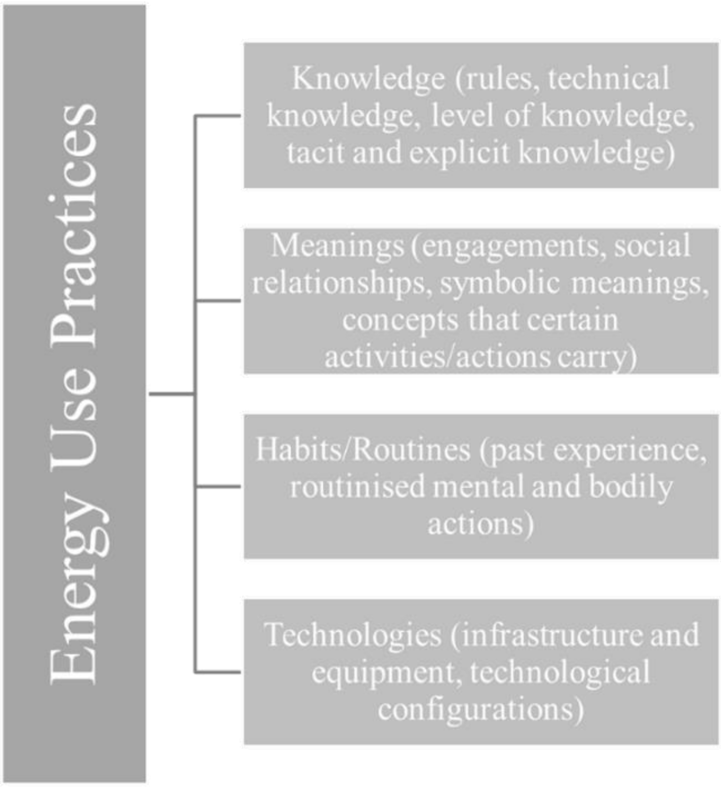

Figure 3-1. Elements of energy use practices (Adapted from Gram-Hanssen, 2010)

Routines are embodied habits and know-how, i.e. knowing what to do and how to react in a situation. Routines include activities carried out by practitioners when both body and mind respond and contribute to sustaining and developing a practice. Within an office environment, this can be exemplified by considering how people respond every time that they feel cold. Such responses can involve a reaction to warm the human body by either wearing more clothes or turning ‘on’ a portable heater fan in order to maintain comfort. Knowledge includes rules, ways of understanding, know-how to do things and technical background knowledge. For instance, to explore the element of knowledge in the practice of switching off a computer monitor to save energy involves an understanding of the individual’s knowledge of the energy consumption of electrical devices, their knowledge of how to set default settings, and their understanding of why energy saving might be important. Meanings are socially shared ideas or concepts associated with the practice that gives it meaning, and/or gives reasons to engage in it. Meanings accumulate through engaged practitioners and are an important element of holding a practice together. For example, building design practices may stress meanings of modernity and efficiency through modern design and facilities (e.g. technological advances), thus appealing to purchasers or renters more than older buildings, without necessarily being more functionable and/or efficient in performance.

3.5 Operationalizing the Gram-hanssen Scheme of Social Practice Theory

The operationalization of this framework for the present study involves the exploration of the four elements in terms of energy use practices in non-domestic environments as outlined in Figure 3-2. The first element knowledge includes office workers’ technical knowledge and understanding of energy used by office devices. The first element is explored through the question: 'Do you know the effect of what you do?' The second element, meanings, reflects workers' engagement and the meaning behind what workers are doing (i.e. the performance of their activities/actions). The exploration of the second element is through the question: 'What makes you do these things/activities in that way?'. The third element is related to the habits and routines of office workers, in terms of what they do (i.e. routinised activities) and where (i.e. office spaces). This element is explored through the question: 'What activities do you perform?'. The last element includes the involvement of technologies as part of the activities' performance. This includes office devices/equipment used in the workstation such as computers and printers, devices used in the kitchen (e.g. mini fridge, microwave, coffee machine, kettle) and TV screens used in the communal areas and meeting rooms. The last element is explored through the question: 'What type of office devices do you use and why'?

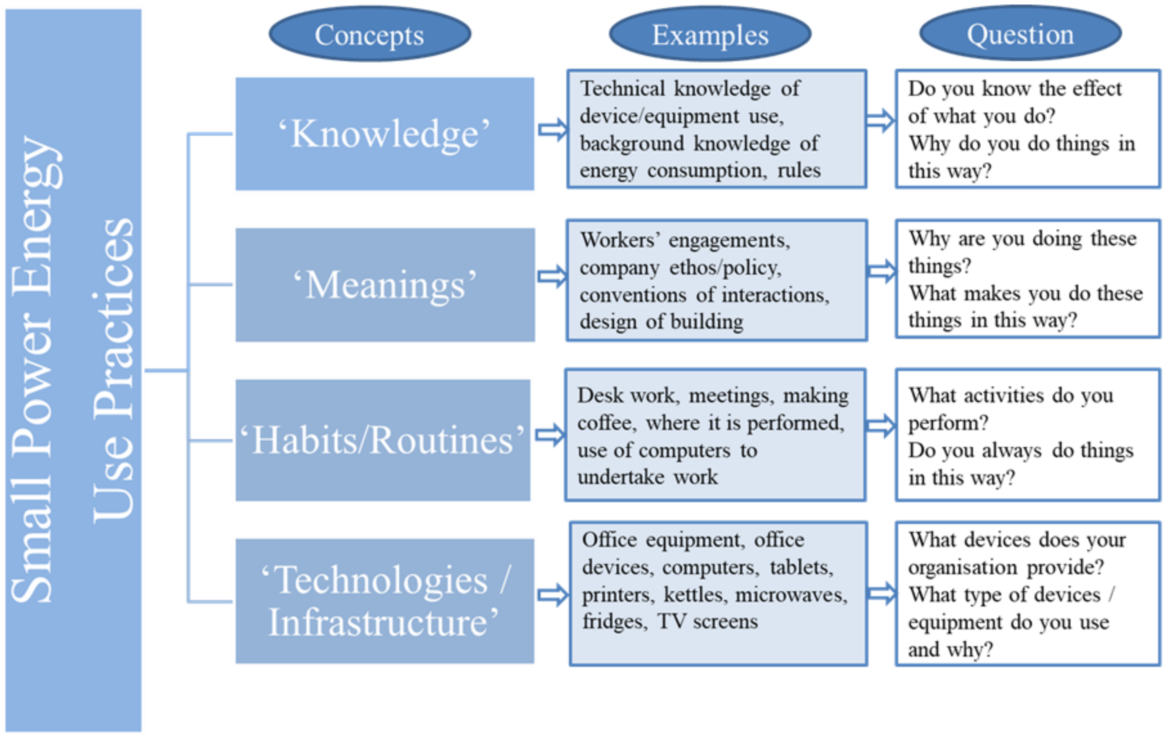

Figure 3-2. Elements of practices related to small power energy use (Adapted from Gram-Hanssen, 2010)

The preceding discussion above shows how the key concepts of SPT can be adopted to study small power energy use practices. In particular, this research explores concepts of knowledge, meanings, routines, and technologies in office work practices as a means of understanding small power energy use. The following chapter extends the development of this framework and maps out the methodological approaches used to examine the linkage between office work practices and small power energy use.

Chapter 4: Research Methods

4.1 Overall Research Design

This study explores small power energy use in terms of office work practices and, in particular, the relationship between the work activities involved, office space, and device or equipment use. Previous chapters outlined how small power use can be examined using both quantitative and qualitative approaches and in particular how Social Practice Theory (SPT) can contribute to this enquiry by exploring office work practice and the implications for small power energy consumption. This chapter discusses the research strategy for achieving the study aims and objectives, and the methods adopted to explore the four elements of small power energy use practices (knowledge; meanings; habits/routines and technology/infrastructure). It begins with an outline of the overall research design and discusses the rationale for using a case study approach. It then details the quantitative methods (to understand small power energy use from office devices and equipment) and qualitative methods (to explore routine activities and device usage as well as meanings and knowledge in terms of small power energy usage) used to conduct the research, examining the context of work practice associated with small power energy use in offices. The limitations of the approach are outlined, as are the ethical considerations for the research.

4.1.1 Overview

The research design of this study was developed by taking into consideration how office work practices can be explored in the real-world setting of contemporary office buildings and the organisations they accommodate. A comparative case study approach was adopted to support the development of an understanding of what people are doing in offices and the implications of their work practices and associated device usage on small power energy consumption. The justification for the case study approach is provided in the following sections, together with an explanation of the key elements of the research design and the methods adopted. To put that discussion in context, it is helpful to outline here the following two main parameters around which the case study approach was built:

- Office environments are expected to demonstrate a wide range of small power uses. While the contribution of small power to overall electricity consumption in offices is highly variable (see Section 4.2), offices with higher electricity usage (electricity intensity) are expected to involve a greater range of work activities and equipment use.
- Different types of office workers, by virtue of their 'mobility' (i.e. the extent to which they undertake work in different spaces) and associated equipment use, were believed to place different demands on office small power. This is explained further below but for present purposes these workers are simply categorised further as 'static' and 'mobile'.

Figure 4-1 illustrates the overall research design. It shows that multiple cases of relatively high electricity intensity office sites, are used to explore the energy use practices of different types of workers ('static' and 'mobile').

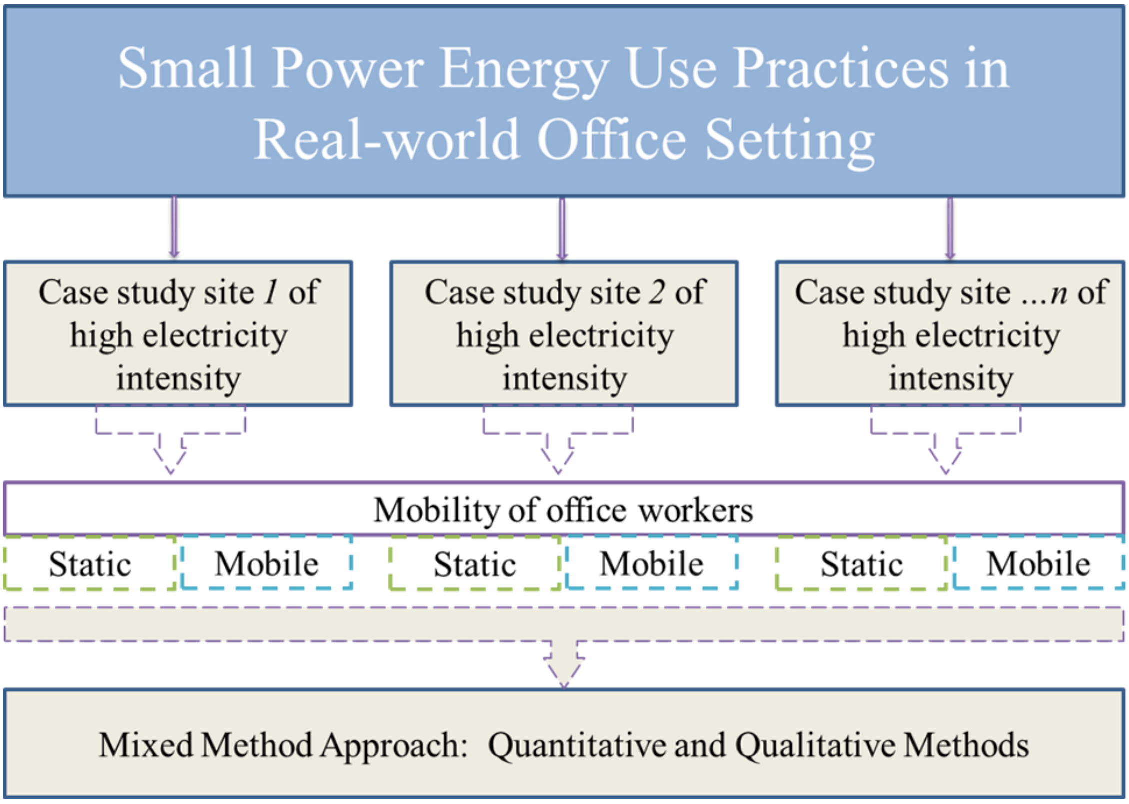

Figure 4-1. Overall research design

The research design involves using a deductive approach (by exploring an existing theory and tests its validity in given circumstances by designing a research strategy to examine the research questions arising from that theory, according to Wilson, 2010), using mixed methods approach to explore the relationship of work practices and small power energy use in different office settings with relatively high electricity intensity. Work practices are explored through elements of Social Practice Theory as routines and habits (work activities), knowledge and meanings (affecting individual electricity usage) and technology (device usage) in combination with empirical work capturing quantitative data on small power energy usage relating to work practices.

4.1.2 Rationale for a Comparative Case Study Approach

The definition of what constitutes a case study varies considerably (see Starman, 2013; Gerring, 2004; Kaarbo, 1999). A widely used definition is that a case study is “an empirical inquiry that investigates a contemporary phenomenon (the case) in-depth and within its real-world context” (Yin, 2014, p.16). In this study, the phenomenon under enquiry is the small power use associated with the undertaking of everyday office practices and the real-world context is the contemporary office setting. In addition, case studies allow “analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods” (Thomas, 2011, p. 513). This flexibility allows for multiple forms of activities to be captured using a range of appropriate methods. Case studies are particularly well suited to exploratory research when “a ‘how’ or ‘why’ question is being asked about a contemporary set of events over which the researcher has no control” (Gray, 2004, p.124) as is the case when exploring how small power energy use is affected in offices. The use of a case study approach has also been shown to be beneficial when a phenomenon needs to be examined in context (Robson, 2011), but caution needs to be exercised when combining elements across case studies to ensure the validity of any generalisations that are drawn (Gray, 2004). In addition, this approach allows for complex multivariate conditions to be investigated (Yin, 2008), as in the case of studying the relationship between small power use and office work in office settings. For these reasons a case study approach was considered appropriate for this research.

Different categories of case studies (e.g. exploratory; descriptive; explanatory; Yin (1984)) and cases study research designs (e.g. single case study-diachronic; single case study-synchronic; single case study-synchronic and diachronic; comparative historical; comparative method (Gerring, 2007, p.28)) can be used to conduct a study. For this research, a comparative case study approach has been considered. A comparative case study is used to compare two or more cases, which share the same unit of analysis, and allow for more generalised reflections on the nature of the phenomenon under investigation (Gerring, 2004). In addition, comparative case studies emphasize comparison of the phenomenon of interest in a study within and across contexts as well as across sites and scales (Bartlett and Vavrus, 2017). This study explores the mobility of office workers associated with small power energy consumption within and across office sites. Case studies, including comparative case studies, rely on analytical rather than statistical generalization which relate "a particular set of results to some broader theory" (Yin, 1994, p. 36). This comparative case study mobilises the criteria of SPT to explore how office work practices affect small power energy use in office settings. This observation demonstrates the need for clear criteria to be used in the case study development and comparison and this is further discussed in Section 4.2 below.

Different types of cases[13] can be used to support a study based on the nature of the research objectives. The case, as the subject of the inquiry, can be explored and explained through an analytical frame which is developed for a particular instance of a class of phenomena (Thomas, 2011). The research design for this study uses real-world office settings as cases which have a common single unit of analysis (worker mobility associated with small power electricity usage). These cases have different, relatively high, electricity intensities (see further below and in Section 4.2.1) which would suggest the undertaking of a range of small power uses. Thus, the case study approach allows an examination in detail of the phenomena of interest (energy use) in terms of the context and features of two or more instances (the case office settings) (Bryman,

[13] The different types of cases are mainly the critical case (considering a well-developed theory in which a hypothesis can be tested), the extreme or unique case (which is commonly focused on clinical studies), the revelatory case (which explores a phenomenon previously inaccessible to scientific investigation), the longitudinal case (which can be studied for over a lengthy period) and the typical case (which is used to capture the circumstances and conditions of an everyday or commonplace situation) (Bryman, 2008).

2008, p.62), by capturing and comparing the circumstances and conditions of everyday or commonplace occurrences (the routine office activities and device usage of office workers) across time (i.e. over a working day).

The electricity use of work practices is expected to vary according to the nature of work and the ongoing presence or absence of office workers in particular spaces (Delzendeha, Wu, Lee and Zhou, 2017; Holmin, Levison and Oehme, 2015). An important consideration therefore was the selection of cases where office sites accommodated office workers who carried out their work across a range of different office spaces/settings during a working day (referred to as ‘mobile’) as well as those whose work was undertaken predominantly in a single office space/setting (‘static’). Furthermore, as noted above, electricity consumption varies considerably across different types of offices. It was considered that offices with potentially relatively high electricity consumption were more likely to accommodate a wide range of small power energy using practices than those with lower electricity consumption. Additionally, and as will be explained further below, electricity use in relatively high electricity intensive offices tends to vary, and combining these characteristics led to a comparative case design of three cases of office sites of varying (though relatively high) electricity intensity, (see Figure 5-1), each accommodating a range of worker mobility. This allowed the primary consideration of the impact of worker mobility on small power energy use to be examined in a small range of contemporary office settings, and the exploration of a wide range of energy use practices.

4.2 Identification of Cases

To allow comparison of small power use between different type of office workers, it was important to consider cases of office sites with high electricity intensity. This would allow an exploration of the potential variation of activities performed and range of devices used. Both parameters were considered due to expected variations on small power energy use arising from work activities within different office spaces and the devices used by different types of office workers based on their mobility. These factors are discussed in the following sections.

4.2.1 High electricity intensity of Offices (Building Size as a Proxy for Electricity Intensity)

The inclusion of high electricity intensity cases of office sites is important because this allows the examination of potential variation of small power energy consumption from different types of offices based on the types of workers, as well as the performance of office work activities and the device usage.

The electricity intensity of office buildings has been classified by DECC (2014a) in terms of floor area. That study used data for 56,530 office buildings of different floor areas (ranging from 0-49 m^2 to 5000+ m^2 (see Table 4-1[14])) provided by energy suppliers across England and Wales in 2011. The study by DECC (2014a) identified the electricity intensity of office buildings and categorised them based on their size (floor area). This analysis by DECC (2014a) shows that size of offices is associated with electricity intensity and demonstrates that the

[14]To construct Table 5-1, DECC (2014a) excluded upper and lower values of energy consumption because they can be considered to skew the sample. In addition, DECC (2014a) excluded values for electricity consumption with more than 100 kWh per year, in order to be consistent with the methodology used for the DECC sub-national consumption statistics (DECC, 2014a). The data on electricity intensity of office buildings presented in Table 5-1 are reported considering the median electricity usage from the office buildings assessed. This is because median is argued to be more resistant to the outliers and not to skew the results in large samples.

offices with both the smallest and the largest floor area space have the highest electricity intensity.

Table 4-1. Median electricity intensity of office buildings by floor area space, England and Wales (2011)

Floor area space (square meters)	Median Electricity intensity (kWh/m^2) of office buildings
0-49	154
50-99	89
100-249	78
250-999	81
1,000-4,999	130
5,000+	209

Adapted from DECC (2014a)

In the absence of prior data on energy use and worker mobility for case study selection, it was felt that the inclusion of a range of office sites in the size bands associated with high electricity intensity could reflect variations in small power energy use practices in offices, that would be useful to study. From the DECC report (2014a) three office sizes may be used as a proxy to meet this criterion for high electricity intensity:

- an office space less than 50m^2 (c.154 kWh/m^2)
- an office space with floor area space between 1,000m^2 and 4,999m^2 (c.130 kWh/m^2)
- an office space more than 5000m^2 (c.209 kWh/m^2)

The high electricity intensity office sites considered for the selection of cases are further discussed in Section 4.3.

4.2.2 Classification of Office Workers: Worker Mobility

Different types of office workers can be categorised based on ‘mobility’, whether their work is mainly undertaken at a fixed desk/workstation [‘static’] or is more distributed across the office spaces [‘mobile’] or, indeed, takes place outside of the office building altogether. This difference in mobility can be expected to have an impact on small power requirements based on the work activities undertaken within office spaces and the devices used in order for the work activities to be performed. The different types of office worker mobility are discussed below.

Worker mobility has been examined by the Office of Government Commerce and DEGW (OGC and DEGW, 2008) based on the workstyles of office workers in UK organisations - see Figure 4-2. The different types of office workers examined on this study were classified as ‘residents’, ‘internally mobile’ and ‘externally mobile’. This study also identifies the dependency of each type of office worker on information and communication technologies (ICT), their need or not to be located in an office building, as well as the type of workstation they need to occupy (OGC and DEGW, 2008). Figure 4-2 identifies these different types of office workers in terms of their key features (‘workstyle characteristics’) rather than the work activities that might be associated with the different mobilities of workers.

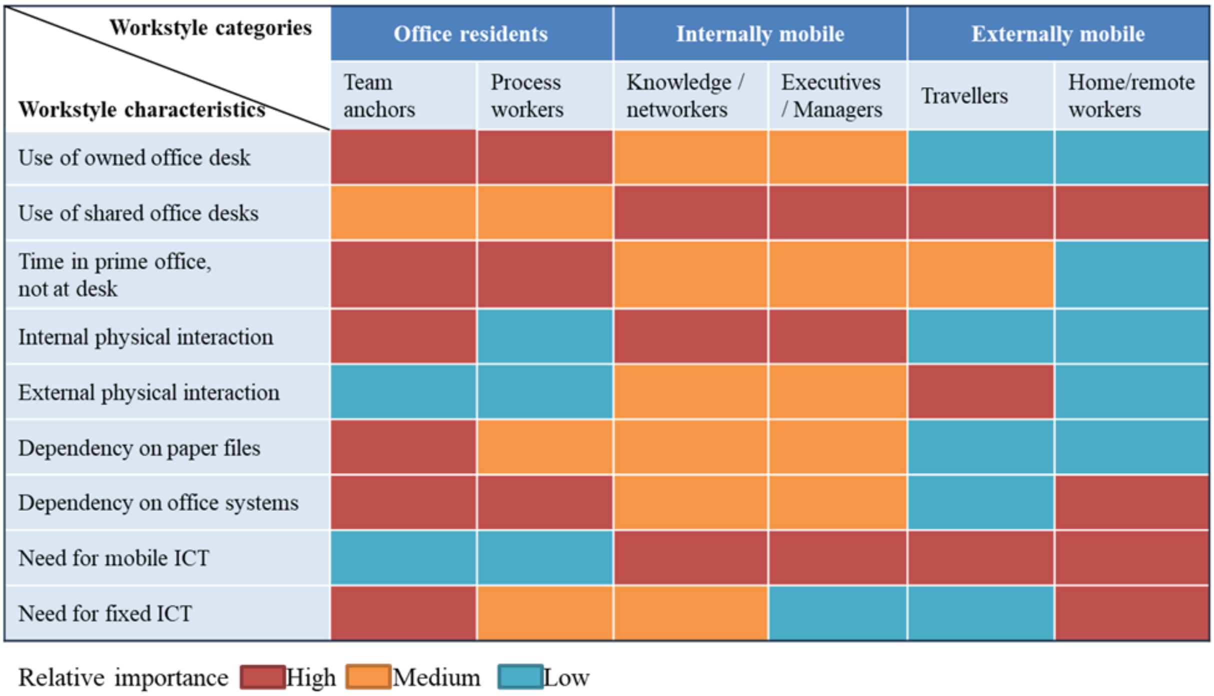

Figure 4-2. The new workstyles of office workers (Adapted from OGC & DEGW, 2008)

This generally accepted classification of office workers covers a wide range of different types of workers but includes sub-categories which differentiate between different worker roles. As this research is concerned with mobility and small power energy use practices, rather than specific worker roles, a broader classification based only on the mobility of office workers was required. Classifications of office-based workers, mobile workers within office premises, and externally mobile workers were developed based on the different office settings in which work activities are performed. Whilst externally mobile workers arguably affect small power consumption in other spaces (other office buildings, in the home, in ‘third’ spaces etc.), they are of somewhat limited interest as they are frequently absent and so do not directly affect the small power energy consumption in the case office sites (office building spaces), they were therefore excluded from this study. For the purposes of this study, the criteria for mobility of office workers was considered to be either ‘static workers’ (workers who spend the majority of their time in a single office setting e.g. at a desk or the workstation[15]) or ‘mobile workers’ (workers who use multiple office settings within a working day), in order to explore variations in their small power energy use from work activities performed in different office spaces. Considering to what extent externally mobile workers may occasionally affect small power energy use in office settings, this may occur through remote access of office equipment (e.g. servers). However, given the challenges of examining the work practices of dispersed absent workers, and their likely small demands on office small power energy, these workers were excluded from the study. Therefore, ‘static’ and ‘mobile’ workers were the two broad categories of office workers used in the preliminary discussions with potential office sites, to ensure that both types of workers were represented before selecting the case office sites. These two broad categories of workers were subsequently used to classify and enrol the participants in relatively high electricity intensity case office sites.

4.3 Details of Cases Used in the Comparative Case Study

The cases for this project were developed to reflect variations of small power energy use which may be associated with the activities performed and devices used in different office settings in high electricity intensity offices (based on their building size as a proxy for relatively high electricity intensity). Five office sites of high electricity intensity (using office size as a proxy for electricity intensity) in the United Kingdom were approached to support the data collection for this study between September 2018 and April 2019, and access was negotiated to three of these sites. These offices were of different sizes, each matching the size criteria (as a proxy for

[15] ‘Desk’ and ‘workstation’ are used interchangeably in the thesis, having the same meaning.

high electricity intensity) identified in Section 4.2.1 above and were thus suitable for inclusion in the research design.

Case office sites were also selected to reflect mobility of workers (static, mobile), and this was identified after discussions with the senior management of each office site prior to its selection. The case office sites selected in the United Kingdom are as follows:

1. office-based workers and mobile workers in ≤50m^2 office (floor area 49.5m^2);
2. office-based workers and mobile workers in 1,000-4,999m^2 office (floor area 1994m^2);
3. office-based workers and mobile workers in 5,000+m^2 office (floor area 9635m^2).

In order to examine fully the relationship between work activities, office spaces and devices/equipment usage, each case office site included a comparable set of different departments and business units within the organisations, and workers from different job roles. The characteristics of these case office sites are presented in Table 4-2 below.

Table 4-2. Characteristics of cases

Cases office sites	**Office-1**	**Office-2**	**Office-3**
Size[16]	49.5m^2	1,994m^2	9,635m^2
Number of Office Workers	10	203	1,068
Occupancy density	4.9m^2/person	9m^2/person	9m^2/person

[16] The size of each organisation is based on the measurement of the net internal area including kitchen(s) and/or common function area (such as printing area), break-out area, meeting rooms and toilets. The data, which were retrieved from the Valuation Office Agency, were provided by each organization.

	Office-1	Office-2	Office-3
Nature of organisation	Facility Management	Distribution Network Operator	Energy company
Number of floors	1	1	4
Single tenant building / multi-tenant building	Multi-tenant	Multi-tenant	Multi-tenant

4.3.1 Recruitment of Office Workers

Once the cases for the comparative case study had been identified, office sites were approached to negotiate involvement and accessibility, recruitment of office workers, and timeline of the study. Several formal meetings took place with Directors and Managers of the Facilities Management (FM) teams within each organisation to discuss the processes involved for the data collection. The timeline of the study was set between September 2018 and April 2019 for the three UK office sites involved in the study.

After arrangements were agreed between the researcher and FM teams in each office site, it was necessary to recruit the office workers within the organisations to take part in this study. To do this a self-completion questionnaire-based survey was developed to identify potential participants on the basis of their mobility (details are provided in Appendix B). The Stoddart Review (2016)[17] combines the level of mobility of workers (based on description of time that workers spend on a single location within the building, or using different spaces within the

[17] This questionnaire examines the mobility of office workers from a large number of organisations across the world (e.g. UK and Ireland, US, Russia, Australia, Central Asia, Middle East and Africa)

office building to undertake their activities), and demographics (e.g. gender, age and length of time that workers work for an organisation). The operational definition of mobility in that review was developed without making explicit the time spent by workers in a single office location, using expressions such as ″I perform most / all of my activities at a single work setting and rarely use other locations within the office″. For the purpose of the present research, the options related to the level of mobility provided from the Stoddart survey were combined with an assessment of explicit working hours (considering eight hours as an average working day) in a single location (such as workstation) within the office. For example, the range was from six or more hours spent working at the desk ('static') to less than two hours spent working at the desk ('mobile'). Specifically, the differentiation of workers was as follows:

- workers who spend less than two hours in an office setting were characterised as 'mobile workers',
- workers who spend from two to three hours in a single office setting were characterised as 'mainly-mobile',
- workers who used an office setting for four hours or more were considered 'mainly-static' while,
- 'static' workers were considered those who work in a specific office setting for six hours or more.

The survey questionnaire also included the type of profession, as defined in the standard occupational classification of professions by the ONS (2010), and the age and gender of workers. The purpose was to identify one worker from each broad category of professions and demographics, in order to reflect the range of work activities undertaken. Details of the survey which identified the mobility of office workers and facilitated the recruitment of participants are appended (Appendix B).

The survey questionnaire was distributed to the entire staff list of each organisation via an email from the Human Resource Department. This was to identify a cross section of potential participants from different job roles and different business departments, as well as with different mobility profiles. The questionnaire identified to what extent the work activities of each office worker are performed in a single, ‘static’ work setting, or across other spaces/locations either within their normal office building or outside of it. In this latter case, those workers whose activities take place mainly outside the buildings considered were not included in the list of potential participants. The following section gives more details about the process of participant selection, but it was important to have a similar balance of participants within each category across the case office sites.

4.3.2 Sample of Office Workers

The aim of this study is to obtain insights into the phenomenon (Ishak and Bakar, 2014) of small power energy use in offices, not to generalize to a population. The qualitative component of this mixed methods study (Onwuegbuzie and Collins, 2007), focused on understanding work practices which affect small power energy use, is key to developing these insights. Therefore, the selection of office workers to study in each case was purposefully done to focus attention on this phenomenon. Purposeful sampling is generally used in case study research (Creswell, 1998) and in this research a homogenous sampling approach as part of mixed method research is adopted to identify groups and/or individuals for study based on similar or specific characteristics (Onwuegbuzie and Collins, 2007), in this instance focusing on workers’ ‘mobility’ and office work role.

The aim of the sample selection was to have equal distributions in terms of number of each type of worker and mix of job roles within each case for the comparative case study. Different types of office workers in an equal mixture of job roles were recruited across the cases, allowing for comparison of their mobility and small power energy use practices.

In general terms, Boddy (2016) suggests that for case studies a total interview sample size of between 15 and 30 may be adequate. More specifically, for comparative studies Sandelowski (1995) suggests that amongst a homogenous population the sampling size should be at least ten participants per group or case. In line with Sandelowski's recommendations, between 10 and 11 participants for each case (in total three cases) were recruited for the present study. Details of sample recruitment is discussed in the following section. A further consideration concerns the number of participants that may cause saturation[18] to be achieved. In the case of this research, the determining factor for the number of participants was the available workforce in the smallest office (see next section), which met the criterion of comparative study sample size. In order to achieve similarity of sample size across the cases, the number of workers in the smallest office ($<50m^2$) was the constraint on sample size rather than the level of saturation.

Generally, a purely quantitative approach would have required a larger sample size to allow for generalizations to a wider population. The purpose of this study was to improve understanding of small power energy use practices and not generalize the findings to a wider population, and the selection of three comparable cases with a relatively small sample sizes was considered appropriate.

[18] The term saturation comes from the concept of grounded theory and is described as "theoretical saturation", implying that the collection of more data provides no new relevant information to the understanding of the research (Galvin, 2015). In addition, saturation can be reached when there is a high rate of duplication in responses or recurrence of responses and no new codes are produced (Guest et al., 2006).

4.3.2.1 Details of Sample Recruitment

Although the number of office workers in each case office site varied, it was intended to recruit comparable sample sizes for each case office site in terms of number of participants for each type of office worker ('static' and 'mobile') and role. Therefore, the number of participants recruited for the comparative case study was based on the worker type (i.e. static office-based worker or mobile worker) and role (e.g. Director, Manager, Administrator). Office-1 was the smallest office, with 10 workers, and all of them participated in this study. Eleven individuals completed the survey in Office-2 (out of 203 workers) and 49 individuals in Office-3 (out of 1,068 workers). In order not to preclude just one participant and to meet the minimum sample size suggested by Sandelowski (1995) from Office-2, samples of 11 workers from the second and third organisations were therefore identified. This also gave a similar distribution of the different type and role of workers across the cases. Table 5-3 presents the different types of office workers who participated in this study as well as their level of mobility from each case office site. Some samples have small imbalances between static and mobile workers – specifically within office sites <50m^2 (Office-1) and 1000-4,999m^2 (Office-2) – caused by the availability of personnel for each case. This resulted in an adjustment of the sample in case of office site 5000+m^2 (Office-3) to reflect an equal distribution across the cases in terms of mobility of workers.

Table 4-3. Type of office workers and mobility level

CASE OFFICE SITES	PARTICIPANT ROLE	NUMBER OF PARTICIPANTS	STATIC	MAINLY-STATIC	MOBILE	MAINLY-MOBILE
Office-1 (<50m^2)	Managers, directors and senior officials' occupations	4	1	3	0	0
Office-1 (<50m^2)	Professional occupations	3	2	1	0	0
Office-1 (<50m^2)	Sales and customer service occupations	1	0	0	1	0
Office-1 (<50m^2)	Administrative and secretarial occupations	2	2	0	0	0
SUB-TOTAL		*10*	*5*	*4*	*1*	*0*
Office-2 (1000-4,999m^2)	Managers, directors and senior officials' occupations	3	0	0	3	0
Office-2 (1000-4,999m^2)	Professional occupations	6	0	2	1	3
Office-2 (1000-4,999m^2)	Administrative and secretarial occupations	1	0	0	1	0
Office-2 (1000-4,999m^2)	Associate professional and technical occupations	1	1	0	0	0
SUB-TOTAL		*11*	*1*	*2*	*5*	*3*
Office-3 (5000+m^2)	Managers, directors and senior officials' occupations	4	1	1	1	1
Office-3 (5000+m^2)	Professional occupations	6	1	1	1	3
Office-3 (5000+m^2)	Administrative and secretarial occupations	1	0	0	0	1
Office-3 (5000+m^2)	Associate professional and technical occupations	0	0	0	0	0
SUB-TOTAL		*11*	*2*	*2*	*2*	*5*
TOTAL		32	8	8	8	8

Figure 4-3 below shows demographic data of the sample in terms of the role of the participants, reflecting the diversity of the sample[19]. The role of participants was considered in order to see if there is an association between workers' mobility and their professional roles. In addition, by considering a mixture of roles, potential variations in the nature of office work and device usage that might affect small power energy consumption could be examined.

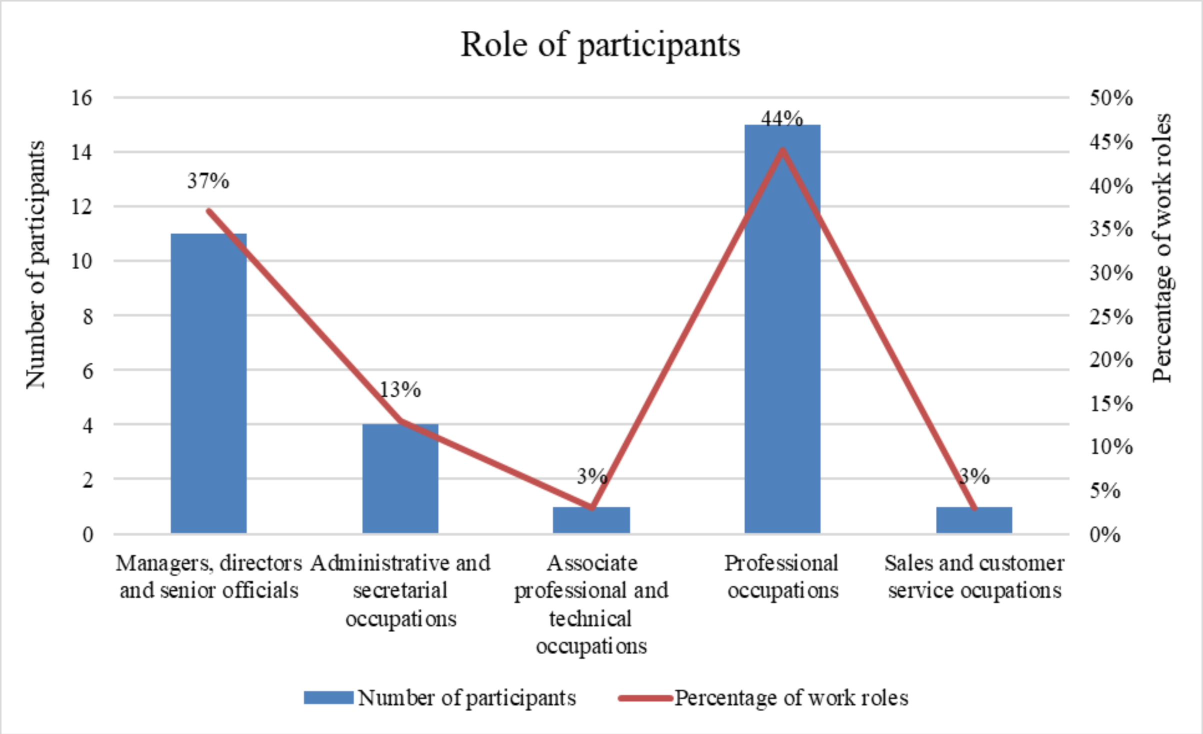

Figure 4-3. Work occupations of study participants

Considering this role classification, Figure 4-3 shows that senior roles such as senior officials, managers and directors together with professional occupational roles and administrative roles

[19] As outlined in Section 4.3.2.1, the classification of job roles was developed considering the classification of roles from the Office of National Statistics (2010) and is included in the mobility survey (Appendix B).

formed the majority of the sample for this study, with fewer participants coming from associate professional and technical roles or sales and customer service roles. Whilst an attempt was made to include a variation of different professions, this was not always possible. The main factors which were considered for the selection of the sample were the level of mobility and role of workers.

4.4 **Operationalizing Work Practices**

4.4.1 The Role of Work Activities

In order to examine work practices of the office workers to be studied, it was important to have a means of operationalizing the kind of work that people do in offices. To this end, a list of the types of activities performed in different office spaces was developed. These categories of activities were mainly concentrated on the individual worker and the office space used.

Work activities can take place at all available spaces within an office environment (Kleijn et al., 2012) and certain activities by their nature involve the use of office devices and equipment (e.g. printing/copying). Work activities are performed mainly in single locations (e.g. workstation) and in shared office spaces (e.g. meeting rooms). Knowing where activities are performed helps to differentiate activities (as also recommended by Tabak, 2009) between individual and group activities (i.e. shared activities). This approach differentiates activities based on whether they require interaction between office workers or not.

Individual activities can mainly be performed independently, without requiring interaction with other office workers. However, ‘moments of shared activity’ (e.g. dealing with incoming telephone calls at the workstation) and ‘accidental interaction’ (e.g. accidentally meeting up people while walking to different office locations) are examples of individual activities that may involve interaction between people (Tabak, 2009, p.30). In contrast to individual activities, shared activities involve several office workers with a shared common goal (e.g. meetings). The composition of groups of people associated with these activities is not fixed and can change over time (Tabak, 2009, p.30). Considering that work activities may be differentiated between individual and shared activities, based on the private or shared office spaces in which activities are taking place, Appel-Meulenbroek et al. (2011) has made an attempt to categorize typical activities, including the various office locations in which these are usually performed. The list of office activities presented in Figure 5-4 below is based on a number of studies which assessed work activities in the built environment (see Zhao et al., 2013; Nguyen and Aiello, 2013; Kleijn et al., 2012; Appel-Meulenbroek et al., 2011; Tabak, 2009; Steen et al., 2005). This list of work activities (see Figure 4-4) was used as a means to explore office work practices (see Section 4.3.3).

The list of activities was developed to support an examination of workers' office work practices through direct observation (see further under methods below) and the spaces in which such activities are performed. The following sections detail how categories of activities to be examined were defined, and how the method (direct observation) for examining them was developed.

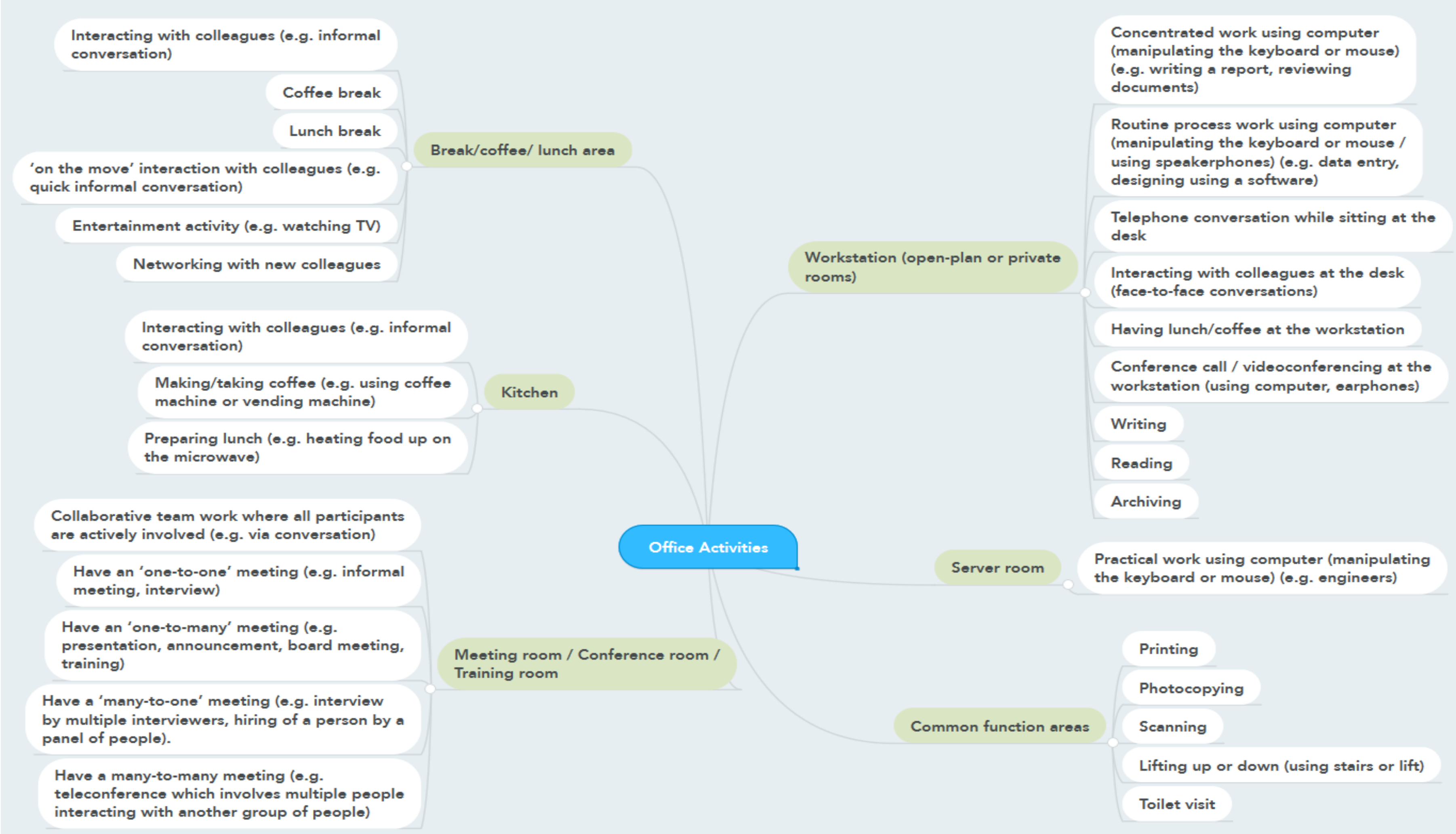

Figure 4-4. Mind map of individual and shared office activities

(Author's assessment based on Zhao et al., 2013; Nguyen and Aiello, 2013; Kleijn et al., 2012; Appel-Meulenbroek et al., 2011; Tabak, 2009; Steen et al., 2005)

4.4.2 The Classification of Work Activities

A synthesis of the studies considered above provides a map of typical activities performed in offices, either individual or shared, and the complex dynamics of analysis considering the relationship of different work activities and their association with devices/equipment usage across different office spaces, triggering the use of small power energy. As the effect of these activities on small power energy use is not indicated from the reviewed studies discussed in the preceding section, the map may be used to help investigate the performance of work activities in different spaces over a working day, in order to understand their effects on levels of small power use in office buildings.

The map (Figure 4-4) was used to develop a list of work categories, differentiating them based on the office space in which work activities are expected to be performed and eventual associated device usage. The list of activities was mainly extracted from relevant studies of office work (see Zhao et al., 2013; Kleijn et al., 2012; Tabak, 2009; Steen et al., 2005) and was used in this research to provide the basis for linking work, device usage and associated small power energy consumption. Table 4-4 presents an extended categorisation of work and other activities used in this study based on the different spaces of the office environment (e.g. workstations; common function areas such as break-out area, corridor, printing area and toilet; meeting rooms, kitchen).

Table 4-4. List of work and other activities based on office spaces

Office Spaces	Activities
Workstation	W1-Archiving at the workstation
	W2-Concentrated work using desktop computer at the workstation
	W3-Concentrated work using laptop at the workstation
	W4-Routine process work using desktop computer at the workstation
	W5-Routine process work using laptop at the workstation
	W6-Telephone conversation while sitting at the workstation
	W7-Reading at the workstation
	W8-Writing at the workstation
	W9-Interacting with colleagues at the workstation
	W10-Having lunch/coffee at the workstation
	W11-Having a meeting at an enclosed workstation
Common Function Area	CF1- Interacting with colleagues in the corridor
	CF2-Lifting up or down (using stairs or lift)
	CF3-Photocopying
	CF4-Printing
	CF5-Toilet
Break-out area	BA1-Coffee break in the break-out area
	BA2-Entertainment activity (e.g. watching T.V.) in the break-out area
	BA3-Interacting with colleagues in the break-out area
	BA4-Lunch break in the break-out area
	BA5-Networking with new colleagues in the break-out area
	BA6-'on the move' interaction with colleagues
Kitchen	K1-Interacting with colleagues in the kitchen
	K2-Making coffee in the kitchen
	K3-Preparing lunch in the kitchen
	K4-Having lunch in the kitchen

Office Spaces	Activities
Meeting Room	MR1-Collaboative teamwork in a meeting room
	MR2-Have a many-to-many meeting in a meeting room
	MR3-Have a many-to-one meeting in a meeting room
	MR4-Have a one-to-many meeting in a meeting room
	MR5-Have a one-to-one meeting in a meeting room
Other Activities	O1-Out of office
	O2-Other activity

4.5 **Overview of Methods Used**

This deductive research examines work activities and small power energy in an office environment, using a mixture of quantitative methods (power monitoring) and qualitative methods (observations and interviews) to build up a picture of what office occupants are doing when they are using energy. One of the quantitative methods which has been widely used to examine small power energy use is energy monitoring (Menezes et al., 2011; Menezes et al., 2012a; Crowe, 2013; Mulville et al., 2014; Tetlow et al., 2015) using hardware to obtain electricity usage from devices in use. This type of monitoring has been selected so that the detailed electricity consumption when devices are being used can be attributed to each office worker. With respect to the qualitative approaches, direct participant observation, short questionnaire and semi-structured interviews will support the scope of this study to understand what workers do in offices that gives rise to small power energy use.

The discussion developed in Chapter 2 (Section 2.6.2) concluded that qualitative methods or a mixture of qualitative and quantitative methods have seldom been used to explore small power energy use in offices. However, there are several examples of interdisciplinary and crossdisciplinary work on practices of energy usage (see Gram-Hanssen, 2010; Higginson, 2014; Jensen, 2008; Palm and Darby, 2014) which combine quantitative and qualitative research. According to Bryman (2008, p.163), when components of quantitative and qualitative data are put side by side, “interesting but unanticipated insights may be thrown up”. To support this argument, Bryman (2008) discusses a project by Hammond which used mixed methods (a qualitative study of the benefits of lifelong learning preceded by a quantitative study) and describes how this approach allowed the development of several unanticipated outcomes. This quantitative-qualitative distinction operates at three levels of research practice: data collection, data analysis, and interpretation of results (Howe, 1988). It is important to preserve the distinction between qualitative and quantitative aspects of data at the data gathering level, but when these are combined at the level of analysis and interpretation, they give an enhanced understanding of the research in hand. According to Howe (1988), it is impossible to imagine a study without "qualitative" elements, which suggests that all research ultimately has a "qualitative grounding” (Campbell, 1974). Howe also argues that it is impossible to imagine a study without "qualitative" elements at the level of data collection. Therefore, far from being incompatible, Howe (1988) argues that quantitative and qualitative methods are inextricably intertwined.

The application of the mixed method approach in this research is intended to give a more nuanced understanding of the office work practices that are giving rise to small power energy use. The measurement of small power energy consumption is therefore complemented by an examination of the work carried out by office workers and their associated device usage within office spaces (including an exploration of how this work is accomplished and understood, using social practice concepts of knowledge and meanings discussed in Chapter 3) to help understand its implications on small power energy use. The following sections give a more detailed account of the specific methods adopted, dealing in turn with quantitative and qualitative approaches.

4.6 Quantitative Methods

The preceding discussion of the literature (Section 2.7) identified that quantitative analysis features prominently in studies of energy use in offices, and can partly support the aim of this study by supporting an assessment of small power energy consumption (through monitoring) and associating it with office work practices. While quantitative methods can be limited in the exploration of the underlying relationship between work practices, office spaces and the devices/equipment involved, they are nonetheless an important component of the present study and are described in detail below. Within the context of this study, an understanding of how variations of small power energy use are influenced by the composition of different working practices is needed. This level of analysis is better captured by including qualitative methods (e.g. observation methods and interviews). The qualitative methods used in this study are described in more detail in Section 4.7.

4.6.1 Quantitative Approach – Monitoring of Small Power Use

All accessible electrical devices used by the office workers studied have been monitored using plug-in smart monitors. This is to identify electricity consumption when a device is in use or is in ‘on’ / ‘idle’ mode, in order to provide insight into the impact of office worker activity on small power consumption. Kitchen devices and devices which were located in meeting rooms and common function areas (e.g. printing room) were also monitored. Continuous monitoring of all devices that are in ‘on’ / ‘idle’ modes within each of these office spaces was carried out to examine the frequency and intensity of device use. Walk-through audits were conducted in each case office building in order to identify the available electric devices. Smart monitors of 1-minute resolution were used (after conducting the pilot study, it became clear that workers’ activities may change minute to minute and monitoring of device electricity usage needs to reflect this - see Section 4.7.1 below). The smart monitors were installed between a wall socket and the relevant electric appliance. The smart monitors enabled the recording of electricity used per device in Watt every minute, communicating in series with all devices that were monitored, and data were retrieved (showing electricity usage per minute of each device) wirelessly via a pre-installed web-based application (see Appendix F).

4.6.1.1 Hardware Used and Testing of Hardware

The hardware used to obtain data on electricity usage of office devices was the VOLTCRAFT SEM-3600BT-UK Smart Energy Meter. This technology was selected out of different technologies available in the market because: it is one of the few available hardware which enables the power monitoring per minute; it was an easy technology to be used with high accuracy (measuring from 0.23Watts up to 3600Watts); and it facilitates wireless data transmission Bluetooth 4.0 with a range up to 30m. These smart monitors enable easy installation between a wall socket and the electric appliances and can be controlled via an application (App) downloaded from the Internet onto a mobile device or a tablet. The App enabled viewing of line voltage, current consumption, power, power factor, frequency, energy consumed and cost of electricity consumption. This technology also supports graphical display energy consumption for 90 days (24 records/day), enables retrieving of per minute data every four hours, and is an economical technology allowing an adequate number of smart monitors to be used in different spaces of an office building.

Prior to the actual energy monitoring of office devices within office buildings, testing of the selected smart monitors was conducted on different types of office devices within an office environment. The testing included a variety of office devices such as desktop computers, screens, laptops, multifunction devices, desktop lamps, portable heaters and fans, and kettles with a power range between 5Watts and 3000Watts. The results of the testing showed that the monitoring of devices could be done accurately, retrieving data with even higher accuracy (less than 0.23Watts) than the specifications of the monitors. This data obtained in the testing of smart monitors, showing small power energy usage (in Watts per minute) of several devices used in offices, is provided with this thesis in an attached CD ROM.

4.7 Qualitative Methods

Qualitative research takes many forms which are supported through the use of various techniques of data gathering. Chapter 4 outlined how SPT can be mobilised in this research to help understand office work practice in non-domestic settings (both as routine work activities and also their link to the use of office devices/equipment as material artefacts). SPT is used to capture the four elements of small power energy use practices which hold practices together (see framework on small power energy use practices – Section 3.5) in order to understand and map the link between office work practice and small power energy usage.

Observation and data gathering in qualitative research can follow different forms: interviews, participant observations, focus group, diaries, coding of existing texts and documents, and historical research (Law et al., 1998). In order to support the research aims, this study used a combination of different qualitative methods: interviews, direct participant observations and self-recorded observation. The use of qualitative empirically based reflections (as part of interviews and observations) which assess practices as performed and observed, has been recognised as allowing a more nuanced understanding of when and how practices are performed (e.g. Browne et al., 2013; Warde, 2005). This study uses observational methods to supplement the information given through more usual semi-structured interviews and allowed the observer to follow how some practices may merge and develop. These are developed in the Section 4.7.2.3.

4.7.1 Pilot Study to Test Qualitative Methods

Conducting a pilot study has several advantages, which include: indication of potential failure of the main research project; revealing if research protocols can be followed; or whether proposed methods or instruments are appropriate (van Teijlingen and Hundley, 2001). After developing the list of office work activities (Section 4.4.2), a pilot study was conducted to develop, test and refine the method of direct participant observation to be used in office spaces. In addition, the pilot study was intended to develop a better understanding of the research territory, developing a sense of what data could be generated and how it could be captured and analysed, testing likely approaches to data capture, examining the practical issues associated with observing work activities, and testing the appropriateness of the activity categories used. As the pilot study was designed primarily to test methods, approaches and protocols rather than as a source of primary data, it was conducted in a familiar office environment which was not part of the main case study group. However, it was important that this pilot study involved workers from occupations and roles which closely reflected the main case study group.

The pilot study of office work activities was conducted in office buildings at the University of Reading to examine whether observations of work and other activities and office spaces could be used to identify the core activities associated with small power energy use. In total, seven individual office workers and five different office spaces – workstations, meeting room, kitchen, break-out area, and printing area – were observed during a working day for each of the participants and for each of the different office spaces during February and March 2017. To facilitate the collection of data, a proforma was developed to include work activities and office devices associated with these activities (see Section 4.7.2.1). In addition, it was anticipated that the main study would include interviews with office workers using a semi-structured interview outline to help examine their understanding of the work practices they were engaged in and provide further insights into the observed work activities. While this outline was not formally tested on the pilot study, informal discussions were held with office workers to help identify issues of importance to them in their day to day work. Feedback from these discussions – as well as from the use of the observation pro-forma – was used to help develop an interview outline for the semi-structured interviews on the main study (see further in Section 4.7.2.3 below, and in Appendix D).

4.7.1.1 Observation Technique for Pilot Study

Direct observations of office workers were undertaken every five minutes, to observe the activities they were undertaking at that time, as well as the office devices involved. Activities were subdivided into ‘main’ activities which are typically performed first by an individual (e.g. making coffee in the kitchen) and ‘secondary’ activities which are those following a main activity (e.g. interaction with colleagues in the kitchen following making coffee in the kitchen). The recording intervals for observations of work activities (i.e. the duration of a main activity until a secondary activity or the next main activity to occur) was set to 5-minutes, because standard available plug in monitors for electricity measurement typically record data in 5-minute intervals. It was anticipated that this observational data could then be directly related to electricity usage monitoring data.

A sample of the data obtained from the pilot study data shows that direct observation can identify:

- The main and secondary activities performed during a working day by all participants and the devices that were ‘on’ and ‘idle’ during the performance of each activity.
- The main and secondary activities performed during a working day in each observed office space and the devices that were ‘on’ and ‘idle’ in these spaces during the performance of these activities.

An example of the data captured from the direct observation of main and secondary activities of participants in the pilot study is appended (Appendix A1). Following the observation of activities, all devices which were available in the office environment to facilitate the performance of these activities were identified and recorded. An example of how this was done is presented in Appendix A2.

Considering the observational data of work activities and office devices from the pilot study, while device use may be associated with the frequency and duration that an activity (e.g. working at a desk) is performed, the energy use associated with it may also be dependent on the distribution of the activity across available office spaces within a working day. Moreover, the performance of secondary activities together with the main activities may increase the number of devices used. It was felt that the pilot study would help establish how the distribution of work activities and device usage in different office spaces over a working day could be observed and recorded.

4.7.1.2 Outcome and Implications of Pilot Study

The pilot study showed that direct observations and work shadowing was an appropriate method for identifying activities performed in office spaces and the associated device usage. The pilot study also led to some informal discussions between the researcher and the participants, helping the researcher to understand why certain simultaneous activities were performed. For instance, while a participant was using a multifunction device for printing which was located in the kitchen, the participant also prepared coffee using a kettle and the mini fridge due to his/her presence in the kitchen.

Several challenges to the observation methods initially deployed were identified during the pilot study. For instance, the observation interval (i.e. 5-minute observation interval) was found to be over-long as the duration of some activities (e.g. making coffee, preparing lunch or printing) and in turn the usage of office devices associated with these activities was shorter than 5 minutes. Therefore, the interval for capturing energy usage of office devices was revised from 5 minutes to 1 minute for the main study and the hardware selected for monitoring the electricity usage from office devices reflected this change (see Section 4.6).

In addition, the direct participant observation in some office spaces such as meeting rooms was not always sufficient to capture all activities and associated device usage. With respect to meeting rooms, it was challenging to collect data on all the devices being used by different meeting participants simultaneously when visibility inside a meeting room was restricted, and when direct observation was not permitted due to concerns over confidentiality. In these cases, an alternative method was used for the activity ‘having meeting in a meeting room or at the workstation’. This involved the completion of a short questionnaire by the participating workers, which provided information on device usage (e.g. what devices were used, mode of the devices used and duration that devices were used) and the number of people involved during a meeting.

In addition to this short questionnaire, informal discussions helped to develop the questions to be used in semi-structured interviews. Feedback captured during the pilot study was used to amend the list of questions and included specific examples related to different modes of devices and associated energy usage (to capture participants’ understanding of the energy implications of their devices, or the organisational rules in relation to device use, settings and so on).

The pilot study proved to be a useful exercise and the main empirical study was conducted based on a refinement of the pilot study approach. This included revisions of the observation interval (i.e. observation interval 5 minutes reduced to 1 minute) the tool used in the pilot study (i.e. list of activities and web-based proforma of office activities and devices), and technology (smart monitors) to support the small power energy consumption.

4.7.2 Qualitative Methods for the Main Study

This study used a combination of direct participant observation, self-reporting through questionnaires, and interviews to understand the different activities performed and the implications of these on small power use in offices. These approaches are detailed in the following sections.

4.7.2.1 Observation of Work Activities

The list of office work activities presented in Table 4-5 below was used to conduct direct observations of workers and their device usage in office environment. Office workers were observed and monitored in terms of the activities that they performed as well as devices and equipment they used in different office spaces. The role of the researcher as non-participant observer was to observe from a distance (while being discrete) the work activities undertaken and device usage during a working day, with the consent of the participants. The methods which have been applied for data collection are shown in the table below and are related to individuals (i.e. office workers) and the accessed office spaces, including direct observation of participants, short questionnaire for self-reporting and device electricity monitoring.

Table 4-5. Research methods to examine office activities and small power energy use per office worker in different office spaces

Activities (from Figure 5-4)	*Methods Applied*		
	Direct Observation	**Short Questionnaire / Self-reporting**	**Device Energy Monitored (in Individual & Shared Spaces)**
Concentrated work using computer at the desk	√		Desktop computer / Laptop
Routine process work using computer at the desk	√		Desktop computer / Laptop
Interacting with colleagues at the desk	√		
Photocopying	√		√ Multi-function device (MFD) in Common Function (CF) area
Printing	√		√ MFD in CF area
Having lunch/coffee at the workstation	√		√ Kitchen devices
Reading at the desk	√		
Telephone conversation while sitting at the desk	√		
Writing at the desk	√		
Archiving at the desk	√		
Having a meeting at an enclosed workstation	√	√	Desktop computer / Laptop
Making coffee in the kitchen	√		√ Kitchen devices
Preparing / Having lunch in the kitchen	√		√ Kitchen devices
Interacting with colleagues in the kitchen	√		√ Kitchen devices
Have a many-to-many meeting in a meeting room	√	√	√ Available devices in meeting room(s)
Have a one-to-one meeting in a meeting room	√	√	√ Available devices in meeting room(s)

These categories above were developed to facilitate the observation. Details of the methods of observation used are presented below.

The direct observation took place over two randomly selected working days, within a two-months period in each case office site, to record activities involved minute by minute observation of the participating office workers, and the devices they used in different office spaces to perform work and other activities. The aim of using two randomly selected working days was to capture any potential diversity of work activities over different week-days (e.g. Fridays were seen to involve much less interaction between workers than other week-days due to the absence of a large number of workers who were working from home or elsewhere). Periods of observation were selected to avoid the effect of seasonality in terms of extended holidays or seasonal changes to working patterns (e.g. over Christmas meetings schedules may be affected due to absence for the office). Direct observation was conducted over the following periods: Office site-1: September to October; Office site-2: January to February; Office site-3: March to April. During the above timeline, most workers were present in the organisations involved during typical working hours (between 9am and 5pm), undertaking associated work tasks with their individual roles.

The direct observation was recorded using a modified web-based tool (e.g. online proforma, developed for the pilot study) on a tablet which included a predefined list of work activities and office devices as well as office spaces. An example of the observational data obtained through the proforma is presented in Table 4-6 below and the extended proforma is in Appendix G.

Table 4-6. Proforma for recording direct observation

Activities					Devices				
List of Activities	Main	Secondary	Not performed		***List of Devices***	In use	Not in use - ON	Not in use - Idle / standby	Not in use - OFF
W1- Archiving at the desk					D1- Water tank				
W2- Concentrated work using computer desktop at the desk					D2- Camera charger				
W3- Concentrated work using computer laptop at the desk					D3- Computer speakers				
W4- Routine process work using computer desktop at the desk					D4- Desktop main unit				
W5- Routine process work using laptop at the desk					D5- Desktop monitor				
W6- Telephone conversation while sitting at the desk					D6- Desktop fan				
W7- Reading at the desk					D7- Desktop printer				
W8- Writing at the desk					D8- Desktop lamp / Task light				
W9- Interacting with colleagues at the desk					D9- Dishwasher				

List of Activities	Main	Secondary	Not performed		***List of Devices***	In use	Not in use - ON	Not in use - Idle / standby	Not in use - OFF
W10- Having lunch / coffee at the workstation					D10- Electric convection heater				
W11- Having a meeting at an enclosed workstation					D11- Fan heater				
CF1- Interacting with colleagues in the corridor					D12- Fax machine				
CF2- Lifting up or down (using stairs or lift)					D13- Information display				
CF3- Photocopying					D14- Kettle				
CF4- Printing					D15- Laptop				
CF5- Toilet					D16- Microwave				
BA1- Coffee break in the break-out area					D17- Mini fridge				
BA2- Entertainment activity (e.g. watching TV) in the break-out area					D18- Mobile charger				
BA3- Interacting with colleagues in the break-out area					D19- Multi-function device				
BA4- Lunch break in the break-out area					D20- Paper shredders				
BA5- Networking with new colleagues in					D21- Photocopier				

the break-out area									
List of Activities	Main	Secondary	Not performed		***List of Devices***	In use	Not in use - ON	Not in use - Idle / standby	Not in use - OFF
BA6- 'on the move' interaction with colleagues					D22- Printer				
K1- Interacting with colleagues in the kitchen					D23- Projector				
K2- Making coffee in the kitchen					D24- Refrigerator				
K3- Preparing lunch in the kitchen					D25- Scanner				
K4- Having lunch in the kitchen					D26- Tablet				
MR1- Collaborative teamwork in a meeting / training room					D27- Telephone				
MR2- Have a many-to-many meeting in a meeting room					D28- Toaster				
MR3- Have a many-to-one meeting in a meeting room					D29- Vending machine				
MR4- Have a one-to-many meeting in a meeting room					D30- Water cooler				
MR5- Have a one-to-one meeting in a meeting room					D31- Other device 1				
O1- Out of office					D32- Other device 2				

List of Activities	Main	Secondary	Not performed		***List of Devices***	In use	Not in use - ON	Not in use - Idle / standby	Not in use - OFF
O2- Other activity					D33- Other device 3				
					D34- Other device 4				
					D35- Coffee machine				

The energy consumption by devices used by participants at workstations was monitored during the same days of the observation, as described in 4.6.1 above. Similarly, electricity usage from devices in other office spaces such as the kitchen, meeting room(s) and Common Function (CF) areas (e.g. printing area) were monitored when in use by the people being observed.

4.7.2.2 Self-reporting of Work Activities

Where direct observation was restricted or was not allowed due to confidentiality of information shared (e.g. during informal or formal meetings), a short questionnaire was developed which was provided to office workers to record their activities and device usage. The participants could indicate in the short questionnaire what activity was performed, the number and duration of devices used, and the number of people involved in the activity (see Appendix C). The office workers were asked to complete the short questionnaires on the same day of participation to help supplement the researcher's direct observation of each participant.

Therefore, in order to capture a complete picture of the office work activities performed and devices used, a combination of direct observation (using the online proforma) and the short questionnaire was used. At the end of the observational day, the researcher also had short interviews with the participating workers about the routine activities performed and the associated device usage during typical working days as discussed in the following section.

4.7.2.3 Short and Semi-structured Interviews

Two types of interviews were developed to supplement data obtained via direct observation and self-reporting. The first, short interviews were conducted with the participating office workers where direct observations of office workers could not be conducted. This situation arose when direct observation was restricted either by room configuration or by the participants' request for confidentiality. Office workers who perform the activity 'having a meeting in a meeting room or at an enclosed workstation' either formally or informally, were asked for information related to their device usage during the performance of this activity and the number of people involved during this activity.

In addition to the short interviews, more in-depth semi-structured interviews (each lasting approximately 30 minutes) were conducted with participating office workers at the end of the observational day. The focus of the semi-structured interviews was to explore the relationship between work activities and small power energy use and to examine whether the direct observation of office workers was typical of what an office worker does most of the time. An interview schedule was developed prior to the interviews to frame the direction of discussion and these questions were informed by four elements of SPT related to energy use practices (see Section 3.5). The semi-structured nature of the interviews enabled them to unfold in accordance with the interview schedule's key questions and topics of focus in a relatively informal and conversational manner. Open-ended questions prompted office workers to explain their usage of different office spaces and devices based on their work requirements. The purpose of the semi-structured interviews was to explore four important elements of SPT (knowledge, meanings, routines, and technology) relating to small power energy use practices and interpret the observational data of office work activities performed and the devices used. The revised version of questions developed from the pilot study is appended (Appendix D). Interviews were audio-recorded and transcribed for analysis (see further in 4.9.4 below).

4.8 Summary of Research Methods

The detailed research design used to support the data collection and analysis of this study is illustrated in Figure 4-5 (below). A comparative case study was conducted in three office sites of high electricity intensity (using the size of offices as a proxy for electricity intensity), involving three different organisations, to identify work and other activities and devices used in office buildings related to small power energy use. Qualitative data involved direct observation for static and mobile workers when in the office. Self-observation through short questionnaires was used for static and mobile workers when observation could not be conducted. Smart monitors were deployed to quantitatively measure the electricity consumption of office devices. In order to examine the relationship between working practices and small power use, semi-structured interviews with office workers were also conducted. The application of the above methods was used to identify patterns of small power energy consumption from different types of office worker (e.g. static office-based workers and mobile workers).

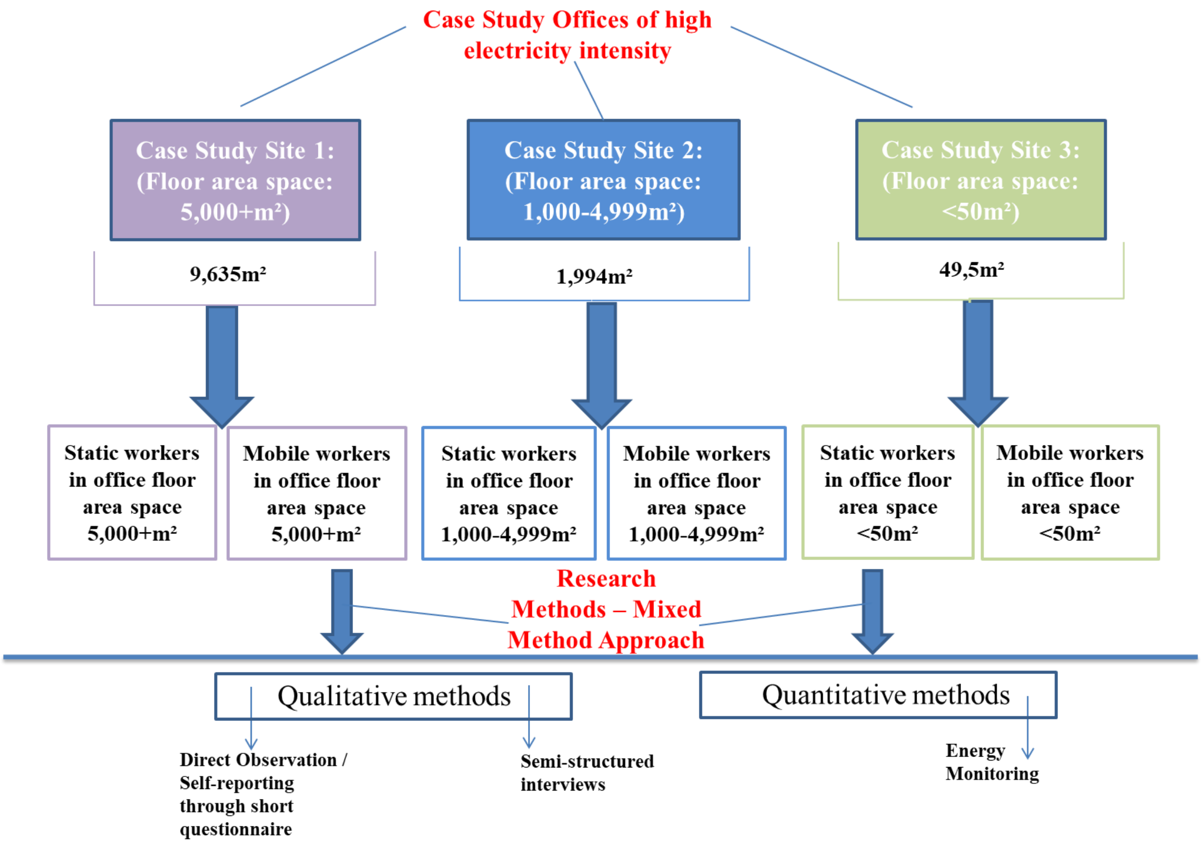

Figure 4-5. Detailed research design

Each of the four research objectives for this study together with the associated research method is summarised below. A further discussion of the research objectives is presented at Section 4.10 that describes the data analysis techniques used in respect of each.

Objective 1 - To understand what office work and other activities are performed in different office spaces that use energy-consuming devices and equipment.

This objective was addressed through direct observations of work and other activities performed by office workers and associated devices used in different office spaces. The direct observations of office workers, involving predefined categories of activities, office devices and spaces, aimed to identify activities performed in office spaces but also helped to develop an understanding of why certain activities (either main or secondary activities) are performed. This was achieved through short interviews with workers during observations.

Objective 2 - To understand what types and quantities of office devices and equipment are used to support the performance of office work activities.

This objective was addressed through walk-through audits in order for office devices/equipment used in different office spaces to be identified, and then observed and recorded individual and shared devices used by each participant.

Objective 3 - To measure what small power energy is consumed by these equipment/device-using activities in different office spaces.

This objective was addressed by monitoring the electricity usage of office devices/equipment associated with activities performed in different office spaces accessed from participants.

Objective 4 - To explore how small power energy use practices shape the usage of devices and the way that work and other activities are performed in an office environment.

This objective was addressed through semi-structured interviews with office workers in order to understand ‘how’ and ‘why’ small power energy use is affected by the activities performed from different type of office workers (e.g. ‘static’ and ‘mobile’). The semi-structured interviews had also been developed to obtain data on the four elements of SPT – knowledge, meanings, routine, and technology – in order to capture the relationship of small power energy use practices with the use of office devices in different spaces within office buildings.

4.9 Challenges and Limitations

A number of practical challenges had to be overcome in accessing the case study sites and in collecting data, that give rise to limitations in terms of what the study has explored and what the study has not shown. These limitations can be related to the theory used or research design developed, and can be perceived as "blind spots" and "blank spots" (Wagner, 1993, p.17) which are related to the area of study and deficiencies in the research data. The challenges and associated limitations of this research are discussed below.

4.9.1 Blank Spots (Considering Data Collection)

At the initial stages of the research, there was limited information about the organisational structure and the type of workers in each organisation that was initially considered. This lack of information caused uncertainty about the diversity of workers in each organisation in terms of their role and mobility and consequently led to questions about the number of organisations to be included. Initially, five organisations (three of them were accommodated in large office buildings - more than 5,000m^2) in the United Kingdom had verbally agreed to take part in this study. Two of these organisations subsequently withdrew from the research and this reduced the diversity of the sample in terms of specialist activities carried out in the organisations considered. However, the three remaining organisations are believed to be reflective of a wide range of functional departments, type of worker (static and mobile), and work role that typically can be found in contemporary offices (e.g. Directors, Executives, Managers, Administrators).

Access to case office sites was negotiated by the researcher and was subject to a formal confidentiality agreement between the researcher's university and the case study host organisation. The process of completing these legal agreements lasted longer (between four and six months) than was initially anticipated (from two to three months) in order for arrangements to be put in place to ensure that the requirements of both parties could be met. This delay affected the time available for the completion of this study, though did not adversely affect data collection once each case study was underway (see also under 5.10 Ethics below).

The availability of information about the devices used by each organisation prior to the monitoring days was also limited. Initially it was assumed that the devices to be monitored in each organisation to support the most common activities (e.g. routine process work or concentrated work, printing and scanning, making coffee and heating food up) would be similar. However, the devices used in two organisations were neither equivalent (in terms of technology), nor equally accessible compared with the other organisation. This is because the electrical connections for some devices (e.g. hot water dispensers, microwaves and TVs / information displays) were wired directly to the power supply and hidden behind partitions or above ceilings and there were no wall-mounted plugs to plug-in the smart monitors. The energy consumption from the non-monitored devices had therefore to be estimated based on assumptions of electricity consumption of the equipment's specified output, instead of being recorded from smart monitors. This did not significantly affect the results, however, because of the small number of devices involved (three) and the availability of comparable data from similar devices in the other organisations that could be used to estimate small power energy consumption.

In terms of the methods considered to address the research objectives of this study, video recording was a method initially considered to obtain data on shared (enclosed) office spaces (e.g. meeting rooms) where observations were restricted. However, this method was not accepted by the host organisations and therefore was not used. Data collection was based on an alternative technique of self-reporting through short questionnaires and short interviews of participating workers, and also energy monitoring of devices used by them. Although this restriction prevented direct observation of certain activities (e.g. meetings), the adopted technique outlined above enabled the data collection to be double checked within a short period of time and did not compromised the quality of the data.

4.9.2 Blind Spots (Considering the Theoretical Framework Used and Research Methods)

With respect to the theoretical perspective, SPT provides a ‘lens’ through which the office work giving rise to small power energy use may be examined, and the opportunity to develop new insights into small power energy consumption in offices. However, while SPT explores how work practices are developed by office workers, it does not focus particularly on individual behaviours (and associated aspects including personal perceptions, attitude, and preferences) that may influence how work is performed. Therefore, individual behavioural aspects (for example, individual preferences for switching-off devices when leaving a work area) were not explored in this research. Instead, the focus of this study is more on understanding observed work practices in the day-to-day routines and processes of office work, to help understand their effect on small power use in offices and so to address the research question of ‘what small power energy is used for’. All four of Gram-Hanssen’s elements of SPT were explored to interpret the quantitative data on small power energy consumption. This approach allowed an understanding of office working practices which affect small power energy use but did not give an exhaustive understanding of all energy practices in offices.

Finally, while a diversity in terms of type and role of workers was reflected in the sample of workers across the case office sites, there are inevitable limitations in terms of the range of workers included as well as the different types and stages of work activities covered and their associated device usage, and how these evolve over time. For example, project managers could be more 'static' in the initial stages of their projects while more 'mobile' towards the later stages as they spend more time interacting with people in different office spaces or being away from the office (e.g. at the project site). To explore these kinds of issues a longitudinal case study may have been more appropriate, but this was outside the scope of the present study.

4.10 Analysis of Quantitative and Qualitative Data

To capture and codify the data as well as conduct the quantitative and qualitative data analysis three different software packages were used. These are further discussed below.

Microsoft office suite Excel package 2010 was used to store the observational data as well as energy monitoring data in order to conduct descriptive analysis. Some technical support in the development of coding was provided by a third party to support the analysis regimes. The third party developed a suite of python scripts and libreoffice macros in order to treat and manipulate the energy usage data as they were stored in the Excel sheets. The macros were used to normalize the different types of data collection (electricity monitoring and observational data) and the python scripts were used to merge the different types of observations, convert energy use in watts to kWh and aggregate the energy consumptions from devices 'in use' and 'not in use-on'. They also helped to associate devices with work activities performed by different types of workers (static, mobile). The code is provided with this thesis in an attached CD ROM. The analysis regime developed by the researcher used IBM SPSS Statistics 24 package to conduct the statistical analysis, including parametric and non-parametric tests (e.g. ANOVA and Kruskal-Wallis test), to compare small power energy use between different types of workers. Finally, for the qualitative section of analysis, NVivo 11 package was used to develop the coding and conduct the analysis of the semi-structured interview data. In order to develop themes and nodes, the elements from SPT were considered but also other themes were explored (e.g. office space design, and style of work such as agile working) related to office activities and electricity usage. The analysis of interviews was focused on comparing similarities and differences between the different types and roles of workers as well as their associated activities and office device usage. The following sections describe in more detail how these packages support the analysis to address each of the research questions, outlined in Figure 4-6 below.

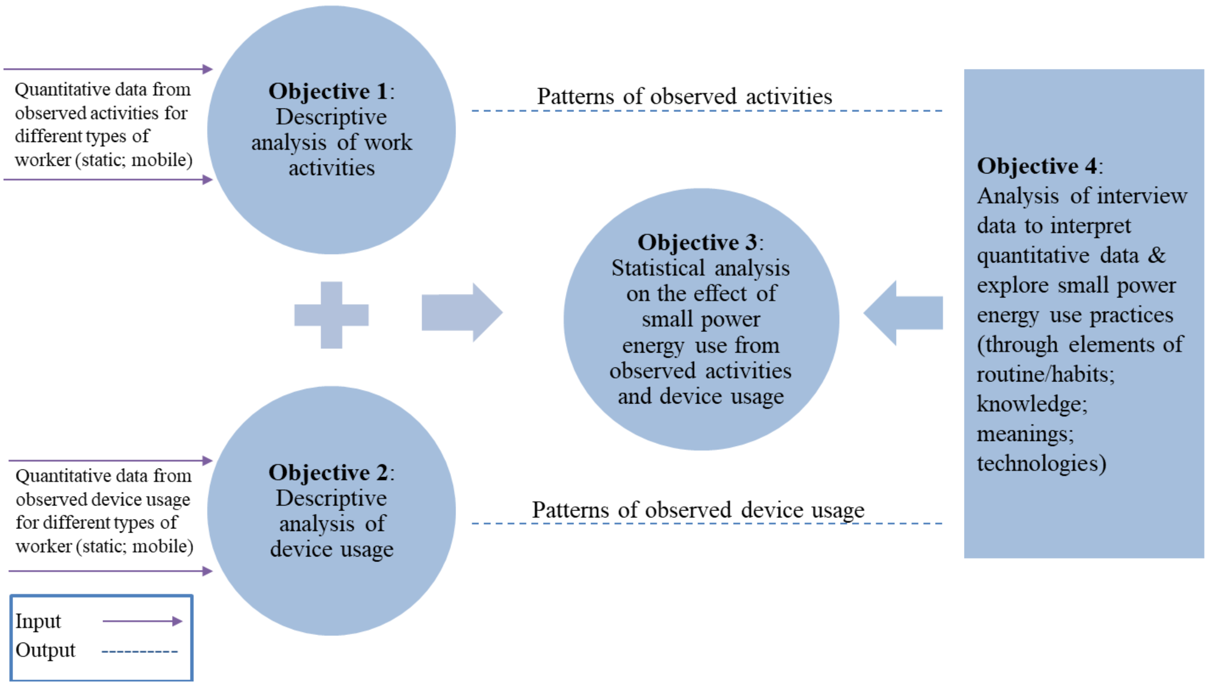

Figure 4-6. Linkage of objectives and interrelated data analysis

Figure 4-6 shows that descriptive analysis conducted for Objective 1 and Objective 2, together with measured small power energy use, contribute to the statistical analysis of Objective 3. The figure also shows how the analysis of interview data (exploring small power energy use practices through habits/routine-based data, meanings-based data, knowledge-based data, technologies-base data - Objective 4) also helps interpret the empirical data relating to Objective 3 (and Objective 1 and Objective 2 also).

4.10.1 Analysis of Objective 1: To understand what office work and other activities are performed in different office spaces that use energy-consuming devices and equipment

Observational data described in Sections 4.7.2.1 and 4.7.2.2 was used to develop descriptive analysis to associate different types of worker mobility ('static' and 'mobile') with work activities performed, and the effect on small power energy usage. In order to conduct this analysis, the Microsoft office suite-Excel package 2010 was used to help identify patterns in small power energy consumption from activities performed in different office spaces by different types of workers.

4.10.2 Analysis of Objective 2: To understand what types and quantities of office devices and equipment are used to support the performance of office work activities

Observational data outlined in Section 4.7.2.1 and 4.7.2.2 was used to develop descriptive analysis to associate different types of workers ('static' and 'mobile') with the devices used by each type of worker. Microsoft office suite-Excel package 2010 was used in order to help identify patterns in the quantity and type of devices used by different types of worker mobility.

4.10.3 Analysis of Objective 3: To measure what small power energy is consumed by these equipment/device-using activities in different office spaces

Observational data obtained from Objectives 1 and 2 and monitoring data outlined in Section 4.6.1 were used to develop descriptive and statistical analysis to associate small power energy usage with activities performed and devices used, across different case office sites by each type of office worker. In addition, descriptive and statistical analysis was conducted to associate different types of worker mobility with small power energy usage regardless of case office site, as well as small power energy use of different office spaces for different types of workers regardless of case office site.

Statistical analyses including parametric tests (e.g. Factorial-ANOVA and Multivariate analysis of variance (MANOVA)) and non-parametric tests (e.g. Kruskal-Wallis test) were conducted. The combination of parametric and non-parametric tests is associated with the normal distribution of the sample for the different level data analysed (case level data of three different case office sites and associated mobility of workers; mobility level data of three different types of worker regardless of case office site; space level data of three different types of workers regardless of case office site). These statistical tests are mainly related to the analysis of variance and compare the arithmetic means of small power energy consumption (mean small power energy use out of two working days) from activities performed and devices used in different office spaces between the different types of worker ('static' and 'mobile') across different case office sites. The statistical analyses aim to identify potential statistically significant differences of small power energy use from work activities performed and devices used between the different types of worker and across the different case office sites. Statistical analyses were conducted using MANOVA and Factorial ANOVA (parametric tests), as well as Kruskal-Wallis test (non-parametric test) because of the type of dependent and independent variables that are compared for the analysis of variance. The Factorial-ANOVA is a parametric test which considers normally distributed data - nominal and scale data - and compares two factors (nominal independent variables). The test was conducted to compare means of small power energy consumption (out of two working days) from work activities performed and associated device used (dependent factors) for different types of worker (static and mobile) and across different case office sites (as two independent factors). The MANOVA[20] is a parametric test which examines statistical differences on multiple continuous/scale dependent variables by an independent grouping variable (which is categorical/nominal). This test was conducted to compare means of small power energy use (out of two working days) from activities performed in different office spaces and associated device usage with the different type of worker mobility

[20] The MANOVA compares whether a combination of multiple continuous dependent variables differs by the different groups, or levels, of the independent variable. The MANOVA is used to test whether the independent grouping variable simultaneously explains a statistically significant amount of variance in the dependent variable (Warne, 2014).

(static and mobile) regardless of case office sites. Kruskal-Wallis test is a non-parametric test which is used for comparing continuous/scale dependent variables for three or more groups as independent variables (which are categorical/nominal). This test was conducted to compare means of small power energy consumption (out of two working days) from work activities performed in different office spaces and associated device usage with the different types of workers (static and mobile) regardless of case office sites.

These analyses were conducted considering small power energy consumption from office devices which were ‘in use’ in office spaces accessed by participants as well as from devices in mode ‘not in use-on’ at the workstation when participants performed activities at the workstation, because at workstations the personal devices used are not shared devices. Any shared devices in ‘not in use-on’ mode and ‘not in use-idle/standby’ mode were excluded from the analyses due to lack of information on the number of people who used them during the observational day of each participant. This study is primarily focused on understanding what gives rise to small power energy use (the effect of observed activities and monitored associated device used). Therefore, when devices were not being used for the performance of an observed activity (e.g. desktop computer on ‘idle/standby’ mode at an empty workstation), the monitored small power energy use was not considered in these analyses.

Table 4-7 summarises the rationale for the selection of the different statistical analyses conducted to show potentially significant differences of small power energy use from activities performed and devices used in different office spaces, considering the different case office sites and types of worker or worker mobility regardless of case office sites.

Table 4-7. Summary of data variables and statistical tests used

Independent variable for comparison	Independent variable distribution	Type of test required	Number of Independent variables	Independent variable type	Dependent variable for comparison	Dependent variable type	Statistical test
Different case office sites and types of workers	Normal	Parametric	2 or more independent variable groups	Nominal / Scale	Differences in means of small power energy use	Nominal / Scale	Two-way (N-way / Factorial) ANOVA
Different type of worker mobility (3 types of workers) and mean small power energy use from work activities and associated device usage, regardless of case	Normal	Parametric	One independent variable with two or more levels / independent groups	Categorical / Nominal	Differences in multiple means of small power energy use	Continuous / Scale	Analysis of variance – one-way MANOVA
Different type of worker mobility (3 types of workers) and mean small power energy use from work activities and associated device usage in different office spaces, regardless of case	Non-normal	Non-parametric test	One independent variable with two or more levels / independent groups	Categorical / Nominal	Significance of mean small power energy use	Continuous / Scale	Kruskal-Wallis test

4.10.4 Analysis of Objective 4: To explore how small power energy use practices shape the usage of devices and the way that work and other activities are performed in an office environment

Semi-structured interviews were conducted in order to help interpret the quantitative data analysis and give in depth information about how work practices from different types of workers affect small power energy use. NVivo 11 software was used to analyse the semi-structured interviews. The coding themes and nodes were initially based on the four elements of SPT (knowledge, meanings, habits/routines, and technology). Additional themes emerged from discussions within the interview (such as the design of office environment; the style of working) due to their "recurring regularities" (Ryan and Bernard, 2003, p.89). Figure 4-7 below shows a screen print of representative nodes used while a full list of the nodes developed from the coding of semi-structured interviews is given in Appendix H.

The main themes of SPT to support the analysis of interviews according to the elements of energy use practices are as follows (see also Chapter 3):

- Knowledge (considering organisational rules on device usage, theoretical and practical knowledge of electricity usage, as well as understanding of electricity consumption from office devices (e.g. in different modes))
- Meanings (including formality and informality as the reason why some activities are performed in a certain way and their implications on small power energy use)
- Habits/Routines (including activities performed most of the time by office workers)
- Technology/Infrastructure (including devices and equipment provided by the organisation as well as devices used by office workers)

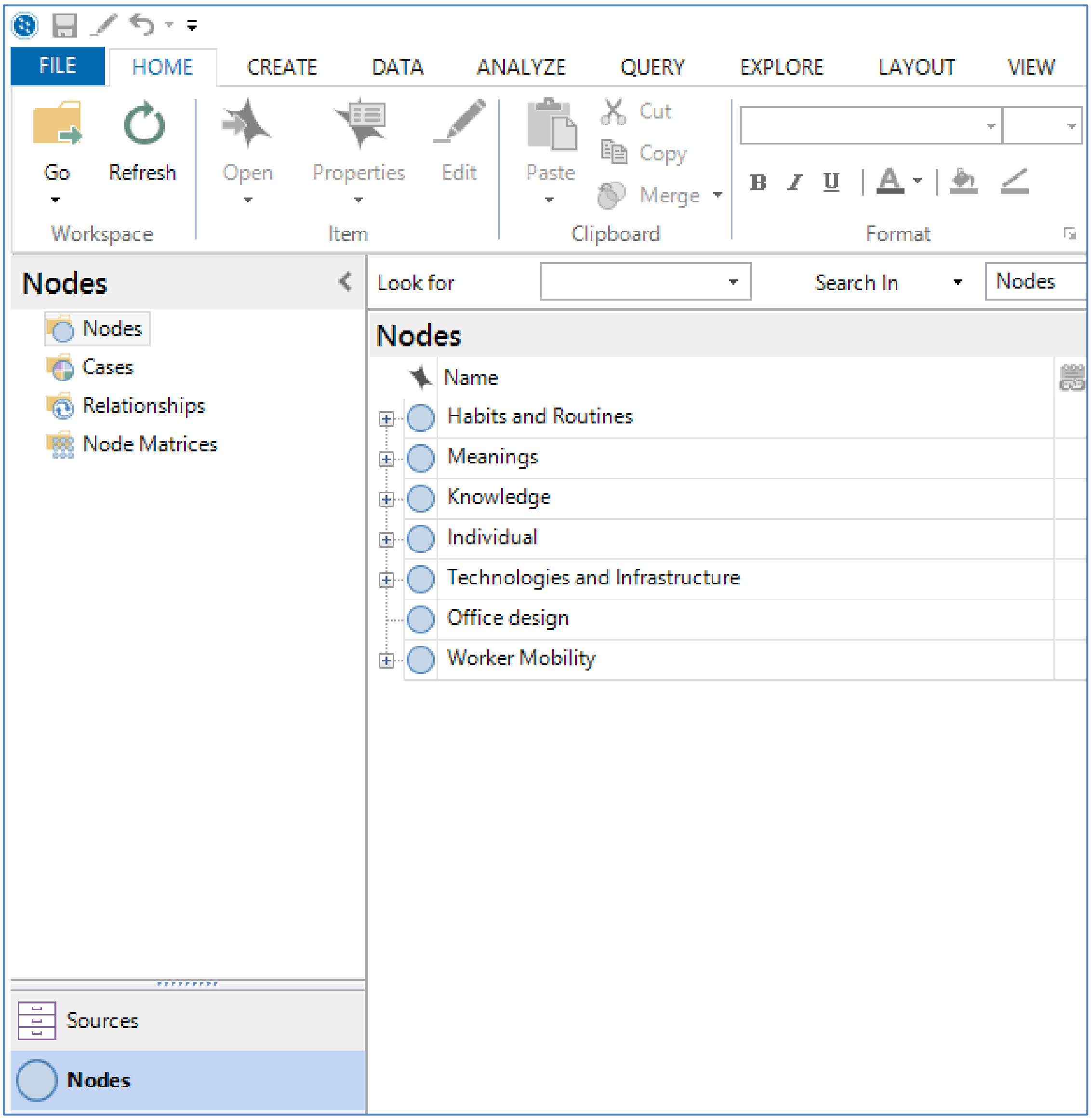

Figure 4-7. Coding themes of semi-structured interviews

4.10.5 Re-classifying the Type of Workers based on Observational Data

Initially four different types of office workers ('mobile', 'mainly-mobile', 'mainly-static', 'static'), with 8 workers in each group were recruited based on their self-identification recorded in the mobility survey (see Section 4.3.1). In order to assess the usefulness of this classification for type of worker, the data from the mobility survey were compared with the observational data, considering the time that workers spent using a single office setting (e.g. workstation) and associated activities. While each type of worker was represented based on the mobility survey, the observational data showed that the number of workers in each category was not consistent with how they classified themselves in the mobility survey. For example, based on the mobility survey there were initially 8 workers from each category of mobility (in total four categories). Workers were self-identified as static (including ‘mainly-static’) and mobile (including ‘mainly-mobile’). The observational data showed a different picture, with only one worker being classified as ‘mobile’ (based on their observed time spent at the workstation and associated activities performed), five workers classified as ‘static’, while ten workers were ‘mainly-mobile’ and sixteen were ‘mainly-static’. Because there was only one ‘mobile’ worker, that worker was included in the ‘mainly-mobile’ classification for analysis. This led to a reclassification of types of workers into three instead of four (from the initial mobility survey): ‘mainly-mobile’, ‘mainly-static’, and ‘static’. This was based on the observational data and the time that workers spent in a single office location (e.g. workstation).

4.11 **Research Ethics**

The present research project along with the data collection processes have been conducted following the guidelines of the University of Reading’s Code of Research Ethics. The School of Construction Management and Engineering Research and Ethics Committee approved the design of this project, the research methods suggested and the procedures for data collection. To comply with the requirements of the Committee, sample information sheets and interview consent forms were submitted for review. Furthermore, detailed information about the processes of gathering and storing data were also provided for review and approval. A copy of all the documents can be found in Appendix E.

The process of engaging participants in the project included a brief description of the aims of the study. An information sheet was provided explaining the purpose of the study prior to interviews along with a consent form to be signed by each participant. Participants had the opportunity to discuss potential questions and any concerns they may have had with the researcher. After conducting the interviews, a transcript of each interview was created and sent to participants who had the opportunity to review it and confirm they were happy with it, or suggest any amendments they felt were necessary.

To protect anonymity and confidentiality all data were anonymised, using a code number instead of a name for each participant, before uploading data into NVivo. All names were changed in order to protect each participant's identity and the identity of the participating host organisations. Direct quotes in the thesis arising from the research were attributed to formal roles instead of individuals or specific company positions. Following the same process, all organisations mentioned during the interview were also anonymised.

Every participant had the right to withdraw from the interview or the observation at any time, without having to explain their reasons or having any kind of penalty, and they were informed of this at the beginning. Any possible risks (life balance and mental health risks) because of an individual's participation in the project were assessed by the School Research Ethics Committee but no direct or indirect effect was identified. The Research Ethics Code protocol was followed for the gathering and storing of the data, protecting confidentiality, anonymity and storage security. All digital data were protected with a password on electronic devices (e.g. laptop computer) and data on paper were securely saved in a locked office and filing cabinet.

Chapter 5: Quantitative Findings on Office Small Power Energy Use

Chapter 4 outlined how a comparative case study approach, which consists of three cases, has been implemented for this study to explore work practices and small power energy usage through a mixed method approach. Although the three cases included different organisations (a Facilities Management company, an Energy company and a Network Infrastructure company), the focus was on anticipated energy intensity and worker mobility – organisation type was not a key criterion for the selection of cases (see Chapter 4 - Sections 4.2 and 4.3). Therefore, the following analysis concentrates on the effect of mobility on small power energy use; any potential effect that different types of organisation may have on small power energy use was outside the scope of this study. This chapter presents the findings of the quantitative analysis of the data obtained. A further analysis of qualitative data, together with a discussion of all results, is presented in Chapter 6 and 7.

Descriptive and statistical analysis has been conducted to show the routines and habits of office workers and the associated device usage. This chapter begins by examining the mobility of office workers based on the data obtained. It continues with the analysis of the overall small power energy usage associated with the different type of office workers at each case office site. This allows the comparison of the electricity usage from office devices within each case and across the cases studied. The chapter continues by associating the mobility of office workers (static and mobile) regardless of case office site with small power energy consumption from activities performed and device usage (focusing on the type and quantity of office device used), showing the effect of activities and device usage on small power energy consumption. The chapter finally considers the effect of office space on working practices and the resulting small power energy consumption. In this section single office spaces (e.g. workstation, kitchen) are considered and small power energy consumption is estimated from work activities and device usage for different types of workers. The chapter ends with a statistical analysis of case level, mobility level and space level data to show the statistical significance of the data.

5.1 Observed Office Worker Mobility

The exploratory comparative case study approach involved three case study office sites of varying (though relatively high) electricity intensity (see Section 4.2.1), each accommodating a range of worker mobility and roles (see Section 4.3.2.1). The recruitment of office workers was based on their self-reporting of their mobility type and work roles through the completion of a mobility survey (see Section 4.3.1). The characteristics of participants in terms of their mobility and role for each case office site are presented in Table 4-3 (see Section 4.3.2.1). In contrast to the mobility survey (which obtained data based on self-identification of participants on the time spent in single office spaces, e.g. at workstation), the observation method (where the researcher obtained data based on observation of work activities and device usage across two working days) was conducted to understand activities performed and device usage by office workers in each case office site. This showed that observed mobility level differs from what was self-reported in the mobility survey. This reclassification of office workers in relation to their mobility level has already been discussed in the previous chapter (see Section 4.10.5) and the detailed differences of worker mobility level between the mobility survey and observational data is presented in Table 5-1 below.

Table 5-1. Differences of mobility level of participants between mobility survey and observational data

Case study office	Mobility survey	Observational data	Participant ID
Case 1 office site <50m^2	Static	Mainly-static	P1
	Static	Mainly-static	P2
	Mainly-static	Mainly-mobile	P3
	Mainly-static	Mainly-mobile	P4
	Static	Mainly-static	P5
	Static	Mainly-static	P6
	Mobile	Mainly-mobile	P7
	Mainly-static	Static	P8
	Static	Mainly-mobile	P9
	Mainly-static	Mainly-static	P10
Case 2 office site 1,000 – 4,999m^2	Mainly-mobile	Mainly-static	P13
	Mainly-static	Mainly-static	P15
	Static	Static	P16
	Mainly-static	Mainly-static	P20
	Mainly-mobile	Static	P22
	Mobile	Mainly-mobile	P23
	Mobile	Mainly-mobile	P24
	Mainly-mobile	Mainly-static	P26
	Mobile	Mainly-mobile	P27
	Mobile	Mainly-mobile	P30
	Mobile	Mainly-mobile	P32
Case 3 office site 5,000+m^2	Mobile	Mainly static	P11
	Static	Static	P12
	Static	Mainly-static	P14
	Mainly-static	Mainly-mobile	P17
	Mainly-mobile	Mainly-static	P18
	Mainly-mobile	Mainly-static	P19
	Mainly-mobile	Mainly-static	P21
	Mainly-static	Static	P25
	Mainly-mobile	Mainly-static	P28
	Mobile	Mainly-static	P29
	Mainly-mobile	Mainly-mobile	P31

The comparison of mobility survey and observational data in terms of worker mobility shows that most workers self-reported their mobility level with a considerable divergence from their observed mobility. It has been acknowledged that "there is a discrepancy between reported answers and observed behaviours" when surveys are conducted (Hong et al., 2017, p.524). On the survey reported here, the participants' perceptions may be based on their standard working practices over a period, while observational data reflected their actual practices for the working days selected (two randomly selected working days per worker across the two months of observations spent in each of the three organisations between September 2018 and April 2019). In this way, for this specific two-day period, the mobility level of workers, the activities they performed, and the small power energy they used may be more precisely correlated than if more general information on mobility was used. This is illustrated in the case of workers who self-reported as ‘mobile workers’ despite observational data showing that only one of them falls within this mobility level (spending time at workstation less than 2 hours) for the working days observed. The observational data also shows that the categories of ‘mainly-mobile’ (spending time at workstation for 2-3 hours) and ‘mainly-static’ (spending time at workstation for 4-6 hours) were important to be included, as most of office workers fall within these categories of mobility level. Given this variation, the observational categories of worker mobility (‘static’, ‘mainly-static’, ‘mainly-mobile’) will be used in the analysis, drawing also on data from the monitoring of office devices and the semi-structured interviews.

5.2 Approach to Analysing Small Power Energy Use In and Across Cases

Reflecting on the relationship between office workers, activities, devices and office spaces discussed earlier (Section 2.7), it is necessary to analyse data in the context of this relationship to understand the nature of work and implications on small power energy consumption. Therefore, the following sections have been structured to present the data at three analytic levels; the case level data, mobility level data and office space level data of work activities, device usage and small power energy use. Figure 5-1 illustrates this analytical approach which is detailed in the following sections.

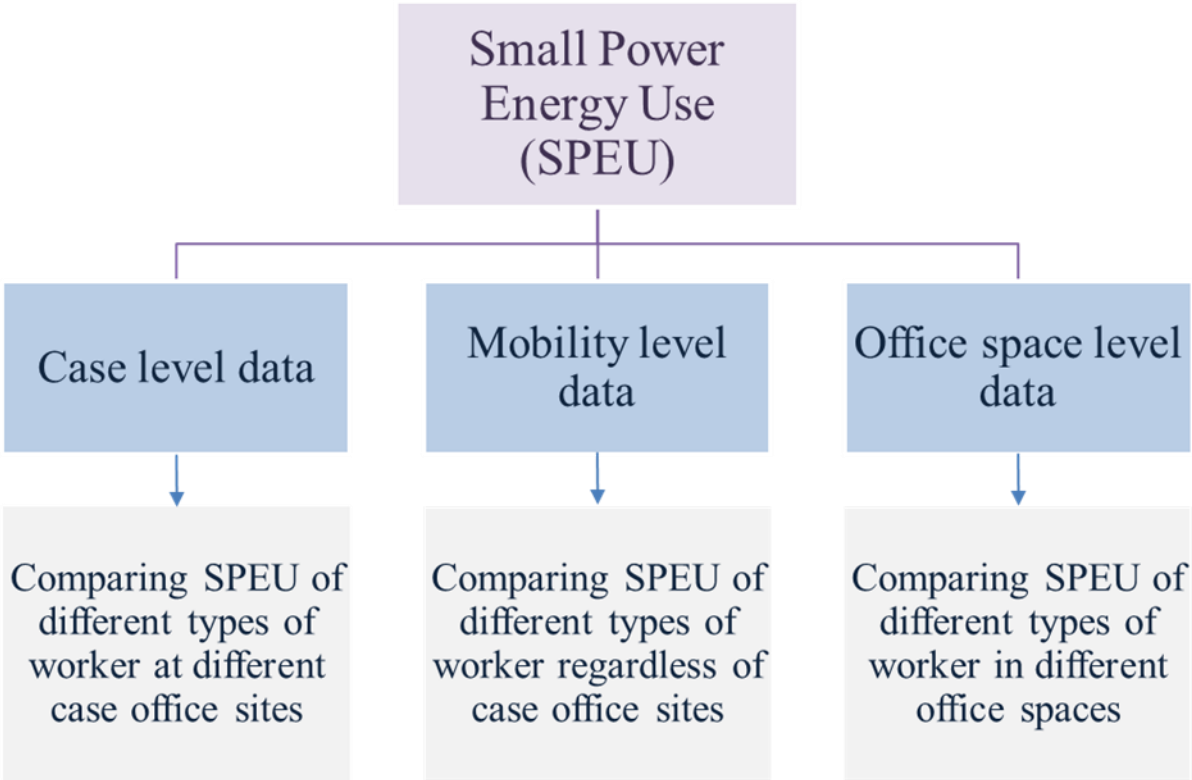

Figure 5-1. Analytical data levels used

At the case level and mobility level, small power energy use is estimated from activities performed by each worker, as well as the specific devices used by each of them. At the office space level small power energy use is considered from the activities of the observed workers using shared devices in the different office spaces. The data analysis (descriptive and statistical analysis) at case level, mobility level, and space level below is based on the mean small power energy usage during the two working days that each worker participated in the study (expressed as mean small power energy use in kWh/worker/working day). As this study is primarily focused on understanding what gives rise to small power energy use (through observed activities and monitored associated device use), monitoring of device electricity use during ‘idle/standby’ mode was not considered in the analysis (e.g. desktop computer on at an empty workstation).

5.3 Case Level Analysis on Small Power Energy Use and Mobility of Office Workers

Work activities in different office spaces (e.g. workstation, meeting room, kitchen) are used as a means to understand work practices in offices and their association with device usage and consequent small power energy consumption. In order to explore variations of work practices associated with small power energy use, the overall small power energy use was associated with different types of worker mobility, the number of devices used, and the number of activities performed at each case office site. Figure 5-2 gives a summary of these variables by case office site.

Figure 5-2 shows variations of small power energy use for the different types of worker mobility (‘static’, ‘mainly-static’, ‘mainly-mobile’, mobile) in each case office site. The data shows that in all office sites (office site <50m^2; office site 1,000-4,999m^2; office site 5,000+m^2), ‘static’ workers and ‘mainly-static’ workers affect small power energy consumption more than ‘mainly-mobile’ workers. The analysis associates small power energy usage per type of worker in each case office site with the number of devices used and the number of work activities performed. ‘Mainly-mobile’ workers perform a relatively higher average number of activities in all case office sites while using a similar average number of devices as the other types of workers (‘static’ and ‘mainly-static’ workers).

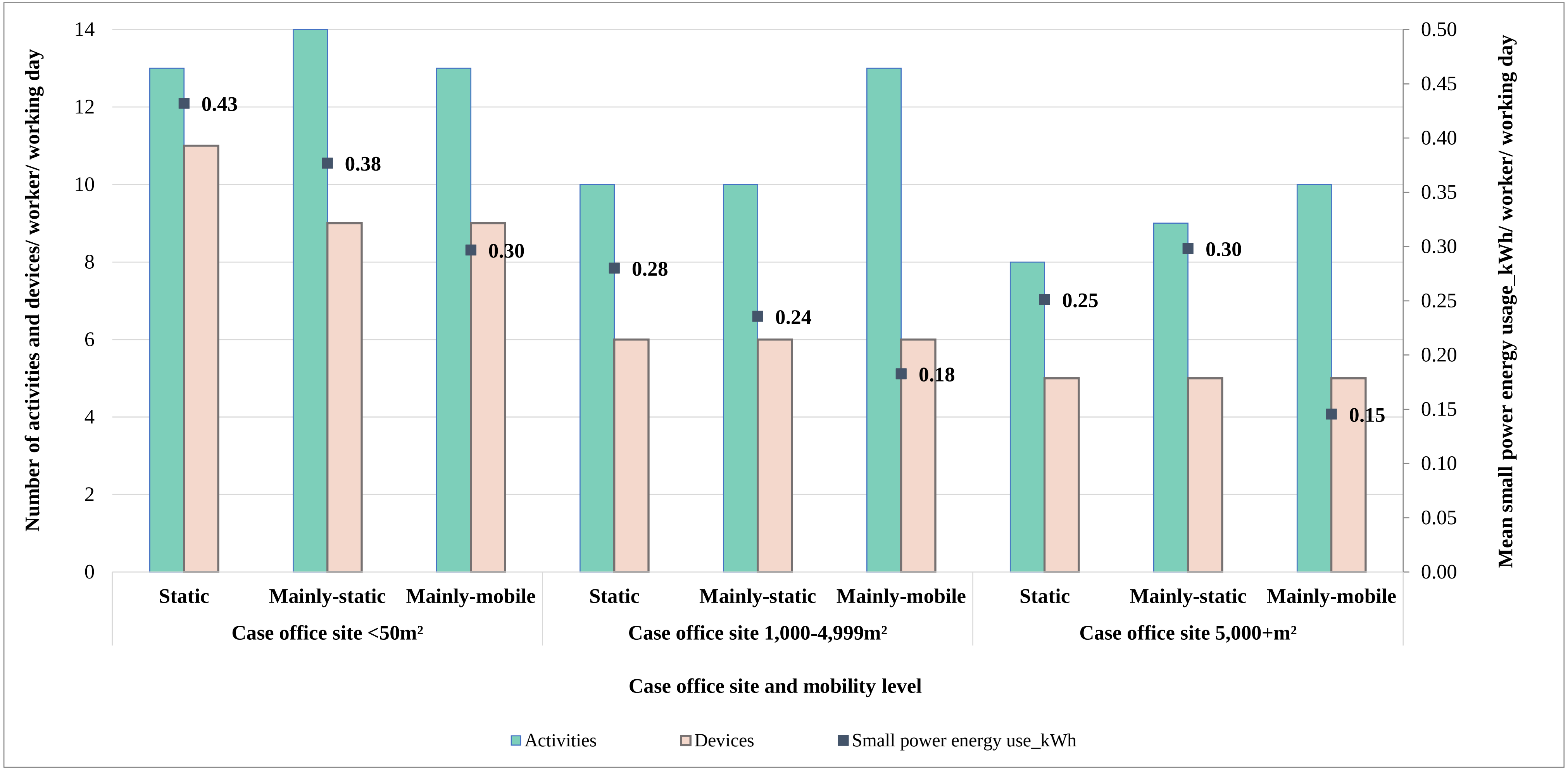

Figure 5-2. Small power energy use from device use per case office site per type of worker

Comparing the different cases used for this study, the analysis shows that there is a variation in the number of activities performed in the working day. Activities varied between an average of 13 (case office site <50m^2) and 9 activities per worker (case office site 5,000+m^2). The case site of 1,000-4,999m^2 had an average of 11 activities per worker. Appendix I gives the detailed number of activities performed per worker for each case office site. With respect to the number of devices used by different types of workers in each office case study, Figure 5-2 shows that the average device usage ranged from 10 devices per worker (case office site <50m^2) to 5 devices per worker (office site 5,000+m^2). Appendix J gives the detailed number of devices used per worker for each case office site.

Having presented the overall small power energy consumption in each case office, the following analysis is mainly focused on small power energy use by different types of worker mobility. Considering the different types of workers and comparing them within each case office site (see Figure 5-2), 'static' and 'mainly-static' workers have the highest small power energy use from activities performed and device used per working day compared to 'mainly-mobile' workers in all case office sites. This higher small power energy usage of 'static' and 'mainly-static' workers compared to 'mainly-mobile' workers may be related to their mobility level (spending more time at workstation and using all available plugged in devices) in comparison with 'mainly-mobile' workers who potentially move regularly and use more portable devices, which are not always plugged, in order to facilitate work in different office spaces.

Data for different types of worker across the three office sites is presented as a percentage of the mean for static workers in the smallest office, which is the group of workers that consumes the highest mean small power energy (0.43 kWh/worker/working day for 'static' workers in case office site <50m^2). Figure 5-3 shows that 'static' workers from the second and third case office sites account for lower 'mean small power energy use', 64% (office site 1,000-4,999m^2)

and 58% (office site 5,000+m^2) respectively, compared to ‘static’ workers of the first case office site (office site <50m^2).

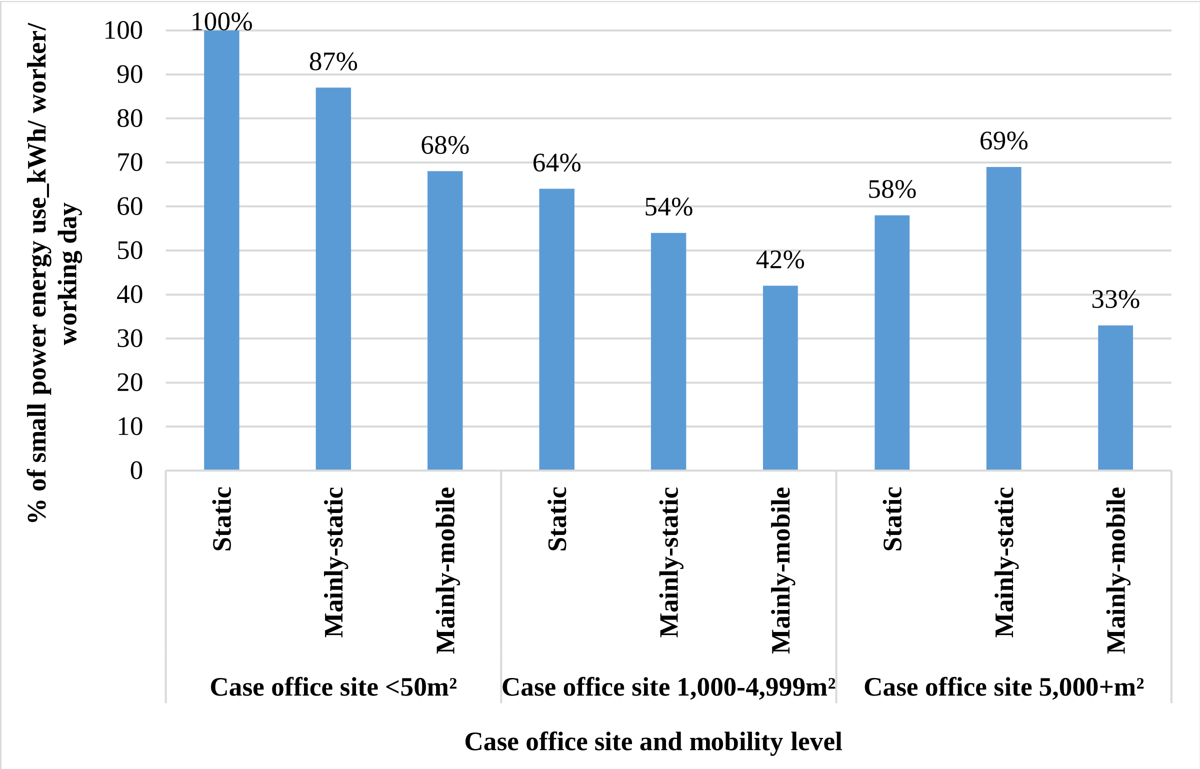

Figure 5-3. Proportion of small power energy use from different types of workers relative to the mean for static workers at the smaller office site

The data above (Figures 5-2 and 5-3) show the considerable difference in small power energy use between the same type of workers in different office sites. This difference in electricity usage from office devices can be related to several factors such as the equipment and devices used by workers in different office sites, the role of these workers and work requirements, as well as the activities and habits of workers. Possible reasons behind the differences in small power energy usage from the same type of workers will be further examined in the following chapter, which will explore the working practices of workers associated with small power energy consumption.

This section covered the comparison of small power energy consumption between the different case office sites. The next section examines the implications on small power energy consumption from the work activities performed and the type and quantity of office devices used for different types of worker mobility, regardless of case office site.

5.4 Mobility Level Analysis: Overall Small Power Energy Use and Worker Mobility type

Mobility level data focuses on the mobility type of workers and the number of activities performed and number of devices used per working day, regardless of case office site. This section presents small power energy usage data associated with the number of activities performed, and small power energy use associated with the number of devices used for different mobility types of office workers. This section also presents the difference between type of worker mobility and the time of the day at which activities were performed, and the devices used. The final part of the section presents the effect of working practices on small power usage.

5.4.1 Mobility Type of Worker and Activities Data

Descriptive analysis was conducted to examine the differences between the different types of office worker mobility and the activities performed. The data is presented in Figure 5-4 which shows that 'mainly-static' workers tend towards the highest small power energy use in different office spaces in comparison with ‘static’ and ‘mainly-mobile’ workers. As an average, ‘mainly-static’ and ‘static’ workers consume similar amount of small power energy (0.30 and 0.31 kWh/worker/working day respectively), while ‘mainly-mobile’ workers consume a lower amount of small power energy (0.22 kWh/worker/working day). This is despite the highest number of activities being performed by ‘mainly-mobile’ workers (average of 13 activities per working day) compared to ‘static’ and ‘mainly-static’ workers (an average of 9 and 11 activities per working day respectively).

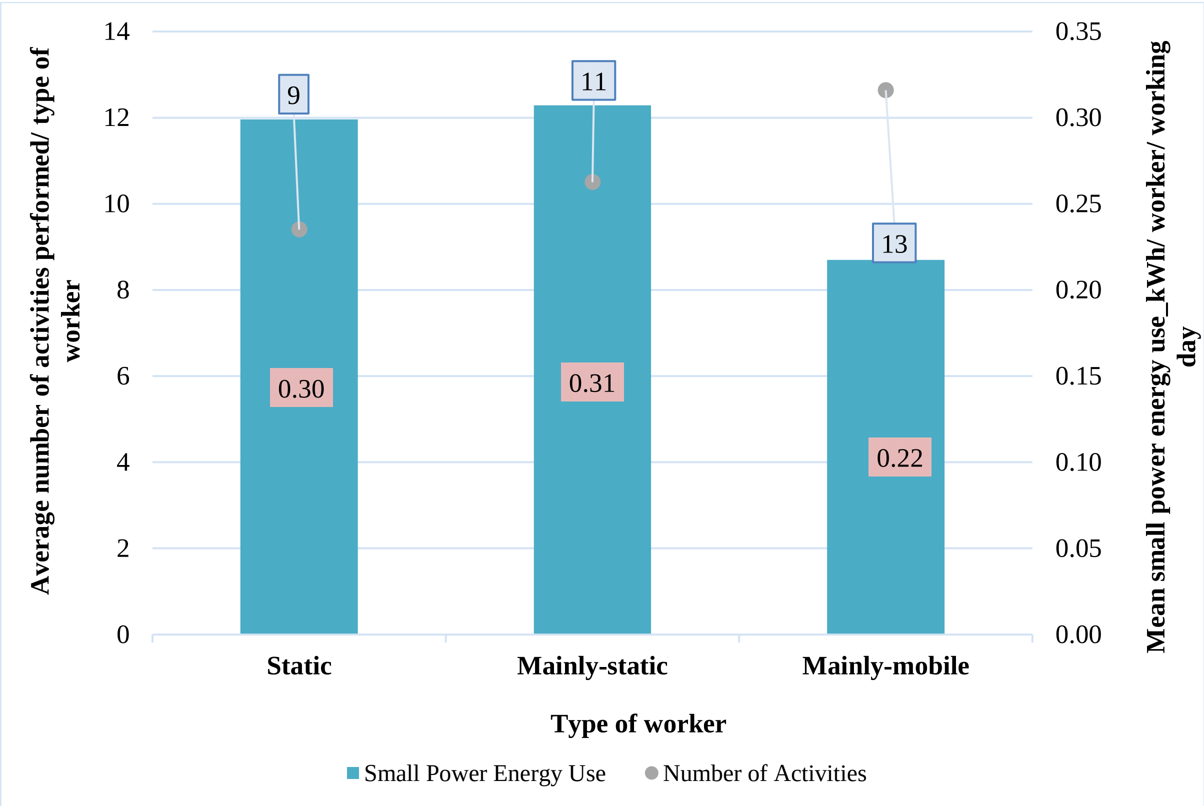

Figure 5-4. Mean small power energy use from work activities per type of worker

Detailed association of mean small power energy usage and number of activities per worker per working day is presented in Figure 5-5 below. The graph shows all activities performed per office worker sorted from lowest to highest number of activities per type of office worker. It also shows that the associated mean small power energy use varies despite the performance of the same number of activities (e.g. worker ‘P8’ and worker ‘P1’ performed 13 activities but their mean small power energy use is 0.43kWh and 0.59kWh respectively). However, despite these workers performing the same number of activities, the types of activities undertaken differ between them (e.g. worker ‘P8’ performed W2, W4, W5, W9, W10, CF1, CF4, CF5, K2, MR4, MR5, O1, O2 while worker ‘P1’ performed W1, W4, W6, W9, W11, CF1, CF5, K1, K2, MR2, MR4, O1, O2 as indicated in Figure 5-5) and this helps explain differences in small power energy use. This variability of small power energy consumption from work activities may be associated with the role of workers, different ways that work activities are completed, and accessibility of different office spaces during a working day. These observations will be further discussed in the next chapter.

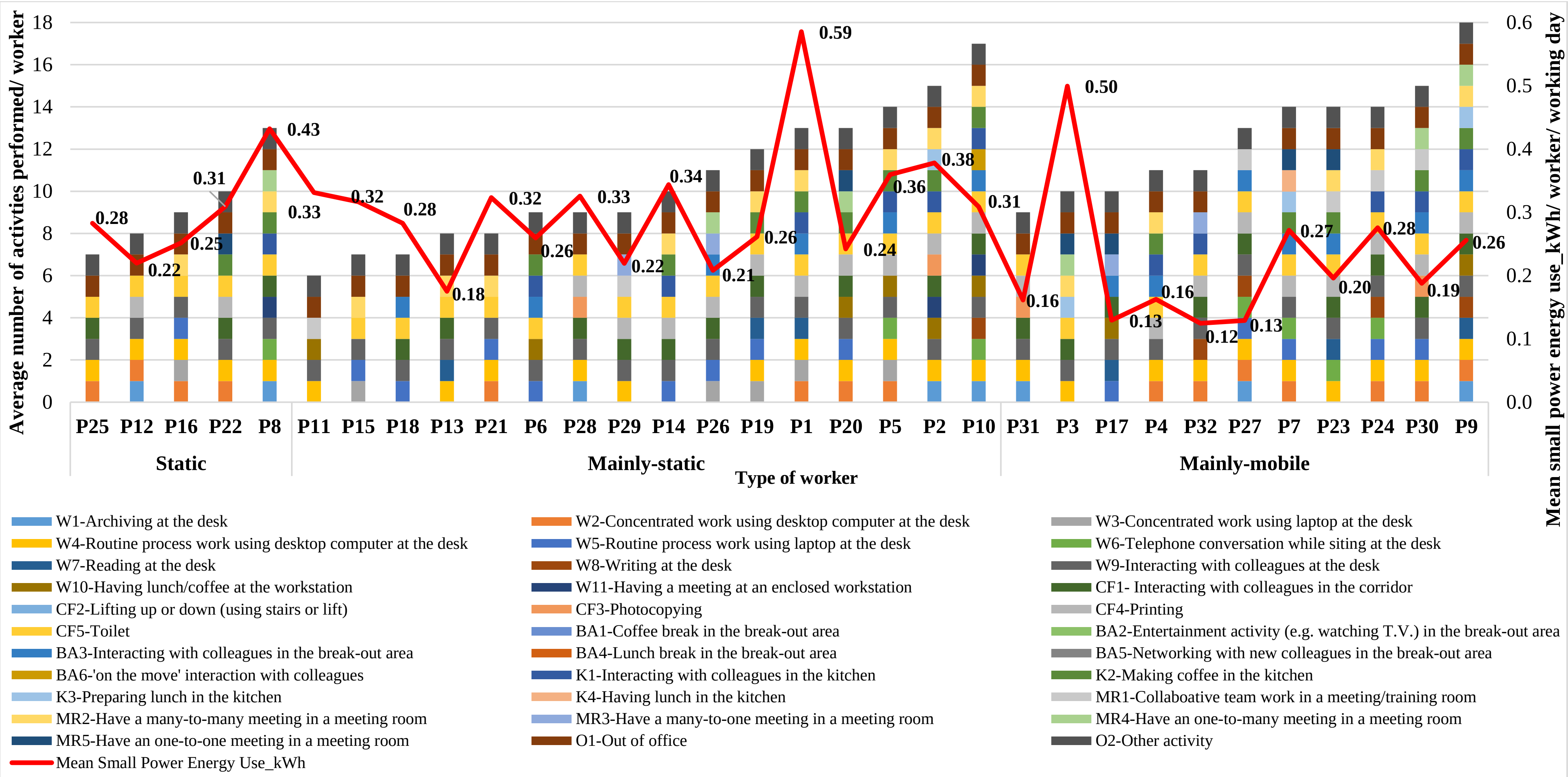

Figure 5-5. Mean small power energy usage and activities performed per worker per working day for different types of workers

5.4.2 Mobility Type of Worker and Devices Data

The analysis of work activities above shows that activities can be performed in different office spaces and involve the use of a range of office devices (e.g. concentrated work using laptop at the desk, printing and so on). This section explores the relationship between device usage and associated small power energy usage by different types of office worker mobility.

Descriptive analysis of small power energy use from device usage per worker was conducted for different mobility level of workers, as presented in Figure 5-6, and shows the type and quantity of devices used per worker and in turn their effect on small power energy use.

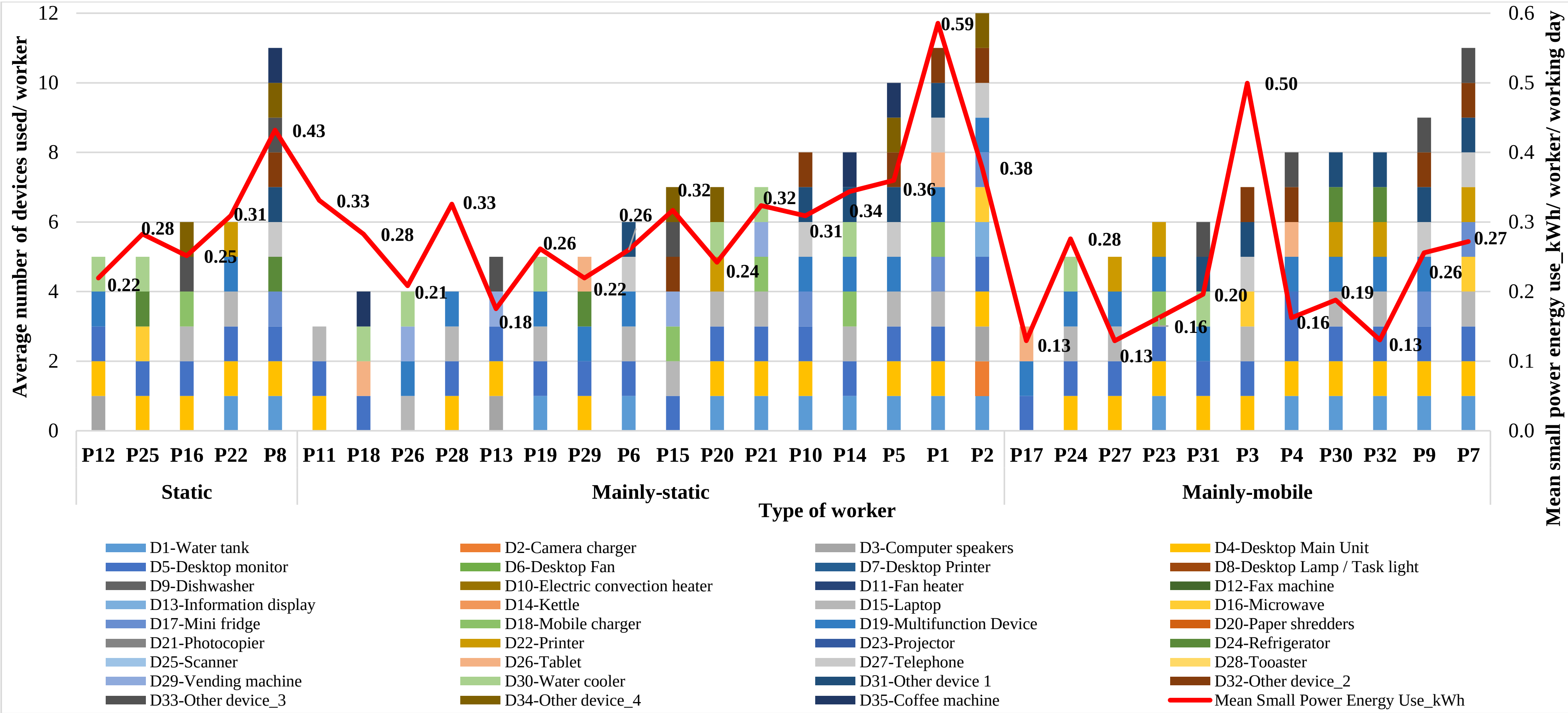

Figure 5-6. Mean small power energy use from office devices[21] used per worker per working day for different types of workers

[21] 'Other Devices' include: Desktop monitor B; Black and white printer B; Refrigerator B; Plot printer; Multifunction Device (MFD) B; Radio speaker; Shared TV screen in meeting room.

With respect to the type and quantity of office devices used, ‘static’ workers used an average of 6.6 devices per working day, similar to ‘mainly-static’ workers, and ‘mainly-mobile’ workers used an average of 6.9 devices per working day. Comparing the number of devices used per worker with associated mean small power energy use, Figure 5-6 shows that despite the usage of the same number of devices (i.e. 11 devices from workers P8, P1, and P7), the small power energy use varies considerably (see workers ‘P8’: 0.43 kWh/working day, ‘P1’: 0.59 kWh/working day, and ‘P7’: 0.27 kWh/working day). This variation in terms of number of devices used and small power energy consumption for different type of office worker mobility may be associated with the business type, role of workers, the task requirements of each office worker and associated device usage, as well as the technological infrastructure provided by the organisation. This is further explored and discussed in the discussion section of the thesis (Chapter 7).

5.4.3 Timing and Type of Worker Mobility Data

Beyond an analysis of the implications of small power energy use by different type of workers from activities and device usage during a working day, the timing of work activities during the day was further considered to examine variation on small power energy consumption. Small power energy use from activities performed and devices used was analysed considering different time periods during a working day such as morning (7am-1pm) and afternoon (1pm-7pm). This analysis was conducted to identify the effect of small power energy use during different periods of a working day by different type of worker mobility.

Figure 5-7 shows higher small power energy consumption from all types of workers during the morning compared to the afternoon. ‘Static’ workers use more energy from office devices in the morning compared to the other types of workers, while ‘mainly-static’ workers affect small power energy usage more in the afternoon in comparison with ‘static’ and ‘mainly-mobile’ workers.

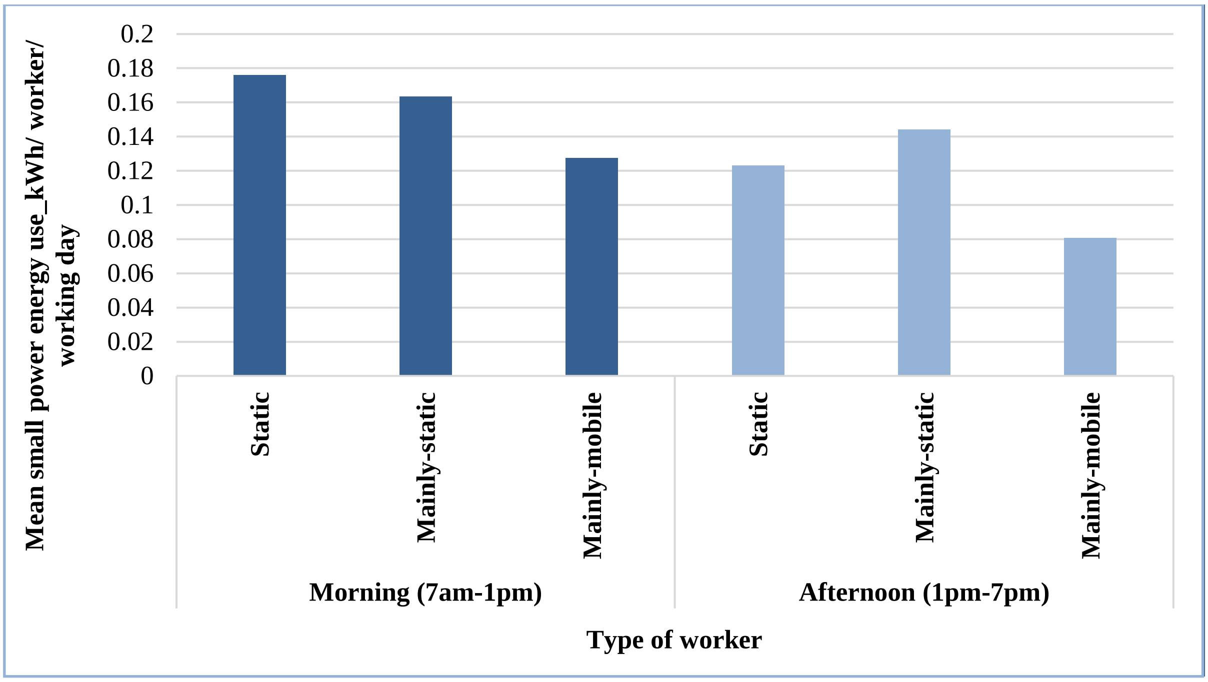

Figure 5-7. Mean small power energy use per worker per working day during morning and afternoon

This variation amongst the different types of workers during the different time periods of a working day may be associated with their work requirements. For instance, ‘mainly-mobile’ workers may interact with colleagues and have meetings throughout a working day compared to ‘static’ and ‘mainly-static’ workers, using portable devices instead of desk-based, plugged in devices. This may be associated with their lower small power energy use in comparison with ‘static’ and ‘mainly-static’ workers, who spend more time at the workstation than ‘mainly-mobile’ workers and use desk-based devices which are plugged in. This variability of small power energy usage by different type of workers over different time periods of a working day will be further discussed in the next chapter.

5.4.4 Working Practices and Associated Small Power Energy Use

Considering the variation in small power energy use during different time periods of a working day by different type of worker mobility, this section details what people are doing in offices, by presenting every activity they performed (as a proxy for working practices) and the associated small power energy use for different types of workers. Activities which were performed by all workers for the majority of the working day were used as a means to support the analysis of working practices. These activities were ‘W4’ (Routine process work using computer desktop at the workstation) and ‘W5’ (Routine process work using laptop at the workstation). The analysis of working practices considers what activities were performed between the start and finish time of activities ‘W4’ or ‘W5’ for different type of worker mobility. The analysis indicates the start time of these activities for each observational day for each worker (observation was conducted for two working days for each worker) and the associated small power energy use.

Figure 5-8 shows the work activities for static workers only, recorded from monitored data (small power energy use from office devices) and observational data (observation of activities performed by office workers) over two working days, designated A and B for each participant (i.e. P8A, P8B, P12A, P12B, etc). The start and finish time of activity ‘W4’ is also shown, as well as the start time of all other activities performed within the duration of activity ‘W4’. Activity ‘W5’ was not performed by ‘static’ workers. The data (Figure 5-8) shows that ‘static’ workers perform most of their working activities during the morning time (until midday) while small power energy use from activity ‘W4’ ranges between 0.2 and 0.4 kWh/working day.

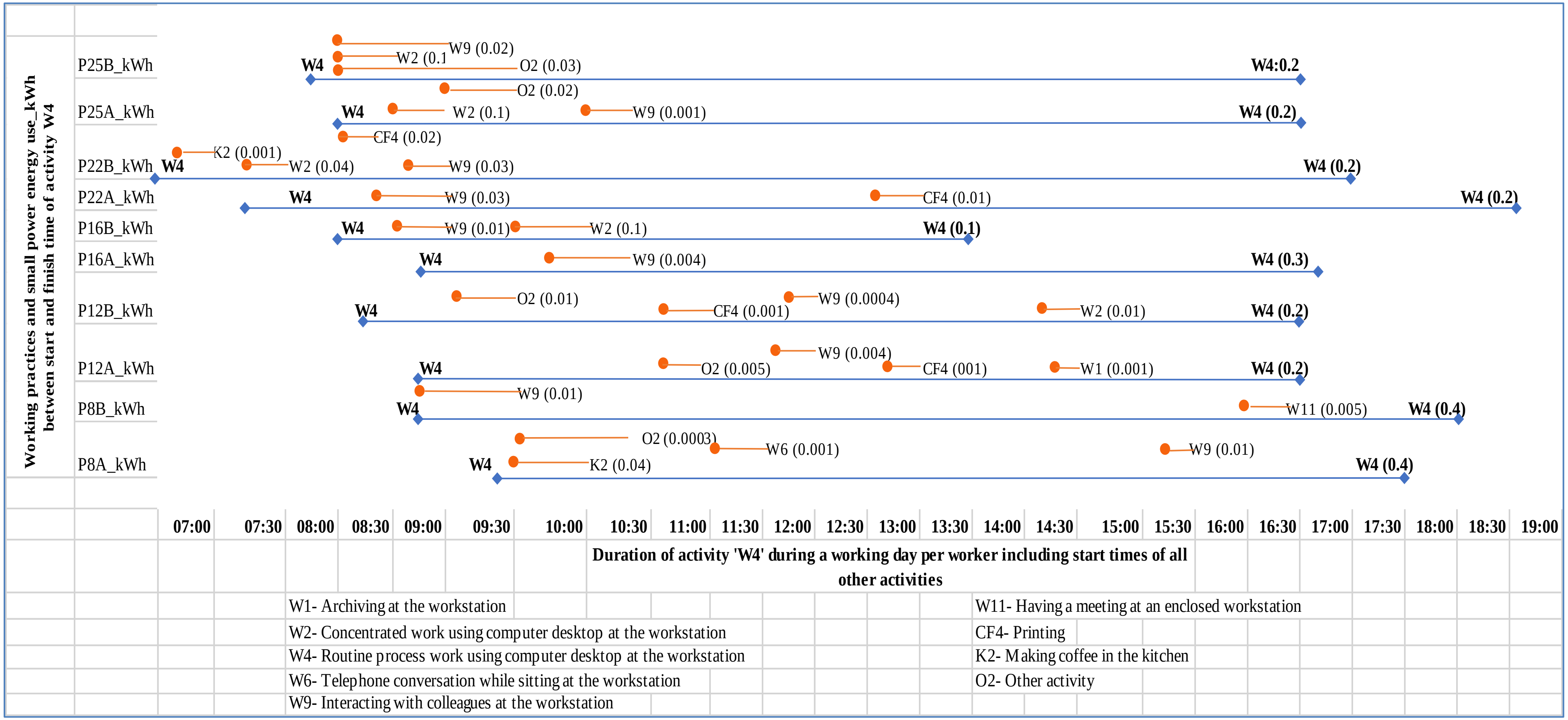

Figure 5-8. Working practices and small power energy use (kWh) per 'static' worker per working day (observation A and B) between start and finish time of activity 'W4'

With respect to working practices of ‘mainly-static’ workers (see Figure 5-9), considering activities performed within the duration of activity ‘W4’ or ‘W5’, their performance is more distributed across a working day compared to ‘static’ workers (see Figure 5-8). Also, small power energy use from activities ‘W4’ or ‘W5’ varies considerably, with a greater range (0.1 kWh to 0.4 kWh per working day) compared to ‘static’ workers.

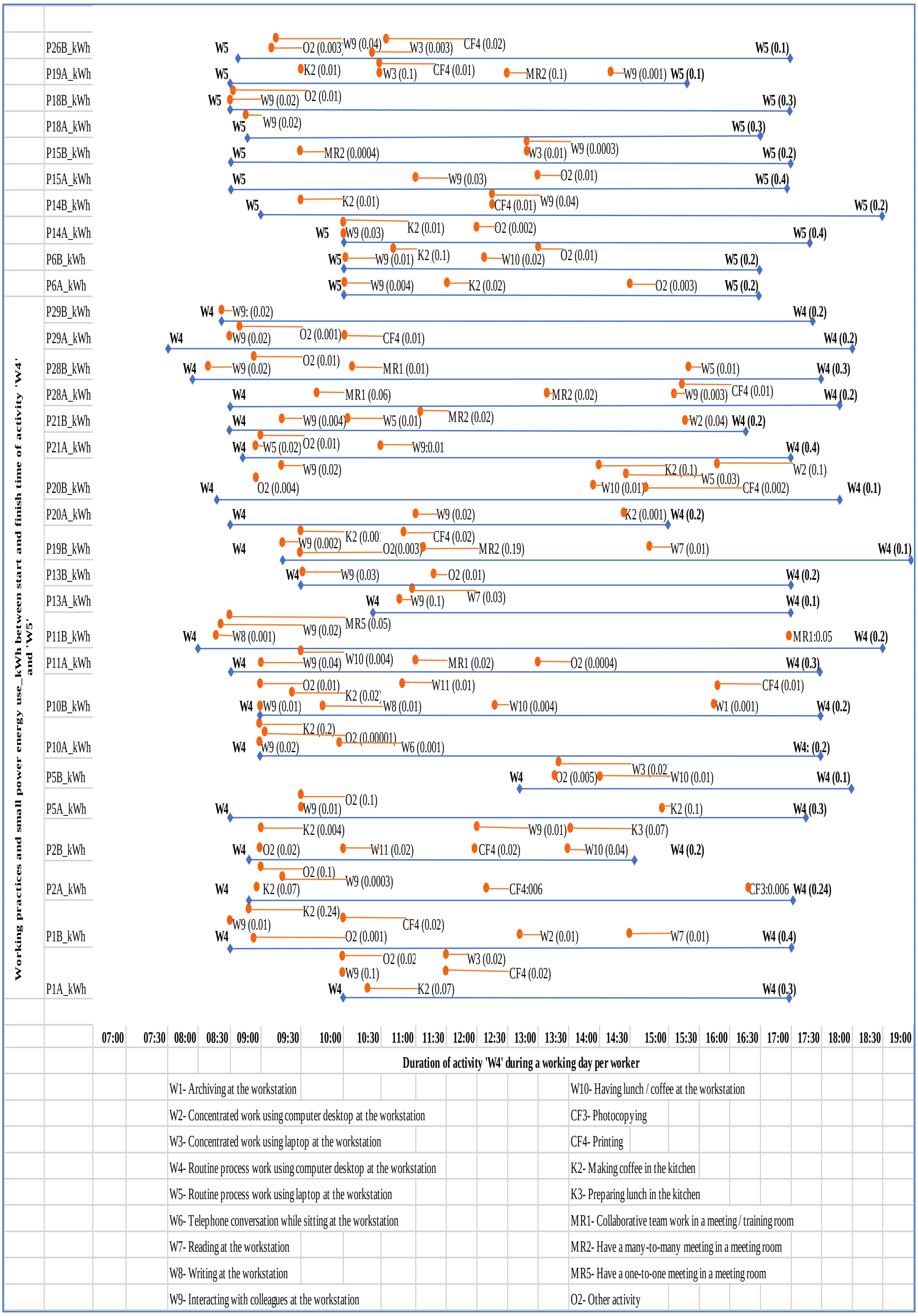

Figure 5-9. Working practices and small power energy use (kWh) per 'mainly-static' worker per working day (observation A and B) between start and finish time of activity 'W4' or 'W5'

Observing the working practices of ‘mainly-mobile’ workers, the data show that activities are even more distributed over a working day compared to ‘static’ and ‘mainly-static’ workers (see Figure 5-10). Also, data show differences between activities performed in the first observation and the second observation (e.g. participant 3 and participant 4) as well as small power energy used for each activity. The variation of small power energy use from activities ‘W4’ and ‘W5’ as great for ‘mainly-mobile’ workers as for ‘mainly-static’ workers in comparison with ‘static’ workers, ranging between 0.01 and 0.3 kWh per working day.

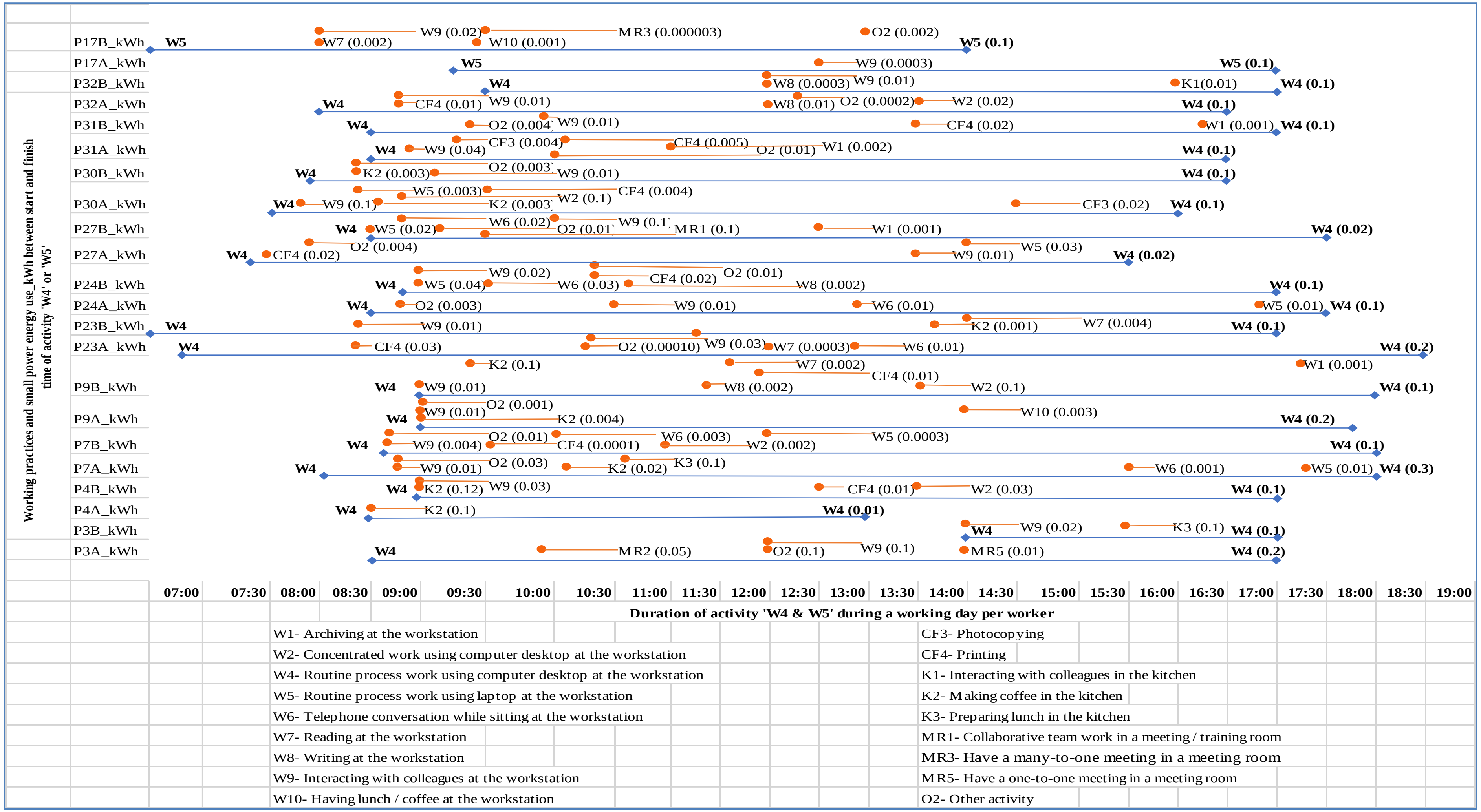

Figure 5-10. Working practices and small power energy use (kWh) per ‘mainly- mobile’ worker per working day (observation A and B) between start and finish time of activity ‘W4’ or ‘W5’

In addition, the temporal distribution (between mornings and afternoons) of working practices for ‘mainly-mobile’ workers is observed to be greater compared to ‘mainly-static’ and ‘static’ workers. Observing temporal distribution of working practices considering mornings (between 7am and 1pm) for ‘mainly-mobile’ workers, Figure 5-10 shows that they perform more activities and different activities in comparison with the distribution of activities during afternoons (from 1pm to 7pm). This increased mobility of ‘mainly-mobile’ workers during mornings, using different office spaces other than desk and different devices other than desk-based devices can have different implications on small power energy use. This may explain why ‘static’ and ‘mainly-static’ workers consume relatively more small power energy from activities ‘W4’ and ‘W5’ compared to ‘mainly-mobile’ workers.

Comparing working practices for different types of worker, the data analysis above shows variations on small power energy use due to different number and type of activities performed, the duration of activities and their distribution throughout a working day, and associated device used. Working practices shown through activities performed for different type of office workers with implications on small power energy use are further explored and discussed in the next chapter.

5.5 Office Space Level Analysis: Overall Small Power Energy Use and Type of Worker Mobility

The following analysis is focused on office space level data which refers to total small power energy use in single office spaces and examines activities performed by different levels of worker mobility in different office spaces (for example, activities carried out at workstations, kitchen, meeting room, common function area and break-out area).

Figure 5-11 presents small power energy consumption per working day in office spaces used by different type of office workers. The data shows that ‘static’ workers consume more small power energy at their workstation than the other types of workers (‘mainly-static’ and ‘mainly-mobile’ workers) but use less small power energy in the kitchen, meeting rooms and common function areas compared to ‘mainly static’ and ‘mainly-mobile’ workers. This is in line with the expectation that static workers would perform a higher number of activities at their workstation in comparison with ‘mainly-static’ and ‘mainly-mobile’ workers who were expected to access also other office spaces such as meeting rooms and break-out area due to their mobility level (spending time at workstation 4 hours or less).

Although ‘mainly-static’ workers spend less time compared to ‘static’ workers at the workstation (6 hours for ‘static’ workers and 4 hours or less for ‘mainly-static’ workers), they use similar amount of small power energy. Figure 5-11 shows the considerable difference of small power energy use at the workstation of both ‘static’ (0.28 kWh/worker/working day) and ‘mainly-static’ workers (0.25 kWh/worker/working day) compared to ‘mainly-mobile’ workers (0.15 kWh/worker/working day). Details of activities that are performed at workstations are shown in Appendix K.

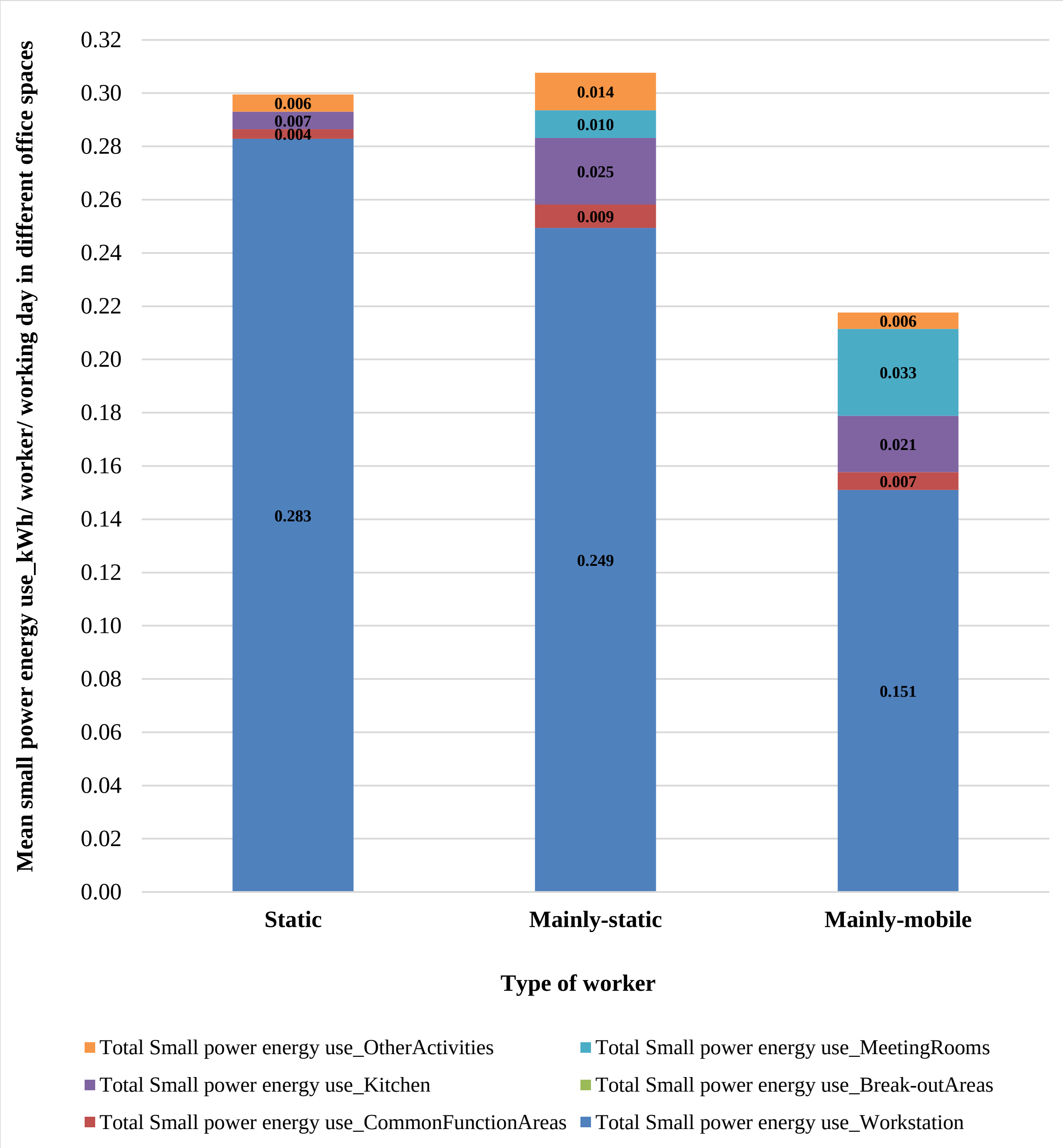

Figure 5-11. Average small power energy consumption from activities in different office spaces from different type of workers

Similarly, the average small power energy consumption in the kitchen shows variation between the different types of workers. 'Mainly-static' and 'mainly-mobile' workers are shown to consume more small power energy compared to 'static' workers (0.007 kWh/worker/working day for 'static' workers; 0.021 kWh/worker/working day and 0.025 kWh/worker/working day for 'mainly-mobile' and 'mainly-static' workers respectively). This variation is common across the different case office sites despite the different type and quantity of kitchen appliances used.

The average usage of devices at the workstation (average use of three devices per working day) and in the kitchen (average use of one kitchen appliance per working day) is shown in Appendix L and Appendix M. Despite the variation of small power energy usage between the different type of workers in different office spaces, the average usage of office devices at the workstation and in the kitchen does not show significant differences between the different types of workers. This may be associated with the type of devices used by different types of workers.

The use of different office spaces and associated small power energy consumption by different type of workers is further explored and discussed in the next chapter. While the previous sections present a descriptive analysis of data in relation to small power energy consumption for the different types of worker mobility, the following section presents the statistical analysis of the above data which was conducted to identify the significance of these results.

5.6 Statistical Analyses of Small Power Energy Use

In order to identify which data are statistically significant, and which results should be considered and discussed in detail, extensive statistical analysis was conducted. This section presents the statistical tests and techniques that were used and how they were analysed. The analysis was conducted considering:

- the case level data on small power energy use by different types of workers,

- the mobility level data for different types of worker and implications on small power energy consumption,
- the space level data and associated electricity consumption from office devices in different office spaces.

5.6.1 Significance of Case Level Data on Small Power Energy Use

Case level data, which involves aggregated data of total mean small power energy consumption (out of two working days) from observational data of activities performed and monitored data from devices used for each case office site and different types of workers, were analysed to identify statistically significant results. Initially, a test of normality has been conducted to identify to what extent the sample (the number of workers participating in each case office site) is normally distributed in order to select appropriate statistical tests. The next step in the statistical analysis involves a comparison of the averages of small power energy use per working day (mean small power energy usage out of two observational working days per worker) within each case office site and across the cases.

5.6.1.1 Sample Characteristics for Case Level Data

In order to decide whether a parametric or non-parametric tests are the most appropriate to compare the mobility of workers and their associated small power energy use across the different case office sites, the first step is to identify if the data for the independent variable (case office sites) is normally distributed. Therefore, a Shapiro-Wilk test ($p > .05$) of normality (Shapiro and Wilk, 1965; Razali and Wah, 2011) was conducted. Histograms, normal Q-Q plots, and box plots were checked to identify the normality of case level data across three different case office sites (case office site <50m^2 with 10 participants; case office site 1,000-4,999m^2 with 11 participants; 5,000m^2 with 11 participants).

The statistical results show that small power energy usage across the different case office sites was normally distributed, despite the small sample size (n=32). The results of the normality test related to significance (p value) as well as results on degrees of freedom (the number of independent values that can vary in an analysis without breaking any constraints), skewness and kurtosis (normally distributed data identified by resulted z-values which are in the span of -1.96 to +1.96) are presented in Table 5-2 below.

Table 5-2. Results of Shapiro-Wilk test

Case office sites	p value	Standard Error (SE)	Skewness (z-value)	Kurtosis (z-value)	Degrees of freedom (DF)
< 50m^2 (n=10)	.857	.0402	0.747	-0.137	10
1,000 – 4,999m^2 (n=11)	.670	.0197	0.074	-0.792	11
5,000+m^2 (n=11)	.260	.0216	-1.049	-0.469	11

Table 5-2 shows that the null hypothesis (Ho) for the test of normality related to 'case level' data is not rejected because p-values (significance level) are not below 0.05. Therefore, the data is normally distributed and lead to the selection of a parametric statistical test to compare averages of small power energy use across different case office sites from different type of workers as discussed below.

5.6.1.2 Statistical analysis of Case Level Data on Small Power Energy Use

Considering the results of the normality test (Shapiro-Wilk test) above which show that the data is normally distributed across the case office sites, a parametric test was conducted to compare averages of small power energy use as independent factors with two dependent factors: i) different types of workers and ii) different case office sites. The Factorial ANOVA test is a commonly used statistical test for the analysis of variance (i.e. differences in the means between two or more groups), testing both main effects and the interaction effect of sample sizes ('static' workers=5; 'mainly-static' workers=16; 'mainly-mobile' workers=11) (Howell and McConaughy, 1982; Keppel, 1982). The results of the Factorial ANOVA statistical test identify the following:

- A Levene's test for equality / homogeneity of variance was conducted to assess the null hypothesis (Ho) that the variance is equal between the independent variable groups (a p value less than 0.05 indicates a violation of the assumption). The result is not statistically significant at the 0.05 level (p value=0.375). Therefore, the null hypothesis is not rejected, and we may assume that there is a statistically significant difference in the variances between the groups (i.e. different case office sites and different type of workers).
- The null hypothesis (Ho) that there is no difference between mean small power energy use across different case office sites is rejected because: i) the mean difference between case office site <50m^2 and case office site 1,000 – 4,999m^2 features a p value=0.005;

and ii) the mean difference between case office site <50m^2 and case office site 5,000+m^2 features a p value=0.006. The statistically significant results are evidence that case office site <50m^2 consumes more small power energy (mean: 0.370) in comparison with case office site 1,000 – 4,999m^2 (mean: 0.233) and case office site 5,000+m^2 (mean: 0.232).

- The null hypothesis (Ho) that there is no difference between small power energy use for different type of workers across the different case office sites is rejected because: i) the mean difference between 'mainly-mobile' workers and 'static' workers features a p value=0.029; ii) the mean difference between 'mainly-mobile' workers and 'mainly-static' workers features a p value=0.012. The statistically significant results are evidence that 'static' workers consume more small power energy (mean: 0.322) in comparison with 'mainly-static' workers (mean: 0.304) and 'mainly-mobile' workers (mean: 0.209).
- The pairwise comparison of the test between the case office sites and types of workers shows that there is mean difference which is statistically significant at the 0.05 level between 'mainly-static' workers and 'mainly-mobile' workers at the case office site 5,000+m^2 (p value=0.035). The statistically significant results are evidence that 'mainly-static' (mean: 0.298) consume more small power energy in comparison with 'mainly-mobile' (mean: 0.146) at the case office site 5,000+m^2. Additional results of pairwise comparisons between the case office sites and different types of workers which are not statistically significant are appended (Appendix N).

The statistical results generated by the analysis of case level data for different case office sites and types of workers (see summary Table 5-3) will be discussed in Chapter 7 - Discussion. This discussion aims to explore potential reasons why differences between mean small power energy usage occur for the different case office sites and type of workers in each case office site.

5.6.2 Significance of Mobility Level Data on Small Power Energy Use

Mobility level data, which involves total consumption and per activity consumption of the average small power energy (out of two working days) from observational data of activities performed, and monitored data from associated devices used for different type of worker mobility regardless of case, were analysed to identify statistically significant results. Mobility data explores averages of small power energy use out of two working days for each worker but also averages of small power energy consumption during different periods of a working day, i.e. morning and evening device electricity usage.

In order to test potential differences in the means of small power energy use for the different types of worker mobility (‘static’, ‘mainly-static’ and ‘mainly-mobile’), a one-way ANOVA was conducted. To run the one-way ANOVA, an assumption of equal variances in the comparison groups needed to be met. The Levene’s test for the homogeneity of variances examines this assumption, testing the null hypothesis (Ho) that the variance of the variables is equal across the comparison groups. If the probability is higher than the 0.05 level, the Ho is not rejected, indicating that the assumption of the equality of variances is met and ANOVA can be conducted. The Levene’s test was not statistically significant (p= 0.239), meaning that the assumption was met and the parametric test could run with the purpose to examine if there are statistically significant differences in small power energy use across the different types of worker. The ANOVA conducted did not reveal statistically significant results, $F_{(2, 29)}$=2.93 and p=0.069, indicating a trend that could be evidence of a difference in small power energy consumption between ‘static’ (mean= 0.29), ‘mainly-static’ (mean= 0.307) and ‘mainly-mobile’ (mean= 0.217) workers.

Taking into consideration the difference in the sample size in each group (‘static’ (n=5); ‘mainly-static’ (n=16); ‘mainly-mobile’ (n=11)), which was not normally distributed, and the trend identified by the ANOVA, a non-parametric alternative to the one-way ANOVA – the Kruskal-Wallis test (Field, 2013) – was conducted. This non-parametric test compared one independent variable with two or more independent groups (different type of worker mobility) and several dependent variables (total means of small power energy use from all activities performed and associated devices used per worker) to determine if there are statistically significant differences between the groups (Field, 2013).

The results of Kruskal-Wallis test, as a non-parametric test which is used when the sample sizes are not equal, show evidence of statistically significance between the groups (total consumption per worker from all activities performed and associated devices used: Chi-Square= 8.109, df=2, p value=0.017 with mean rank for ‘static’=19.00, ‘mainly-static’=20.19, ‘mainly-mobile’=10.00). Therefore, the test rejects the null hypotheses (Ho) of no difference between mean rank of total small power energy use (from all activities performed and associated devices used) between groups. Measuring the effect size estimate of groups (dividing the value of chi-square (8.109) by n-1 (n=32)), the result shows that 26% of the variability in mean rank results is accounted for by group.

The Kruskal-Wallis test has been expanded to identify which pairs of worker mobility (i.e. ‘static’ and ‘mainly-static’; ‘static’ and ‘mainly-mobile’; ‘mainly-static’ and ‘mainly-mobile’) show evidence of statistically significant results. The analysis shows that the grouping variable between ‘mainly-static’ and ‘mainly-mobile’ workers (Chi-Square=7.366, df=1, p value=0.007) is statistically significant above 0.05 level. This comparison shows that 'mainly-static' workers consume more small power energy (mean rank=17.44) in relation to 'mainly-mobile' workers (mean rank=9.00), considering only mobility of workers, regardless of case office sites.

The data on small power energy usage from each activity performed and associated device used (multiple dependent variables) for different types of workers (independent groups) regardless of case office site were also considered. Similarly to the previous analysis on total activity consumption (described above), a parametric test was conducted for the analysis of variance in order to test potential differences in the means of small power energy use for the different types of workers ('static', 'mainly-static' and 'mainly-mobile') and different activities performed.

With respect to the parametric test, a one-way MANOVA, which compares one independent variable with two or more independent groups (different type of worker mobility) and multiple dependent variables (means of small power energy use from each activity performed and associated devices used), was used to compare the variance in the group means within the sample (Field, 2013). The results of the one-way MANOVA test includes the homogeneity of variance test – Levene's test – which examines the null hypothesis (Ho) that the variance is equal across the independent variable groups (a p value less than 0.05 indicates a violation of the assumption). The Levene's test showed statistically significant results for most activities[22], indicating that the assumption for the homogeneity of variance was not met. Consequently, this

[22] Activities with statistically significant results for different types of workers consist of the following: i) Concentrating work using desktop computer at the desk – In use devices (p value=0.001); ii) Routine process work using laptop at the desk – In use devices (p value=0.001); iii) Telephone conversation while sitting at the desk – In Use devices (p value=0.000); iv) Preparing lunch in the kitchen (p value=0.027); v) Photocopying (p value=0.032); vi) Collaborative team work in a meeting/training room (p value=0.042).

led to the consideration of a non-parametric equivalent statistical test for the analysis of variance, i.e. Kruskal-Wallis test (>2 categories) (Field, 2013; Ali and Bhaskar, 2016).

The Kruskal-Wallis test has been used to determine if there are statistically significant differences between three different types of workers (as one independent variable with two or more independent groups) considering the means of their small power energy use from each activity performed and associated device used (as dependent variables). The results of the statistical analysis show that the null hypothesis (Ho) – i.e. all activities performed have the same small power energy use for the different type of worker mobility – is rejected. This is because small power energy usage of at least one activity e.g. 'Telephone conversation while sitting at the desk _ In Use devices' (Chi-Square=8.408, df=2, p value=0.015) is statistically significant above 0.05 level for the different types of worker mobility (with 'mainly-mobile' (mean rank=20.32) to consume more small power energy compared to 'static' and 'mainly-static' workers (mean rank=14.50 for both types of worker)).

The Kruskal-Wallis test was expanded to identify which pairs of worker mobility (i.e. 'static' and 'mainly-static'; 'static' and 'mainly-mobile'; 'mainly-static' and 'mainly-mobile') show evidence of statistically significant results. The analysis indicates the following:

- Comparing the variables of 'static' and 'mainly-static' workers, the differences between averages of small power energy use was statistically significant ($p < 0.05$) for activities 'Concentrated work using desktop computer at the desk _ In Use devices' (Chi-Square=5.143, df=1, p value=0.023) and 'Routine process work using laptop at the desk _ In Use devices' (Chi-Square=4.239, df=1, p value=0.04). With respect to the former activity, 'static' workers (mean rank=15.80) consume more small power energy compared to the 'mainly-static' workers (mean rank=9.50) while 'mainly-static' workers (mean rank=12.41) consume more small power energy compared to the 'static' workers (mean rank=6.50) for the latter activity.

- Comparing the variables of 'static' and 'mainly-mobile' workers, the differences between the average of small power energy use for activity 'Routine process work using desktop computer at the desk _ In Use devices' (Chi-Square=7.088, df=1, p value: 0.008) is statistically significant ($p < 0.05$), with 'static' workers (mean rank=13.20) to consume more small power energy compared to 'mainly-mobile' workers (mean rank=6.36).
- Comparing the variables of 'mainly-static' and 'mainly-mobile' workers, the differences between averages of small power energy use for activities 'Concentrated work using laptop at the desk _ In Use devices' (Chi-Square=4.009, df=1, p value=0.045) and 'Telephone conversation while sitting at the desk _ In Use devices' (Chi-Square=6.525, df=1, p value=0.011) are statistically significant ($p < 0.05$). With respect to the former activity, 'mainly-static' workers (mean rank=15.72) consume more small power energy compared to the 'mainly-mobile' workers (mean rank=11.50) while 'mainly-mobile' workers (mean rank=16.91) consume more small power energy compared to the 'mainly-static' workers (mean rank=12.00) for the latter activity.

Disaggregating the mobility level data (mean small power energy use over two working days) was based on the timing at which work activities are performed during a working day. Instead of relatively high time-frequency disaggregation of data (e.g. hourly data analysis of small power energy use), which may not provide any meaningful differences between mean small power energy use and different types of worker mobility, small power energy use between morning and afternoon was considered. This analysis was conducted to identify whether there are statistically significant differences between the groups (i.e. types of workers), comparing their mean small power energy use for different periods of a working day (i.e. aggregated data of mean small power energy use between morning: 7am-1pm and afternoon 1pm-7pm).

To identify the homogeneity of variance (i.e. if there are equal variances) across the independent comparison groups (i.e. different types of workers), a one-way MANOVA was conducted (due to multiple dependent variables, i.e. means of small power energy use from activities performed). The results of Levene's test, included in the one-way MANOVA, are not statistically significant (p value <0.05) for small power energy use in the morning (p value=0.280) and in the afternoon (p value=0.266). Therefore, the null hypothesis (Ho) that the variance is equal across groups is rejected and we assume that there is a difference in the variances of the variables. With respect to the comparison between mean small power energy use in the morning and in the afternoon and different types of worker mobility, the results of the one-way MANOVA show evidence that the comparison between 'mainly-static' and 'mainly-mobile' workers is statistically significant in the afternoon energy consumption from office devices (p value=0.020). This comparison shows that 'mainly-static' workers consume more small power energy in the afternoon in comparison with 'mainly-mobile' workers (mean difference=0.44).

An equivalent non-parametric test (Kruskal-Wallis test) was also conducted to test the null hypothesis (Ho) that there is no difference between morning and afternoon small power energy use for different types of workers. The results of Kruskal-Wallis test show that the null hypothesis (Ho) is rejected because there is evidence of small power energy consumption in the morning (Chi-Square=5.997, df=2, p value=0.050) and in the afternoon (Chi-Square=8.192, df=2, p value=0.017) being statistically significant for the different type of worker mobility ('static', 'mainly-static' and 'mainly-mobile'). The Kruskal-Wallis test has been expanded to identify which pairs of worker mobility (i.e. 'static' and 'mainly-static'; 'static' and 'mainly-mobile'; 'mainly-static' and 'mainly-mobile') show evidence of statistically significant results. The analysis shows evidence that the comparison of variables between 'static' and 'mainly-mobile' workers is statistically significant for small power energy use in the morning (Chi-Square=4.393, df=1, p value=0.036). This comparison shows that 'static' workers (mean rank=12.20) consume more small power energy in the morning compared to 'mainly-mobile' workers (mean rank=6.82). The comparison of variables between 'mainly-static' and 'mainly-mobile' shows also statistically significant results for small power energy use in the afternoon (Chi-Square=7.912, df=1, p value=0.005). This indicates that 'mainly-static' workers consume more small power energy in the afternoon (mean rank=17.56) in comparison with 'mainly-mobile' workers (mean rank=8.82).

The statistical results provided by the analysis of mobility data for different types of worker mobility (see summary Table 5-3) will be discussed in the discussion chapter to explore potential reasons for why differences between mean small power energy usage occur for the different types of workers.

5.6.3 Significance of Space Level Data on Small Power Energy Use

Statistical analysis of office space level data has been conducted to examine whether there is statistical significance between mean small power energy usage in different office spaces (e.g. workstation, meeting room, kitchen) and different type of worker mobility ('static', 'mainly-static' and 'mainly-mobile'). Similarly to the previous analysis, in order to test potential differences between the different types of worker mobility (two or more independent groups as independent variable) and the means of small power energy use in different office spaces (multiple dependent variables), a one-way MANOVA (due to multiple variables) was conducted.

Prior to running the one-way MANOVA, an assumption of equal variances across comparison groups needed to be met. The Levene's test for the homogeneity of variances examines this assumption, testing the null hypothesis (Ho) that the variance of mean small power energy use is equal in the comparison groups (i.e. types of workers) across different office spaces. If the probability is higher than the 0.05 level, the Ho is not rejected, indicating that the assumption of the equality of variances is met and MANOVA can be conducted.

The results of Levene's test was not statistically significant at the 0.05 level for three office spaces (workstation p value=0.399; common function area p value=0.134; kitchen p value=0.173; meeting room p value=0.008; other activities p value=0.033). Therefore, the null hypothesis is rejected for workstation, common function area, as well as kitchen and we assume that there is a statistically significant difference in the variances of small power energy usage between the three different groups (different type of workers: 'static'; 'mainly-static'; 'mainly-mobile'). As a result, the assumption of homogeneity of variances was not met for the variables of meeting room and other activities and MANOVA could only run for the variables of workstation, common function area, and the kitchen.

Considering the analysis of MANOVA, the null hypothesis (Ho) that there is no difference between mean small power energy use for different type of workers across different office spaces is rejected. This is because the tests of between subject effects show evidence that the mean small power energy use at workstation is statistically significant for the different types of worker mobility (df=2, F=7.742, mean square=0.025, p value=0.002).

The pairwise comparison of the one-way MANOVA test between the different types of worker mobility and mean small power energy use across different office spaces shows statistically significant difference at the 0.05 level between ‘static’ workers and ‘mainly mobile’ workers at the workstation (p value=0.002, mean difference=0.107) and between ‘mainly-static’ workers and ‘mainly-mobile’ workers at the workstation (p value=0.003, mean difference=0.072). This comparison shows that ‘static’ workers consume more small power energy at the workstation compared to ‘mainly mobile’ workers, and also that ‘mainly-static’ workers consume more small power energy at the workstation compared to ‘mainly mobile’ workers.

An equivalent non-parametric test (Kruskal-Wallis test) was also conducted to test the null hypothesis (Ho) that there is no difference between mean small power energy use of different types of workers across different office spaces. The results of Kruskal-Wallis test reveal the same results as the parametric test (one-way MANOVA), rejecting the null hypothesis (Ho) because it shows evidence that mean small power energy use at workstation is statistically significant for the different types of worker mobility (Chi-Square=12.718, df=2, p value=0.002). The Kruskal-Wallis test has been expanded to identify which pairs of worker mobility (i.e. ‘static’ and ‘mainly-static’; ‘static’ and ‘mainly-mobile’; ‘mainly-static’ and ‘mainly-mobile’) show evidence of statistically significant results. The analysis shows statistical significance at the 0.05 level between ‘static’ workers and ‘mainly-mobile’ workers at the workstation (Chi-Square=9.013, df=1, p value=0.003) and between ‘mainly-static’ workers and ‘mainly-mobile’ workers at the workstation (Chi-Square=8.476, df=1, p value=0.004). This analysis of small power energy usage at workstation for the compared pairs shows that ‘static’ workers (mean rank=13.80) consume more small power energy than ‘mainly-mobile’ workers (mean rank=6.09) at the workstation, and also that ‘mainly-static’ workers (mean rank=17.69) consume more small power energy in comparison with 'mainly-mobile' workers (mean rank=8.64) at the workstation.

The results of the statistical analysis which examined office space level data for different type of worker mobility (see summary Table 5-3) will be discussed in the next chapter. The aim is to explore potential reasons for differences between mean small power energy usage across different office spaces for different types of worker.

5.6.4 Summary of Statistically Significant Results

Table 5-3 gives a brief summary of the statistically significant results from the analysis above. Of the eleven statistically significant results, five results are excluded from further analysis (reasons are indicated in the last column of Table 5-3). These relate either to the fact that results fall outside the scope of this study, or they do not provide the quantitative effect of small power energy use from activities performed for different types of worker. They do, however, indicate what typical activities are performed by different types of worker. The remaining six will be considered for discussion of working practices affecting small power energy use, because they are directly associated with the mobility of workers and their effect on small power energy use.

Table 5-3. Summary of key statistical results

Comparing	Results of statistical significance	Reasons for exclusion of results from further analysis
Case office sites and mean small power energy use for different types of office workers	Case office site <50m^2 consumes more small power energy in comparison with case office sites 1,000-4,999m^2 and 5,000+m^2	The comparison between the small power energy use of different case office sites is outside the scope of this study because the comparison does not include the different types of worker
	'Static' workers consume more small power energy in comparison with 'mainly-static' and 'mainly-mobile' workers across the three case office sites	The number of static workers was too small to support statistical significance
	'Mainly-static' workers consume more small power energy in comparison with 'mainly-mobile' workers at the case office site 5,000+m^2	Key finding 1
Different type of worker mobility and mean small power energy use regardless of case	'Mainly-static' workers consume more small power energy in comparison with 'mainly-mobile' workers, considering only mobility, regardless of case office site	Key finding 2
	Statistically significant differences in the means of small power energy use for activities 'Concentrated work using desktop computer at the desk _ In Use devices' and 'Routine process work using laptop at the desk _ In Use devices' between 'static' and 'mainly-static' workers	The statistical significance of particular activities between different types of workers does not indicate a particular effect on small power energy usage, but shows typical activities performed by different types of worker
	Statistically significant difference in the mean of small power energy use for the activity 'Routine process work using desktop computer at the desk _ In Use devices' between 'static' and 'mainly-mobile' workers	The statistical significance of particular activities between different types of workers does not indicate a particular effect on small power energy usage, but shows typical activities performed by different types of worker
	Statistically significant differences in the means of small power energy use for activities 'Concentrated work using laptop at the desk _ In Use devices' and 'Telephone conversation while sitting at the desk _ In Use devices' between 'mainly-static' and 'mainly-mobile' workers	The statistical significance of particular activities between different types of workers does not indicate a particular effect on small power energy usage, but shows typical activities performed by different types of worker

	‘Mainly-static’ workers consume more small power energy in the afternoon in comparison with ‘mainly-mobile’ workers	Key finding 3
	‘Static’ workers consume more small power energy in the morning in comparison with ‘mainly-mobile’ workers	Key finding 4
Mean small power energy use in different office spaces for different types of worker mobility regardless of case	‘Static’ workers consume more small power energy at the workstation compared to ‘mainly mobile’ workers	Key finding 5
	‘Mainly-static’ workers consume more small power energy at the workstation compared to ‘mainly mobile’ workers	Key finding 6

Chapter 6: Relating Small Power Energy Use Data to Working Practices

Chapter 5 presented the analysis of quantitative data on a case level, mobility level, and space level. This chapter explores some of the work practices underlying the use of small power energy, considering the elements of practices outlined in Chapter 3 (Section 3.5).

The analysis in the previous chapter shows that:

- Different case office sites (i.e. organisations) and types of workers have different small power energy usage (see Section 5.3):
    - ‘Mainly-static’ workers account for more small power energy use in comparison with ‘mainly-mobile’ workers at the case office site 5,000+m^2.
- Different types of worker mobility, regardless of case office sites, have different small power energy usage (see Section 5.4):
    - ‘Mainly-static’ workers account for more small power energy use in comparison with ‘mainly-mobile’ workers, regardless of case office site;
    - ‘Static’ workers account for more small power energy use in the morning in comparison with ‘mainly-mobile’ workers, regardless of case office site;
    - ‘Mainly-static’ workers account for more small power energy use in the afternoon in comparison with ‘mainly-mobile’ workers, regardless of case office site.
- Different office spaces and types of worker have different small power energy usage (see Section 5.5):

- Static' workers account for more small power energy use at the workstation compared to 'mainly mobile' workers, regardless of case office site;
- 'Mainly-static' workers account for more small power energy use at the workstation compared to 'mainly mobile' workers, regardless of case office site.

The statistical analysis presented in chapter 6 shows evidence of statistical significance for the differences between: i) small power energy usage and case office sites considering different types of workers, ii) different types of worker mobility and small power energy consumption regardless of case site, iii) small power energy use for different office spaces and types of workers. These results are important to understand the variation of small power energy use for office workers in the office sites studied (case office sites considered are <50m^2; 1,000-4,999m^2; and 5,000+m^2), worker mobility ('static', 'mainly-static', 'mainly-mobile'), as well as the different office spaces examined (e.g. workstation, kitchen).

The results from the previous chapter (see Section 5.6.4) show that differences in the type of worker ('static', 'mainly-static', 'mainly-mobile') were very important in demonstrating variations in small power energy use. These variations were found by comparing different case office sites, different mobility of workers, and different office spaces. The six key findings outlined above, which show evidence of statistical significance, are concerned with worker mobility and associated effect of small power energy use (see also Table 5-3). To integrate the quantitative analysis and explain these variations, this chapter uses the elements of Social Practice Theory (SPT) to explore small power energy use practices based on worker mobility, in order to help deepen the understanding of how and why small power energy is used.

6.1 Small Power Energy Use and Social Practice Theory

Social Practice Theory (SPT) has been mobilized to help understand working practices associated with small power energy consumption (see Chapter 3). The four elements which constitute the framework of small power energy use practices (as shown in Figure 3-2 - Section 3.4) are knowledge, meanings, habits/routines, technologies/infrastructure. These elements were used as the basis of interview questions to obtain qualitative data to help explore some of the reasons behind the effect of small power energy usage for different type of worker mobility in three different case office sites.

The four elements of SPT constitute the thematic basis for coding. The coding for these elements was developed using NVIVO software to expand each element into nodes for analysis of the interviews. These nodes were used to inform the analysis of interview data as illustrated below in terms of key SPT elements and related themes. The themes and nodes from the coding of interviews are listed in Chapter 4 (see Section 4.10.4 - Figure 4-7 and Appendix H). The elements of SPT and subsequent themes arising from the examination of interview data are discussed below and are illustrated by quotations from the interviews.

The first element of SPT - knowledge - includes themes as follows:

- *organisation rules*, whether or not these are related to device usage and associated electricity consumption, may influence the way that devices are used in the office:

> Obviously just, it's more security things, in terms of make sure your laptop's locked if you're not at your desk, and the same with your computer, control, alt, delete, click, close it goes down so it kind of, but that's more from a security point of view than a consumption point of view [P11 – Mainly-static; 5,000+m^2]
>
> At the end of the day we need to be very mindful of the confidential issues and we're not allowed to leave paper on the printer or next to the printer. We have to shred everything [P12 – Static; 5,000+m^2]

- *technical background* relates to the understanding of technical aspects of device usage. For instance, computers consume different amounts of electricity depending on whether using “heavy” software (handling and processing large amounts of data) or just browsing the internet. These different ways of using devices (e.g. computers) affect the electricity consumption differently. The theme explores if workers are aware of these technical aspects of device usage:

  > I wouldn’t have assumed it was based on the fact that if it’s on, it’s on. But I suppose you could think down more into depths as in running an AutoCAD application might use more processor power, therefore it needs more fan use and more processing and therefore more energy [P18 – Mainly-static; 5,000+m^2]

- *type of knowledge*, including additional subtheme categories:
  - *theoretical knowledge* relates to the theoretical background of energy consumption and may influence the way that electricity of devices is consumed. For instance, knowing what electrical energy is used for, and how it is measured and compared across different organisations and buildings:

    > I know because I am responsible to calculate the energy consumption for all buildings and each organization in multi-tenanted buildings at the [business] park. An engineer from the maintenance office usually helps me; I don’t think someone else can, at least from the [name] team, it’s hard for people to deal with units especially if they don’t have the background [P3 – Mainly-mobile; <50m^2]

  - *verbal knowledge*, which involves understanding of conventional wisdom in relation to office devices and equipment, may affect the device usage and in turn the electricity consumption:

    > I would imagine that the computers are quite energy efficient because we’ve not long been in this office with, it’s quite a new office so I know that it’s probably quite… [efficient equipment] [P21 – Mainly-static; 5,000+m^2]

- *understanding of device energy consumption*, which is related to the knowledge about the amount of electricity consumed by office devices, may affect how devices are used and in turn their small power energy usage:

> Yeah, I can appreciate that, it's bigger and it does more [multifunction device], it does colour doesn't it, not just black and white [printer], so I'm aware of that. But as a percentage increase in consumption I probably wouldn't know about the consumption [P32 - Mainly-mobile; 1,000-4,999m^2]

> I am aware that a computer constantly burns energy, electricity and certainly when you turn a standard box off in the evening that you should be turning the screen off as well because quite often if you turn the box off that shuts off but the screen will stay black and idle but it's still turned on and so I was always very conscious to make sure I would turn that off if I've had that on rather than leaving it [P27 – Mainly-mobile; 1,000-4,999m^2]

The second element of SPT – meanings – includes the following themes from the analysis of interviews:

- *Formality* relates to formal processes or procedures which arise from conventional norms such as holding meetings in meeting rooms, or the provision of documentation for certain purposes (e.g. formal presentation of documentation for meetings, in external communications, etc). These may indirectly influence small power energy usage due to these underpinning processes:

> I remember the first week I joined this team, my manager used to print black and white, but given that we're sending a letter to a customer, I thought it's better to be coloured, to be more formal, because we sign this letter and it doesn't look right, so I told him can I print colour and he said, yeah that's fine [P12 – Static; 5,000+m^2]

- *Informality* relates to 'unofficial' ways that activities and interactions occur in offices (such as informal discussions in break-out areas). These activities may influence space and device usage and so may affect small power energy usage:

> Sometimes you might see a person you meet once in a day, and that'll be in the kitchen when you're making a coffee and then that coffee, instead of it just being a preparing coffee in the kitchen basically it becomes an informal meeting in the kitchen for ten minutes and that then becomes a bit of collaborative working because you might develop an idea in there or something along those lines [P30 – Mainly-mobile; 1,000-4,999m^2]

- *Confidentiality* refers to the sharing of information which generally cannot be divulged further than those sharing it. This can affect small power energy use due to usage of enclosed spaces (e.g. meeting room) and/or particular devices for information sharing.
- *Privacy* relates to freedom from intrusion and tends to be associated with individuals. For instance, using a private space such as meeting room with its associated devices to work alone and/or to avoid being observed.

While confidentiality and privacy have two different meanings, in interviews they tended to be treated interchangeably by the interviewees (as illustrated below) and so these codes were considered together in the analysis.

> So confidential discussions, generally depends, but I'll either go to one of the private breakout areas, or I'll go to a meeting room [P19 – Mainly-static; 5,000+m^2]

> Reports are normally done at my desk or break out area or meeting room and sometimes at home. If there's a report that I need privacy, because some of the reports we write are quite confidential, I can't really do it at my desk because it is an open plan. Depending on the sensitivity [of the report], there's certain areas that you really don't want people overlooking you, so I'll normally do it in a meeting room or at home using my laptop [P3 – Mainly-mobile; <50m^2]

The third element of SPT – habits and routines – includes the following themes:

- *Routine activities* are the activities that are typically performed most of the time during a working day, affecting small power energy consumption:

> It was probably a fair representation of a normal day. I would say at my desk my, 70%, 75% of my work is completed. And then that would leave 30%, 25%

> of my work either working on actual IT units, discussing with occupiers what their issues are or just being a go between in between the two so, yeah, I think 75% of my working day would be at my desk. 25% would at the occupiers [P10 – Mainly-static; <50m^2]

- *Observed work activities* are the activities that are directly related to office work and that workers were observed to perform (these were generally in line with the predefined list in Chapter 4 – Table 4-4). The observation of these activities also recorded the spaces where these activities were performed and the associated device usage, indicating where small power energy is used:

> So, concentrated work would pretty much only take place at my desk. Routine processing work, yeah, that would probably be my desk. Interacting with colleagues would be the desk, kitchen, rarely breakout areas … obviously meeting rooms. Informal meetings are taking place at my desk, probably breakout areas and meeting rooms. In terms of collaborative work, again, at my desk and probably break out rooms and meetings again. Formal meetings, even though they're formal, still at my desk… as well as proper meeting rooms. Telephone conversations, my desk, the breakout areas, sometimes they're good if it's a personal call or if it's a confidential call [P16 – Static; 1,000-4,999m^2]

- *Other observed activities* are the activities that are not directly related to office work but are part of the activities performed during a working day, affecting small power energy consumption:

> So normally I'll buy my coffee, I fill up waters regularly. So, I tend to drink, I try and drink four of those a day and I'll always get it out of the water cooler, I don't get it out of the tap, I don't like tap water. I don't, I probably only make a hot drink once or twice a week [P24 – Mainly-mobile; 1,000-4,999m^2]
>
> Preparing and having lunch, so that'll either be in the kitchen, using occasionally microwave, or I go to the canteen, get my lunch and have it there or at the desk [P28 – Static; 5,000+m^2]

- *Work activities outside of office* are the activities which may affect the building electrical load arising from remote access of office equipment (e.g. connecting to the office-based server) to access software/applications remotely. The electricity usage from electrical equipment such as servers is out of the scope of this study. However, the occasional absence of workers from the case office site who participated in this study (e.g. to attend a meeting outside of office) resulted in reduced small power energy usage. Therefore, 'work activities outside of office' were coded and analysed to understand these variations arising from their absences:

> When I go to sites, I have my phone and my laptop, my tablet with me and I try to do as much as I can but I'm always moving because I have different people in different projects. I can access on my [work/company] applications, tools, etc, through my laptop using [the network of the organization] [P17 – Mainly mobile; 5,000+m^2]

The fourth and final element of SPT – technologies and infrastructure – include the following themes:

- *Office devices* are the devices that are typically used most of the time during a typical working day of a worker, directly affecting small power energy consumption. It is important to note that office devices enable the performance of activities which in turn drive small power energy use. Devices do not per se use small power energy:

> I sit at my desk and use the pc [desktop computer], sometimes my iPad but more often in meeting rooms, and my mobiles. I've got two screens connected to my pc, that helps, and if it's really busy in the office and I'm being distracted then I put headphones in [P1 – Mainly-static; <50m^2]
>
> When I use a meeting room, very rarely use any devices, just notebook pretty much and mobile phone [P4 – Mainly-mobile; <50m^2]

- *Office spaces* are the spaces that are typically accessed by a worker most of the time during a typical working day and are where small power energy is consumed:

> So concentrated work is all desk-based I would say, same with routine process work, interacting with colleagues, desk, break out area … Meeting rooms, we will use them quite a lot. Informal meetings, we go to break out areas, or desk, not necessarily my desk but a desk. Collaborative work, a mixture of desks and sometimes meeting rooms. Formal meetings are always in a meeting room. Telephone conversations, because we wear headsets it tends to be at the desk [P13 – Mainly-static; 1,000-4,999m^2]

Beyond the themes related to the four elements of SPT, three recurring themes were identified from the examination of the interview data. These additional themes did not fit clearly within the four elements of SPT but recurred frequently and so they were used to code the data for further analysis. These are associated with:

- *Worker mobility* (style of working such as agile working) is related to the organizational style of working and may influence the type and quantity of office devices used (for instance using a laptop due to high mobility within the office). This affects small power energy usage in different office spaces:

> If I'm going to be mobile during the day I'll try and use a laptop but if, because I'm not holding out, from an agile working point of view, I'm then not logged into a screen. But if for some reason I've got a few shorter meetings I will tend to log into a machine and then leave it and that's not so good [P27 – Mainly-mobile; 1,000-4,999m^2]

- *Individual - role of worker* may indicate how roles are associated with mobility and influence the performance of activities and associated device usage:

> My role is Property Engineering Manager. I provide engineering support for all the buildings, to the building managers, provide support, lead on the security man guarding, environmental and sustainability, fabric, all hard surfaces, CCTV and electronic security. It depends what I'm doing and where. If I'm going to be moving around during the day, I'll carry and use a laptop [P3 – Mainly-mobile; <50m^2]

- *Individual - personal preferences* may indicate to what extent the small power energy usage is based on personal preferences or depending on (formal) processes to be followed:

> I use the printer for printing stuff, for scanning, if I need it for photocopies. That I definitely do because my boss likes, prefers to have things printed out for her to read or look at it immediately, so whenever she needs me to print out stuff I print out. Personally, for myself, I don't use paper, I use OneNote or my phone or whatever [P14 – Mainly-static; 5,000+m^2]

Office design is related to the office layout e.g. open plan office. Although this could be considered as part of the fourth element of technologies/infrastructure, which focused on exploring and understanding the use of devices and spaces in offices, it became clear that office layout had an important effect on the use of spaces. The *office design* may influence the mobility of workers (due to open plan layout and hot-desking in case of interaction with people) and the usage of devices (e.g. using portable devices):

> One thing with the open plan and the hot-desking is you, obviously I sit at the same desk but others don't always sit at the same desk, so you might need to catch up with somebody and then you, if you look around the office occasionally you'll see people standing up like meerkats, standing up and looking out, trying to find where people are sitting. So that, you've got that aspect that the team is now dispersed across a floor whereas previously we were all together … I can talk to my team at anytime, anywhere, because that's absolutely fine and quite frequently we use a desktop or a laptop, to be honest with you [P27 – Mainly mobile; 1,000-4,999m^2]

The themes related to the elements of SPT as well as additional themes which came from the examination of the interview data are used to explore the effect of working practices on small power energy usage, considering the results from descriptive and statistical analysis. The following analysis of working practices affecting small power use is focussed on office worker type and associated mobility. The analysis starts with exploring the element of habits/routines through the activities performed by different types of worker and goes on to consider the other SPT elements (knowledge, meanings, technologies/infrastructure) to understand some of the work practices underlying the use of small power energy.

6.2 What Activities Do You Perform? Habits / Routines as Part of Small Power Energy Use Practices

Habits/routines is one of the four elements of small power energy use practices which are explored to understand activities performed by different types of worker in different office sites. Responses to interview questions related to habits/routines were coded based on four emerging themes: *routine activities* (which are performed most of the time), *observed work activities* (activities performed during the observation of workers), *other observed activity* (activities performed which are not related to work, e.g. making coffee) and *activities outside of office*. This final theme was used to code responses based on workers self-description to cover activities performed outside the case office sites. Although these activities may not directly affect small power energy usage within the case office building, they help to explain reductions in small power energy use caused by participants' absence from the office (e.g. from having a meeting away from the case office site). The influence of these four themes within the element of habits/routines on small power energy use practices is explored below.

The element of habits/routines was explored through an examination of activities performed in offices by different types of worker ('static', 'mainly-static', 'mainly-mobile'). In general terms, these were either related to work tasks (e.g. routine process work using desktop computer at the workstation) or not directly related to work (e.g. making coffee) with an effect on small power energy usage. Considering *routine activities* performed by different types of worker across different case office sites, it can be observed that typical/routine working days and activities involved vary significantly for different types of worker. Desk-based office work and interaction with people mainly at the desk are associated with 'static' workers. Dividing working time between desk-based work and interaction in the form of meetings or collaborative work in spaces other than at the desk (e.g. break-out areas and, less often, meeting rooms) is mainly related to 'mainly-static' workers. In contrast, 'mainly-mobile' workers mostly interact with people in a variety of different office spaces (e.g. break-out areas, meeting rooms, quiet pods, corridor, the cafeteria of office building) and undertake desk-based work for a small proportion of time during a working day (between two and three hours). Desk based-work for 'static' workers (e.g. routine process work and concentrated work involving for instance emails, documentation) differs from 'mainly-static' workers (routine process work including emails, reports, collaborative work with colleagues) and 'mainly-mobile' workers (routine process work mainly related to emails and reviewing of processes, projects, and progress work). Study participants described these routines in a variety of ways:

> So normally I would arrive between 8am and 8.30am and come straight up to the desk, turn the computer on, go and get either a drink of water or a cup of tea from the kitchen, back to the desk. Settle in, go through emails, start working on documents, maybe call some colleagues, then start through the day of the meetings through conference calls. Then lunch break would be any time between 11:30am and 1pm. And then it's just more of the same, very little interaction with colleagues here in the office, most of it is done over email or phones, or instant messaging. I may occasionally use the meeting rooms on the sixth floor if we've got a requirement to be seen by other people but for me that's quite rare say once or twice a month. Around 5pm, 5.30pm I'll probably power down and head home [P16 – Static; 1,000-4,999m^2]

> I would say a quarter of the time I am actually in a meeting in a different location within the building. And then maybe a quarter of my time I'm on the phone, and then maybe half the time I'm at my desk, working on my own or collaborating with the people around me. I probably primarily use my laptop, but I also tend to use the desktop. I have my laptop with me for when I go to a meeting [P11 – Mainly-static; 5,000+m^2]

> My typical days are made up with meetings and reviews of my team with gaps in between to maybe just manage the email for probably a couple of hours. So, I might use the breakout areas, might use the canteen [cafeteria of the building] a lot, but I also use the meeting rooms, but as a percentage [of time spent on meetings] I would say upwards of 60%, between 60% and 70% maybe [P32 – Mainly-mobile; 1,000-4,999m^2]

With respect to the *routine activities* performed by different types of workers, 'static' workers perform desk-based activities in the morning and in the afternoon may access other office spaces (e.g. break-out areas or meeting rooms) to perform non desk-based activities (e.g. informal meetings) which occur occasionally. ‘Mainly-static’ workers spend their working day performing desk-based activities, using desk-based devices, and activities away from the desk (e.g. meetings in a meeting room, phone calls in the break-out area), using available devices in these spaces or portable devices (e.g. smart hubs, laptops, mobile phone). ‘Mainly-static’ workers usually perform non desk-based activities in the afternoon while ‘mainly-mobile’ workers perform them most of the time during a working day. The latter workers usually use portable devices to perform non desk-based activities away from the workstation (e.g. informal meetings in the break-out area using mobile phone) which may or not be plugged in, thus using less small power energy compared to ‘static’ and ‘mainly-static’ workers. This can explain to some extent why ‘static’ workers consume more small power energy in the morning compared to ‘mainly-mobile’ workers, as well as why ‘mainly-static’ workers consume more small power energy in the afternoon compared to ‘mainly-mobile’ workers (see Sections 5.4.3 and 5.6.2).

The analysis of interviews in relation to *routine activities* shows that a significant number of activities away from the desk are related to ‘communication’, which can take different forms such as emails, teleconference, phone calls, and in-person as physical interaction between people (through formal / informal meetings and collaborative work). *Routine activities* related to ‘communication’ are commonly performed by all workers, regardless the type of worker and case office site. The main difference in relation to the performance of ‘communication’ activities between the different types of worker is the space used for these activities, which may involve some device usage. For example, ‘static’ workers perform ‘communication’ activities mainly at the desk, using available devices at the workstation (e.g. desktop computer with one or two monitors, laptop, tablet), while ‘semi-static’ workers perform them both at the workstation and other spaces (e.g. break-out area, meeting room), using either portable devices (e.g. laptop) or available devices in these spaces. In contrast with ‘static’ and ‘semi-static’ workers, ‘semi-mobile’ workers use a variety of different office spaces to perform ‘communication’ activities such as break-out areas, quiet pods, meeting rooms and the canteen of the building. ‘Semi-mobile’ workers used either portable devices (e.g. laptop, tablet, mobile phone) or occasionally used available devices in commonly used spaces (e.g. TV screens and desktops in meeting rooms). Portable devices were usually not plugged in and so had no effect on small power energy use at the point of use, while available devices in commonly used office spaces had a limited effect on small power energy use. The use of different office spaces and associated devices from different types of worker to perform ‘communication’ activities show that ‘static’ and ‘semi-static’ workers affect small power energy use more than ‘mainly-mobile’ workers. This is due to the considerable amount of time spend at the workstation (more than 4 hours) to perform ‘communication’ activities, using available devices which are plugged in and affect small power energy consumption.

The way and to what extent the *routine activities* of ‘communication’ are performed by each type of worker may be related to the role of workers. This can be explored by considering the influence of the role of workers on their associated mobility through their routine activities, including ‘communication’ activities. The interview analysis shows that senior roles (e.g. directors, heads of department, senior project managers) are associated with ‘mainly-mobile’ workers and their roles involve mainly interaction with other people (e.g. formal / informal meetings) and use of different office spaces. ‘Static’ and ‘mainly-static’ workers are associated with ‘process’ workers (e.g. administrators) and ‘middle-senior’ roles (e.g. managers) with less mobility in different office spaces compared to ‘mainly-mobile’ workers. Comparing routine activities from different types of worker in different case office sites, it is observed that ‘mainly-static’ workers in office site 5,000+m^2 perform a variety of different activities, with most of them involving usage of devices. In comparison, ‘mainly-mobile’ workers in the same office site spend more time interacting with people either in person or through conference calls, with much less usage of office devices. These differences in routine activities and associated device usage from different types of worker can explain to some extent why ‘static’ workers and ‘mainly-static’ workers, who use desk-based office devices the majority of the time during a working day to accomplish work tasks, affect small power energy consumption more than ‘mainly-mobile’ workers (see Sections 5.4.1 and 5.6.2). The latter use mainly portable devices (and often not plugged-in devices) when accessing different office spaces to interact with people, due to their increased mobility.

Beyond *routine activities*, variations in small power energy use and work practices can be understood through *observed work activities* (included in a predefined list, see Chapter 4 – Table 4-4) and *other observed activities*, which are not related to office work but form part of the activities performed in offices (e.g. making coffee). *Observed work activities* were mainly related to routine process work (e.g. budgeting, auditing of logbooks, project process development, working on web-based software), concentrated work (e.g. reading and reviewing documents/contracts), ‘communication’ activities (e.g. emails, collaborative work, interaction through formal meetings or informal meetings, teleconferences, phone calls), as well as ‘extracting/organizing document’ activities (e.g. printing, scanning, photocopying, archiving).

The performance of these work activities relied on device usage (e.g. desktop computers, laptops, multifunction devices), thus affecting small power energy consumption. The differences between the *observed work activities* performed in different office sites were mainly related to the different types of worker. ‘Static’ workers performed mostly desk-based activities, ‘mainly-static’ workers performed partially desk-based activities and partially ‘communication’ activities, while ‘mainly-mobile’ workers performed mostly 'communication' activities, regardless of office site. These differences in *observed work activities* indicate that 'static' and 'mainly-static' workers consume more small power energy due to usage of desk-based devices (e.g. desktop computer connected to one or two monitors), which are plugged-in, and also usage of portable devices (e.g. laptop, tablet) to accomplish work tasks (e.g. routine process work, meetings) compared to 'mainly-mobile workers'. 'Mainly-mobile' workers referenced that most of the time they use portable, often not plugged-in devices (e.g. laptop, mobile phone) to perform their work activities, which are mainly 'communication' activities. This leads to less consumption of small power energy compared to 'static' and 'semi-static' workers (see Sections 5.4.1 and 5.6.2). This result is based on the consumption of small power energy at the exact time that activities were performed and associated devices used. Devices left on standby-mode during working hours from 'mainly-mobile' workers (but also from 'static' and 'mainly-static' workers), such as desk-based devices when they performed 'communication' activities in spaces other than the desk, were not assessed or included in the analysis of this study. As this study is primarily focused on working practices which give rise to small power energy use (i.e. 'active' practice-related energy from observed activities and monitored associated device usage), when devices were not being used for the performance of an observed activity (e.g. desktop computer which was on 'idle/standby' mode at an empty workstation) the monitored device electricity consumption was excluded from the examination of working practices and the analysis. This is further discussed in the next chapter.

> What I do, because of my role, it's a lot of auditing logbooks. Whereas today that you observed me I wasn't auditing any of the logbooks, I was more going through my emails, replying to people, speaking to people on the phone, raising purchase orders, reviewing quotes, administrative things [P2 – Mainly-static; <50m^2]

> As the director of a busy business park, a lot of my time, as you've seen, is spent engaging with people both internally and externally. That was about meetings that took place at various times during the day. A lot of communication was also required at the

> same time in between the two, with emails mostly. So, if I were to look at my time spent on devices, I would say that I spent a couple of hours in the mornings on a desktop PC, followed by most of the morning one-to-one meetings. In between that time, around lunch time, I was also on my phone, cell phone, with emails [P4 – Mainly-mobile; <50m^2]

> I had a few informal meetings today, that's why I took my laptop along because I wanted to show things that we needed to talk, we're doing flowcharts. If we need to design something then I grab a piece of paper from the printer or if I have my note diary with me, I'll use that [P14 – Mainly-static; 5,000+m^2]

> I had meetings most of the day. I think I spent two hours working on my emails, but the rest of the day was meetings, workshops, one-on-one [meetings] [P24 – Mainly-mobile; 1,000-4,999m^2]

With respect to the *other observed activities* performed, these were related to preparing/having coffee in the kitchen, preparing/having lunch in the kitchen, having lunch/coffee at the workstation, having lunch at the canteen of the building. Similarly to *routine activities* and *observed work activities*, *other observed activities* require device usage in order to be performed (e.g. hot boiler for making tea/coffee, fridge to store food or microwave to prepare lunch) and affect small power energy consumption. The main difference observed between the different types of worker across the case office sites in relation to *other observed activities* is that 'static' and 'mainly-static' workers from office site 1,000-4,999m^2 and 5,000+m^2, respectively, may tend to perform them (e.g. coffee/lunch breaks) at a single location (mainly workstation) in comparison with 'mainly-mobile' workers from office sites 1,000-4,999m^2 and 5,000+m^2. 'Mainly-mobile' workers seem to move either inside the building (e.g. canteen / coffee shop) or outside it for the performance of *other observed activities* (e.g. coffee/lunch breaks).

> Sometimes you have to have lunch at your desk, like today, busy day. I just got it from the fridge and came back [at the desk]. I do sometimes have a hot chocolate, so I would do that in the kitchen [P21 – Mainly-static; 5,000+m^2]

> I will rarely go out for lunch. You've seen that I just sit at my desk and eat. I work and just eat whilst I work. Occasionally I may go into town or offsite, but mostly at my desk [P16 – Static; 1,000-4,999m^2]

> I had my lunch and coffee at the canteen and coffee shop, downstairs. That's where I would go normally for that [P27 – Mainly-mobile; 1,000-4,999m^2]

Comparing *observed work activities* and *other observed activities* for different types of worker across difference case office sites, the analysis of interviews shows differences between the activities performed and the associated small power energy use. 'Mainly-static' workers across the three different office sites perform these activities using mainly a single location within the building (e.g. workstation). The performance of these activities involves mainly the usage of desk-based devices, even when 'mainly-static' workers perform *other observed activities* (e.g. having lunch) which are often combined with work activities (e.g. routine process work). This is exemplified by considering 'mainly-static' workers from case office sites 1,000-4,999m^2 and 5,000+m^2 who seem to affect small power energy consumption more than 'mainly-mobile' workers of same office sites. This is because 'mainly-mobile' workers of case office sites 1,000-4,999m^2 and 5,000+m^2 spend considerably less time in a single location (e.g. workstation) and use desk-based devices (such as desktop computer) for a quarter of the working day, performing 'other activities' in communal areas (canteen/coffee shop) or even outside the office building. This exploration of *observed activities* and *other activities* for different types of workers across different case office sites can partly explain why 'mainly-static' workers consume more small power energy compared to 'mainly-mobile' workers at the case office site 5,000+m^2 (see Section 5.6.1.2).

At first inspection, *work activities outside of office* might be considered to fall outside the scope of this research. These activities are conducted outside the office sites examined, based on workers' own accounts (i.e. not directly observed) and do not lead to electricity consumption from office devices. However, these activities do have a secondary effect on small power use and were therefore included as a theme in this element of *habits*/*routine*. Some workers may consume lower amounts of small power energy usage due to their absence from the office site for external meetings in comparison with other workers who were based in office sites for the whole duration of the working day during observation.

> I do also have responsibility to go out to various sites, because I'm responsible for a number of projects as well. But that, a typical day would be just driving to the site, using my laptop when I'm on site. Those days aren't frequent enough [P23 – Mainly-mobile; 1,000-4,999m^2]

> The other day you observed me, I left at two for an external meeting in London. The laptop was needed to deliver a presentation and access documents to reference in the meeting. The travelling time was about an hour and the meeting lasted two hours [P16 – Static; 1,000-4,999m^2]

> But this place is, can be quite noisy at times. Let's say the beginning of the review year, at times this might be the odd occasion where I'd work from home [P18 – Mainly-static; 5,000+m^2]

Work activities outside of office seem to be part of work activities for 'mainly-mobile' workers of office site 5,000+m^2, although these activities are not performed very often. In contrast, 'mainly-static' workers of the same office site do not seem to perform *work activities outside of office* but they occasionally work remotely, e.g. at home for the entire working day. An exception is a 'static' worker from office site 1,000-4,999m^2, who performs *work activities outside of office* while all other 'static' workers from all three office sites are only based in the office. The analysis of interviews shows that 'mainly-mobile' workers from office site 5,000+m^2 may consume less small power energy use in comparison with 'mainly-static' of the same office site (see Section 5.6.1.2) due to their mobility within and outside of office building.

Considering the element of habits/routines, the effect on small power energy usage from *routine activities* and *observed work activities* depends on the way that these activities are performed and the office spaces that are used. It also depends on the usage of devices, such as portable, not-plugged in devices (e.g. in break-out areas, corridor) or devices which are plugged in certain office spaces (e.g. at workstation, in meeting rooms). For example, the use of a quiet pod in order for a ‘mainly-mobile’ worker such as a senior manager to review a strategic plan or a contract with no device usage contrasts with desk-based work, involving data entry and reviewing logbooks, using a desktop computer by a ‘static’ or ‘mainly-static’ worker such as an administrator. Variations of small power energy use between workers - arising from *routine activities* and *observed work activities* - is due to worker type and the associated mobility which is linked to their role. For instance, senior workers are ‘mainly-mobile’ and spend only a few hours (2-3 hours) using desk-based devices to perform desk-based activities. Rather, they tend to use portable devices to perform mainly ‘communication’ activities, using devices which are often not plugged in and consequently have less effect on small power energy usage. More junior workers, who are ‘mainly-static’ or ‘static’, spend half or most of their working day at the workstation using desk-based devices which increase small power energy consumption. *Other observed activities* such as preparing and drinking coffee and preparing and having lunch were referenced by all workers in different office sites, with the main difference being the spaces used for *other observed activities* to be performed (e.g. kitchen, break-out area, desk, canteen/coffee shop of office building) and available devices used. Preparing coffee in the kitchen using (hot-cold) water-coffee machine was a main activity from workers of office site <50m^2, regardless of their type and mobility, compared to workers from office sites 1,000-4,999m^2 and 5,000+m^2. The latter workers performed *other observed activities* (e.g. having coffee / having lunch) differently based on their mobility. For example, ‘static’ and ‘mainly-static’ workers more often performed *other observed activities* using devices (e.g. making coffee in the kitchen using coffee machine or having lunch at the desk using desktop computer). This contrasted with ‘mainly-mobile’ workers who usually performed *other observed activities* with no device usage (e.g. having coffee/lunch in the canteen/coffee shop of the building). *Work activities outside of office* were considered to explain variations of small power energy use between different types of workers. For example, ‘mainly-static’ workers from office sites 1,000-4,999m^2 and 5,000+m^2 may occasionally work from home, while ‘mainly-mobile’ workers of the same office sites perform *work activities outside of office* more often as part of their *routine activities*. These activities reduce electricity usage from office devices due to the absence of ‘mainly-mobile’ workers from office (e.g. attending meetings outside of office). Comparing ‘mainly-static’ and ‘mainly-mobile’ workers, the former spend half of their working day performing activities in a single-location within the office (e.g. workstation), and when they access communal spaces (e.g. break-out areas, meeting rooms, and the kitchen) they tend to use available devices (e.g. laptops, TV screens, kitchen appliances) in these spaces to perform their activities. However, ‘mainly-mobile’ workers perform mostly ‘communication’ activities for considerably less time (approximately 2-3 hours) in a single location (at workstation using desktop computer) compared with ‘mainly-static’ workers. ‘Mainly-mobile’ workers tend to use different office spaces (e.g. break-out areas, quiet pods, meeting rooms) due to the performance of ‘communication’ activities for most of their working day, however this does not increase small power energy consumption because they use mainly portable devices (e.g. laptop, table, mobile phone) which are often not plugged in. This supports the data from Sections 5.4.1 and 5.6.2 and explains to some extent why ‘mainly-static’ workers consume more small power energy compared to ‘mainly-mobile’ workers.

6.3 What Makes You Do These Things That Way? Meanings as Part of Small Power Energy Use Practices

The element of meanings was explored in order to understand reasons for the way that activities are performed in different office spaces, and the involvement of device usage, affecting small power energy usage. Exploring the element of meanings and its influence on the shaping of working practices led to four different themes arising from the interview data. These themes are *formality*, *informality*, *privacy*, and *confidentiality* and relate to certain activities (e.g. 'communication' activities) which were performed in different office spaces, requiring the use of devices, by different types of workers.

These themes were common across the three office sites but the way that certain activities were performed (e.g. informal meetings, formal meetings) by different types of workers, and the space used (e.g. break-out area, meeting rooms) as well as device usage, varied amongst the different types of worker. The main activities performed which were associated with the element of meanings are related to 'communication' activities (e.g. sending emails, speaking on the phone, teleconference, interaction with people through formal/informal meetings and collaborative work). The *meaning* of *formality* and *informality* in relation to 'communication' activities derives mainly from the sensitivity of information to be shared and discussed and also from the people involved in these activities. 'Static' and 'mainly-static' workers performed informal 'communication' activities (e.g. conference calls, informal meetings) mainly at the desk, using desk-based devices, while formal 'communication' activities for 'mainly-static' workers were performed in spaces other than workstations, such as meeting rooms. The performance of formal 'communication' activities for 'mainly-static' workers involved the usage of a variety of different devices available in these spaces (e.g. surface hubs, TV screens) along with portable devices (e.g. laptop, tablet) which may increase small power energy use significantly. 'Mainly-mobile' workers use mainly portable devices (e.g. laptop, mobile phone) to perform both formal and informal 'communication' activities for the majority of the working day, accessing a variety of different spaces. This has a limited (or no) effect on small power energy use. The exploration of 'formality' and 'informality' in relation to 'communication' activities is important in explaining to some extent why 'mainly-static' workers consume more small power energy use compared to 'static' and 'mainly-mobile' workers, regardless of the case office site.

Confidentiality and *privacy* were referenced by 'mainly-mobile' workers in the office sites examined, pointing out the different office spaces used in order to perform 'communication' activities (e.g. speaking on the phone away from desk – using quiet pods, break-out area, corridor – for privacy). The device usage was common for most 'mainly-mobile' workers, using mainly portable devices (e.g. mobile phone, tablet) and often not plugged in, with less effect on small power energy consumption. Their reference to these meanings (c*onfidentiality* and *privacy*) was linked to their role and also to the *design of office* (e.g. open plan office). For example, 'mainly-mobile' workers who were senior workers tended to use multiple spaces, such as meeting rooms, break-out areas, and quiet pods for confidential discussions with limited device usage (occasionally portable devices such as laptop, tablet, or mobile phone) due to open plan office and privacy required.

> It's an open plan office and it's about privacy. Sometimes you would use a meeting room if you wanted to talk to someone and you didn't want anyone else to hear that those conversations do happen [P30 – Mainly-mobile; 1,000-4,999m^2]

> If the phone rings when I'm at my desk I will go out the way of other people, probably in the break-out area which is more private, isn't it? This is because I don't want to disturb them but then I probably don't want them hearing what I'm saying, it may be confidential [P32 – Mainly-mobile; 1,000-4,999m^2]

The element of meanings indicated some of the reasons why certain activities (e.g. ‘communication’ activities) are performed in particular office spaces (e.g. meeting rooms, break-out areas, quiet pods) and involve (or not) device usage. This can explain how small power energy use practices for different types of workers are shaped by the performance of their activities and the meanings ascribed to them: for example, the usage of particular office spaces to perform certain activities, such as informal interaction in the break-out area which may involve no device use; or formal meetings in a meeting room which may involve usage of associated devices available in this space. Whilst the concepts of formality and informality occur across all types of workers, those of confidentiality and privacy are mainly associated with more senior roles (‘mainly-mobile’ workers). In terms of small power energy use, this finding shows that ‘mainly-mobile’ workers (often more senior) are driven to use different office spaces and mostly portable – often not plugged-in – devices to accomplish their work (e.g. confidential and private discussions).

6.4 Do You Know the Effect of What You Do? Knowledge as Part of Small Power Energy Use Practices

Understanding how the element of knowledge influences the shaping of small power energy use practices is approached through exploring different themes and subthemes (*organization rules*, *technical background*, *type of knowledge* including *theoretical knowledge* and *verbal knowledge* as well as *understanding of device energy consumption*). The interview questions related to knowledge are aimed at understanding the level of influence of knowledge in the shaping of working practices, affecting small power energy usage.

With respect to variations in small power energy use, the number of devices provided was considered as part of the *organization rules* and they differed between the case office sites. For example, a desktop and two monitors were available for each worker, regardless their type, in office site <50m^2. In addition, a laptop or tablet was provided, depending on the role of worker and particular tasks to be completed (e.g. building managers used a tablet with software for building inspections). This directly affects small power energy use due to the availability of desk-based plugged in devices. In contrast, limitations were applied in office sites 1,000-4,999m^2 and 5,000+m^2 with respect to provision of devices to workers and their usage. For example, two monitors were not allowed to be used in these office sites, and security policies on device usage were also applied.

> I don’t have two monitors, just because it’s company policy [P20 – Mainly-static; 1,000-4,999m^2]

> There are rules that apply for anything that could be used as a storage device. We're not allowed to plug straight into a PC memory sticks or smartphones or anything like that. When we moved into these offices mid-way through last year, they installed desktop chargers so that people didn't have to put their phones into the computer to charge and that's why we've all got these devices, is because it's from a security point of view [P13 – Mainly-static; 1,000-4,999m^2]

As part of the *organization rules*, the availability of spaces and processes to be followed in order for office spaces to be accessed were different between the different office sites. For instance, workers in office site <50m^2 can access more easily available spaces (e.g. meeting rooms) and use available devices with these spaces in contrast to workers from office sites 1,000-4,999m^2 and 5,000+m^2, who are also constrained by work processes (e.g. booking processes for a meeting to take place in a meeting room).

> If it’s very formal meeting, I would use a meeting room. Depending on the sensitivity [of the agenda to be discussed] and the number of people involved. We normally use

> the conference call as well as the TV screen, so the surface hub is superb for that, we're doing Skype calls and at the same time designing anything there or sharing presentations. But we don't do that very often because it's quite hard to book a meeting room here. Informal discussions can be desk, break-out area or quiet pods if it's confidential [P14 – Mainly-static; 5,000+m^2]

> Formal meetings, that's pretty much always in meeting rooms. It's mainly related to who you are meeting and what's the subject. It's not about the availability of the rooms [P9 – Mainly-mobile; <50m^2]

> So, informal meetings may take place in the canteen for a coffee, might be around my desk or someone else's desk [P22 – Static; 1,000-4,999+m^2]

Energy initiatives undertaken by the organizations (case office sites 1,000-4,999m^2 and 5,000+m^2), as part of their polices and rules, are not necessarily related to the efficient use of devices or reduction of electricity consumption from office devices. While there is an approach on reducing energy consumption in office sites involved in the study, their policies are applied to other electrical end-uses such as lighting, with less consideration given to small power energy usage from devices.

> I know they've just announced an initiative now to make sure you turn off the lights etc. Make sure the lights are turned off in a meeting room. As regards laptop, you have to lock it every time you leave it, because of security not energy saving [P15 – Mainly-static; 1,000-4,999m^2]

Initiatives to reduce electricity consumption was about to be explored in the office site <50m2 at the time of the study with a focus on efficient technologies and cost-effective technologies (e.g. replacing light bulbs with led lamps) without the need for office workers' engagement. Some *organisation rules* of case office sites 1,000-4,999m^2 and 5,000+ m^2 in relation to device usage were based on security aspects (e.g. locking computers when away from the desk so that work cannot be seen by other people). These rules contributed to the reduction of small power energy consumption in comparison with office site <50m^2 because workers not only locked computers when they were away from their desk, but turned them off at the end of the working day. Some 30% of workers at case office site <50m^2 tended to leave computers on after leaving the office.

> Whenever I step away, I have to lock my computer. that’s organisation for security, so no one else can walk past and see what’s on our screen or get into any emails or anything like that, so it’s all about security of data so we have to lock our screen and then after that I think it goes to sleep pretty quickly [P25 – Static; 5,000+m^2]

The *technical background* as well as the *type of knowledge* including *verbal knowledge*, *theoretical knowledge* and *understanding of device energy consumption* varied significantly between workers across different case office sites. For instance, workers of office site <50m^2 tend to use devices ignoring associated electricity use and demonstrated limited understanding of the technical aspects of devices, of the differences between what is processed by devices (e.g. printing in colour in relation to printing black and white), and of device electricity consumption.

> When the computer is idle, it uses less energy, right? But we have never monitored it, so I don’t know the exact difference [P7 – Mainly-mobile; <50m^2]

In contrast, workers from office sites 1,000-4,999m^2 and 5,000+m^2 demonstrated more awareness of device technical aspects, understanding different usage of devices based on what is processed (e.g. using software in comparison with Microsoft Office) and associated electricity consumption, which can influence the way that devices are used. This awareness of *technical background* is shown to influence the way that office devices are used by workers of case office site 1,000-4,999m^2 and 5,000+m^2. This is in contrast to the workers of office site

<50m^2 who use office devices without understanding the influence of this aspect of knowledge on small power energy consumption.

> If I'm running a software, it will slow down the computer massively because it's using huge amounts of memory, it will impact performance of all the other applications that I'm using. So, I use more lighter applications like Outlook or maybe the internet browser to do my work, but I won't run any other applications because I know that this is very memory intensive and memory hungry [P14 – Mainly-static; 5,000+m^2]

> With certain applications no doubt they can be quite processor intensive and you see everything slowing down a little bit. I suppose I'm subtly aware of it. I do, I suppose, more things to try and keep impact to a minimum. If I write notes, I always use notepad on the computer, very lightweight software, hardly notice that even is running. I can be quite bad with tabs sometimes, with Google Chrome, which is quite RAM heavy and it can take its toll on the computer [P26 – Mainly-static; 1,000 – 4,999m^2]

Understanding of device energy consumption was explored to understand to what extent workers of different office sites use devices to perform work activities while having an awareness or consideration of device electricity consumption. While understanding of small power energy consumption from office devices may be limited for workers of the office site <50m^2, workers from the other two office sites (1,000-4,999m^2 and 5,000+m^2) have shown that they pay attention to differences on energy consumption depending the way that devices are used, and they also understand the effect that device usage has on the building electrical load.

> I wouldn't know [about device electricity consumption]. There's probably less [electricity consumption] at home because I only plug my laptop in when I'm charging it. When it's fully charged, I don't need to charge it, so I'm not using any energy in that respect. Here all devices are usually plugged in [P1 – Mainly-static; <50m^2]

> I have this impression when I'm using shared documents, like the Excel spreadsheet, and when I'm going to save the update takes a while, so I feel it needs more energy [P12 – Static; 5,000+m^2]

> They could be completely in the Cloud and just using the smart hub without having to plug their laptop in [P13 – Mainly-static; 1,000-4,999m^2]

Despite understanding how device use affects electricity consumption, different types of worker may not be motivated to reduce their small power energy use. For example, 'mainly-static' workers from office sites 1,000-4,999m^2 and 5,000+m^2 use partially desk-based devices (laptop or desktop computer, connected to a monitor), partially portable devices (e.g. laptop, tablet), and partially other devices available in spaces other than workstation (e.g. smart hubs in meeting rooms). But they are only focused on following organization rules on security aspects rather than on reducing small power energy consumption. 'Mainly-mobile' workers of the same office sites indicate relative understanding of device energy consumption, but without paying too much attention to it because of their limited use of devices (for few of hours per day). This can partially explain why 'mainly-mobile' workers consume less small power energy use compared to 'mainly-static' workers.

> I scan an email back to myself to then email so there's less paper used. But this consumes energy, but it's not that much, at least I save paper [P6 – Mainly-static; <50 m^2]
>
> As in using the device, apart from the IT security policies as in data storage and security, there aren't really any processes in the sense of power consumption as such [P18 – Mainly-static; 5,000+m^2]
>
> Well, I know about it [computer's electricity use when it's in use or idle mode] but I don't pay much attention to it because I don't use it that much [P31 – Mainly-mobile; 5,000+m^2]
>
> I've never really given much consideration, it's just a tool and I use it [[desktop computer / laptop] when I need it, few hours per day [P23 – Mainly-mobile; 1,000-4,999m^2]

The analysis of interviews with respect to the element of knowledge and related themes (*organizational rules*, *technical background*, and *type of knowledge* such as *understanding of device electricity consumption*) shows that small power energy use practices may be shaped unequally by aspects of an element of practice. *Organization rules* may have more influence compared to other themes of the element of knowledge on the shaping of work practices. For example, office workers follow ‘organization rules’ with respect to device usage but these are not necessarily related to the reduction of small power energy consumption. Office workers from office sites 1,000-4,999m^2 and 5,000+m^2 follow security policies on device usage but their *technical background* and *understanding of device electricity consumption* does not influence their small power energy use practices. Workers from office site <50m^2 do not have rules on device usage and have a limited understanding of device energy usage compared with office workers from office sites 1,000-4,999m^2 and 5,000+m^2. The level of *understanding of device electricity consumption* may not influence the reduction of small power energy use because there are no required rules to be followed. This particularly affects ‘mainly-static’ workers who use more office devices for longer period of a working day, at the workstation and other spaces (e.g. meeting rooms), and so they disproportionately affect small power energy consumption.

Considering the element of knowledge and associated themes, these may influence the way that small power energy use practices are shaped. The analysis above shows that some themes have a stronger influence in the shaping of small power energy use practices than others. *Organization rules* tended to shape working practices more than the other two themes (*technical background* and *type of knowledge*). These rules are followed by every worker in case office sites 1,000-4,999m^2 and 5,000+m^2, however not all are related to reduction of small power energy use. Office workers who use fewer devices (‘mainly-mobile’) have less intrinsic effect on small power energy consumption. *Technical background* and *type of knowledge* influence small power energy use practices, but only according to individual motivation. This might be associated with the lack of organizational initiatives to reduce small power energy use. Therefore, consideration of initiatives to reduce small power energy use and increase of understanding of electricity usage from office devices may help shape working practices differently, motivating workers to avoid excessive use of devices and associated electricity consumption (e.g. avoiding leaving devices on after leaving the office).

6.5 What Devices Does Your Organisation Provide and What Type of Devices Do you Use and Why? What Spaces Are Used to Perform Your Activities? Technologies/Infrastructure as Part of Small Power Energy Use Practices

After exploring small power energy use on mobility level, through the elements of habits/routines, meanings, and knowledge, the small power energy use on office space level is explored through the element of technologies/infrastructur*e*. This is to understand how small power energy use practices are shaped by devices/equipment provided (by organizations) and used by workers in different office spaces across different office sites. The examination of the interview data from questions on technologies/infrastructure was based on the themes of *office devices* and the associated *office spaces* in which devices are used by different types of workers.

Extensive references to device usage from different types of workers across different case office sites indicate variations in the type and number of devices used, which may be associated with the required work tasks to be completed as well as the role of the worker. This is exemplified by the references of the different types of worker across different office sites to what devices they typically use in different office spaces to perform work and other activities. The interview analysis shows considerable differences in device usage between 'mainly-mobile' workers and 'mainly-static' workers. For example, 'mainly-mobile' workers from case office site 5,000+m^2 would use either a desktop computer or laptop / tablet connected to the monitor at the workstation, depending on what is provided to each worker by the organization. In communal spaces (such as break-out area, meeting rooms) portable devices (e.g. laptop, tablet, mobile phone) are typically used by ‘mainly-mobile’ workers. These devices are only occasionally plugged in (depending on how activities are performed), and thus the small power energy use associated with activities using these devices varies according to how the devices are used.

> At my desk, I use my tablet, I plug into the monitor that’s on the desk. It just allows me to see everything on my email in a bigger screen. I use the keyboard which is on my desk, I use my work phone and charger. If I’m in a meeting room, if it’s just one to one, then I would normally just open my laptop and we would both look at the one screen. If it’s a big meeting, we have monthly workshops, we would have on the big TV screen. In the kitchen, just the water cooler and in the evening, if I’m here late and I need a snack, I’d use the vending machine. I use the big printer [multifunction device] for scanning to email, printing and photocopying. In the break-out area I may use my tablet, my charger if needed, and my phone [P17 – Mainly-mobile; 5,000+m^2]

In contrast with ‘mainly-mobile’ workers, ‘static’ and ‘mainly-static’ workers of office site 5,000+m^2 reference that apart from the devices provided by the organization (e.g. desktop computer or laptop, work mobile phone), some workers use additional personal devices (e.g. personal laptop) usually at the workstation. For instance, ‘static’ and ‘mainly-static’ workers use a desktop computer and laptop, or only a laptop connected to the desktop monitor, for most of the time during a working day because they mostly perform work desk-based activities alongside with other activities (e.g. having lunch), at the workstation. In addition, when ‘mainly-static’ workers are absent from the workstation, the desktop computer may still run to complete processes related to work tasks (e.g. processing of data).

> At my desk obviously I’ve got a desktop computer provided and I also bring my own laptop, and I’ve got my personal and my work phone. I use chargers to charge my work phone and my personal phone. On days I cycle in, I also charge my bike lights at my desk. I use the printer, I tend to use the multifunction device, … every couple of days … In the kitchen, I’ll obviously use the water cooler quite frequently, the hot water boiler for cups of tea. I will go into the fridge to get milk, but I don’t really store anything in there. And

> then I'll use the microwave to heat up my food. If I do need to shred something, I use the shredder … In the break-out area, sometimes I'll take my laptop with me, and sometimes my phone. That's probably 50% of the time, … When collaborating, I'll either be using my computer [desktop computer or laptop] or I'll being shown something on someone else's computer. And when I'm in meetings, … I would say that maybe a third of the time I'll have my own laptop with me, but there'll always be a laptop being used, and the screen, and most of the time, two thirds of the time there'll probably be somebody dialling in on the phone as well [P11 – Mainly-static; 5,000+m^2]

Comparing 'static' and 'mainly-static' workers with 'mainly-mobile' workers from office sites <50m^2 and 1,000-4,999m^2, interview data indicate that 'mainly-mobile' workers use desk-based devices (e.g. desktop computer) but for a much smaller amount of time in a working day (2-3 hours) in comparison with 'static' and 'mainly-static' workers, due to their increased mobility and using other communal spaces (e.g. meeting rooms, break-out area). In these communal spaces some 'mainly-mobile' workers may use portable devices (e.g. laptop, tablet) or occasionally use available devices within these spaces (e.g. smart monitors or TV screens in meeting rooms). 'Mainly-mobile' workers and 'mainly-static' workers from the same office sites (1,000-4,999m^2) by contrast reference the use of devices that affect small power energy consumption in most of office spaces (meeting rooms, break-out area, quiet pods, common function area such as printing area, kitchen).

> At my desk, I use the company laptop and I've got a work mobile phone which has my work emails and documentations on. My laptop plugged into the desk monitor, so I've got two screens majority of the time, sometimes I just use my laptop. It depends what I'm doing. In the common function area, it'll just be the printer [multifunction device] because I do scan emails. In the break-out area, my laptop and my phone will be used. In a meeting room, depending on what meeting we have, I use laptop, the smart monitor, my mobile phone, and the star phone for conference calls [P15 – Mainly static; 1,000-4,999m^2]

> I've got the desktop computer at work and I've got my own laptop when I'm away for work or when I'm on site. When I'm at my desk I use the desktop computer and monitor, I use my work and personal mobile phone, mobile charger and really those are the only devices I've got. When we're in meetings … It's all pen and paper for me … In the kitchen, I may use the water boiler for coffee, fridge to get milk, and the water cooler. When I am using the printing area, not that often, I use the black and white printer and

> the coloured one [multifunction device], depending on what I'm printing off. In the corridor, it's just my mobile phone. In the breakout area, I always have my notebook and mobile phone, just in case the director is after me for anything [P23 – Mainly-mobile; 1,000-4,999m^2]

Considering the quantity, type, and the way that office devices are used by different types of worker across different office sites, 'static' and 'mainly-static' workers of different case office sites reference the use of desk-based devices (e.g. desktop computer, Notebook, mobile charger) for the majority of their working day. Often their devices are left running to complete work tasks even when these workers are engaged in secondary activities at their workstation (e.g. informal discussion with colleagues), which increases small power energy use. Whereas 'mainly-mobile' workers spend few hours at the workstation during a working day, and when they are moving in different office spaces (e.g. meeting rooms, break-out area) they tend to use portable devices, which are often unplugged, consuming less small power energy compared to 'static' and 'mainly-static' workers.

6.5.1 Summary of Technologies/Infrastructure as Part of Small Power Energy Use Practices

Summarising the exploration of the element of technologies/infrastructure and how this is embedded in working practices, several differences between different types of workers across the different case office sites have been observed. One of these with respect to the provision of devices is related to desk-based devices. Workers from office site <50m^2 used a desktop computer with two monitors as well as laptops or tablets based on the role of worker and associated activities involved (e.g. building manager used a tablet, accessing tools, for building inspections). In office sites 1,000-4,999m^2 and 5,000+m^2 the desk-based devices provided were either desktop computer or laptop connected to a desktop monitor, but using two monitors was not allowed. The device usage in different office sites varies considerably based on the mobility and role of workers, affecting small power energy use in different office spaces. For example, ‘mainly-mobile’ workers – usually senior workers (e.g. senior project managers, directors) – in all office sites used either a desktop computer or laptop for desk-based activities. These desk-based activities lasted less than three hours per working day, and at other times they used mainly mobile phones and/or tablets (often unplugged for the majority of the day) to perform ‘communication’ activities. While ‘static’ workers (usually junior workers, such as administrators) and ‘mainly-static’ workers (usually less senior workers such as managers) used multiple devices to perform desk-based activities (e.g. desktop computer, laptop, tablet, mobile phone, charger), for the majority of the working day or half of the working day. This was often in combination with other activities (e.g. having lunch at the desk using desktop computer) and so these types of worker continuously affect small power energy consumption. The quantity of devices and the ways that devices are used differs between worker types and office sites. For example, ‘mainly-static’ workers from office site 5,000m^2 used personal devices (e.g. personal laptop) as well as devices provided by the organization. They also set the computers to run constantly in order to complete work tasks, regardless of their presence or absence at the workstation. This was in contrast to ‘mainly-mobile’ workers of the same office site, who used desktop computers or laptops connected to a monitor and portable devices (e.g. tablet, phone) but often not plugged in. In addition, ‘static’ workers from office site <50m^2 used multiple devices at the workstation (e.g. desktop computer, two monitors, mobile phone, charger, laptop and/or tablet) in comparison with ‘mainly-static’ and ‘mainly-mobile’ workers of the same office site, who used either desktop computer or laptop with two monitors, as well as tablet and mobile phone occasionally to perform desk-based activities and ‘communication’ activities.

Observing that the quantity, type, and the way that devices are used by different types of worker are linked with their activities which are driven by the *role of worker* and associated *mobility*, the use of *office spaces* varies accordingly. The office space usage is also influenced by the *design of office*. For instance, open plan office contributes to the usage of other available spaces beyond workstations (e.g. meeting rooms, break-out areas, quiet pods), mainly for the performance of ‘communication’ activities in the form of interaction, privacy and confidentiality, as referenced by most ‘mainly-mobile’ workers. All the above factors explain to an extent why ‘static’ and ‘mainly-static’ workers consume more small power energy at workstations compared to ‘mainly-mobile’ workers (see Section 5.6.3). While interview analysis shows that office space usage is influenced by the *design of office*, this research did not specifically focus on office design and only considered it as an emerging theme that was primarily associated with floor layout. It is suggested that further research on workplace design can be approached as a combination of physical spaces (e.g. the type of open plan office and spatial arrangements), virtual spaces (e.g. ICT and social networking) and social spaces (e.g. social relations and space use) and associated office electricity consumption (see previous and recent work by Nenonen, 2005; Boge, et al., 2019).

The analysis has used the elements of SPT related to habits/routines, meanings, knowledge, and technology/infrastructure, to explore how working practices associated with small power energy can be used to interpret the quantitative analysis (presented in Chapter 5). The next chapter synthesizes the quantitative and qualitative findings to improve understanding of what small power energy is used for.

Chapter 7: Discussion of Quantitative and Qualitative Findings

This chapter discusses the quantitative findings from Chapter 5 and the qualitative exploration of the practices behind these findings (Chapter 6) in the context of key literature. Section 7.1 presents an overview of the key findings from the quantitative and qualitative analysis. The following section (7.2) presents a discussion of the quantitative and qualitative analysis of small power energy use in terms of energy-consuming work activities. In particular, it reviews findings relating to how workers understand these activities in terms of the meanings they give to them, the knowledge they share about them and the devices and technologies they use when performing them. The chapter concludes (Section 7.3) with a discussion on the role and usefulness of Social Practice Theory (SPT) in research on understanding small power use in office buildings.

7.1 Overview of Key Findings

The quantitative analysis (see Chapter 5) identifies variations of small power energy use by different types of worker in the office sites examined (see Section 5.6) and shows that worker mobility is a key determinant of small power energy use in these offices. The key findings related to small power energy consumption from Chapter 5 can be understood based on the mobility of workers (regardless of case office site), the time of day that small power energy is used by different types of worker, and the office in which energy consuming work practices are performed. Chapter 6 explores the findings of the quantitative analysis and helps to explain how small power energy use practices, assessed through elements of habits/routines and technology/infrastructure drawn from SPT, are influenced by worker mobility, examines how the role of workers largely determines their mobility, and how elements of meanings and knowledge drawn from SPT can help understand the ways that activities are performed and devices are used. Table 7-1 shows the synthesis of the key quantitative and qualitative findings and how the latter help to interpret the quantitative findings based on the exploration of the elements of SPT and their contribution to understand work practices with implications on small power energy use.

Table 7-1. Synthesis of key quantitative and qualitative findings

Quantitative Analysis (Chapter 5)	**Exploration of small power energy use practices with respect to mobility of workers through the elements of activities, devices and office space usage (Chapter 6)**	**Understanding small power energy use practices through elements of meanings and knowledge (Chapter 6)**
‘Mainly-static’ workers account for more small power energy use in comparison with ‘mainly-mobile’ workers, regardless of case office site. The same result was also found in the comparison of different case office sites (at the case office site 5,000+m^2).	In terms of activities, ‘mainly-static’ workers divide working time between desk-based activities and ‘communication’ activities, using spaces other than the workstation (e.g. break-out areas, meeting rooms) for ‘communication’ activities. In contrast, ‘mainly-mobile’ workers perform more ‘communication’ activities than desk-based activities, using their workstation for less than three hours per day. In terms of devices, ‘mainly-static’ workers use desk-based plugged-in devices (e.g. desktop, laptop, monitor(s)) for half of their working day. They also use devices in other spaces (e.g. laptops, TV screens, and smart hubs in meeting rooms). In contrast, ‘mainly-mobile’ workers use desk-based plugged in devices less often (for less than 3 hours per day) and use mostly portable devices (often not plugged in) in other office spaces.	Different types of workers explained the association of certain activities such as ‘communication’ activities (e.g. interaction with people through formal/informal meetings, confidential discussions and collaborative work, private phone calls) and the spaces in which they were performed by reference to concepts of formality, informality, confidentiality, and privacy.

Quantitative Analysis (Chapter 5)	**Exploration of small power energy use practices with respect to mobility of workers through the elements of activities, devices and office space usage (Chapter 6)**	**Understanding small power energy use practices through elements of meanings and knowledge (Chapter 6)**
'Mainly-static' workers account for more small power energy use in the afternoon in comparison with 'mainly-mobile' workers, regardless of case office site.	'Mainly-static' workers tend to perform more desk-based activities in the afternoon, using desk-based devices which are plugged in, while in the morning they tend to perform more 'communication' activities, using either portable devices (that may not be plugged in) or available devices in other spaces than at the desk. 'Mainly-mobile' workers tend to perform 'communication' activities for a significant period throughout the working day, using portable devices (which may not always be plugged in).	Technical understanding and knowledge of the relative energy processing profiles of devices is only one of the reasons that workers may choose to use certain devices to conduct their work. Other reasons include familiarity, availability of device, environmental concerns etc. This may explain why workers use high specification devices (e.g. multifunction device vs black and white printer) which consume more electricity, when a lower specification device would suffice. This may also explain why a worker might choose to perform a particular activity (based on environmental concerns may choose scanning to save paper instead of printing), rather than considering relative electricity use of devices involved in this activity.
'Static' and 'mainly-static' workers account for more small power energy use at the workstation compared to 'mainly mobile' workers, regardless of case office site.	'Static' workers perform mainly desk-based processing activities, which tend to consume more electricity. They use desk-based plugged-in devices most of the working time (e.g. desktop computer, monitor(s), laptop, tablet), compared to 'mainly-mobile' workers. Similarly, 'mainly-static' workers spend half of their working time performing desk-based activities and use desk-based plugged-in devices compared to 'mainly-mobile' workers. The latter spend limited amount of time at the desk (less than 3 hours) and tend to use mainly portable devices (which may not always be plugged in) to perform mainly 'communication' activities in different office spaces.	Different workers work within different organizational rules depending on the case office site to which they belong (the organisational rules were different across the different office sites). For example, in two case office sites there were rules on provision of devices that allowed the use of only one desktop monitor at the workstation. In addition, securing aspects of device usage were applied (e.g. lock devices when away from the desk to avoid access of others to someone's confidential work)

Expanding on Table 7-1, three important findings emerge. The first relates to different types of workers performing a variety of activities in different office spaces, involving different type and quantity of device usage. An important distinction relates to job role, as follows:

- ‘Static’ workers perform desk-based office work, and interaction with people takes place mainly at the desk, using desk-based devices. This type of worker is associated with ‘process’ workers (e.g. administrators, lawyers) in the case office sites.
- ‘Mainly-static’ workers divide working time between desk-based work and interaction in the form of meetings or collaborative work in spaces other than at the desk (e.g. break-out areas and, less often, meeting rooms). They tend to use available devices in different office spaces (e.g. desk-based devices, devices in the meeting rooms such as smart hubs, desktops or laptops connected to TV screens). This type of worker is associated with ‘middle-senior’ workers (e.g. Managers).
- ‘Mainly-mobile’ workers mostly interact with people in a variety of different office spaces (e.g. break-out areas, meeting rooms, quiet pods, corridor) and undertake desk-based work for a small proportion of time during a working day (between two and three hours). This involves limited desk-based device usage and increased usage of portable, often not plugged-in devices. This type of worker is associated with ‘senior’ workers (e.g. senior managers, heads of department, directors).

Secondly, different types of workers associated certain activities such as ‘communication’ activities (e.g. sending emails, speaking on the phone, teleconference, interaction with people through formal/informal meetings and collaborative work) with the concepts of formality, informality, privacy, and confidentiality (the meanings that workers gave to these concepts were elaborated in Chapter 6). These communication activities are performed in different office spaces, requiring the use (or not) of a range of devices. An important distinction is that:

- Informal ‘communication’ activities (e.g. conference calls, informal meetings) were performed by ‘static’ and ‘mainly-static’ workers mainly at the desk, using desk-based devices.
- Formal ‘communication’ activities which were performed by ‘mainly-static’ workers involved usage of spaces other than workstations, such as meeting rooms, using available devices in these spaces (e.g. surface hubs, TV screens) along with portable devices (e.g. laptop, tablet).
- Formal and informal ‘communication’ activities, which were performed by ‘mainly-mobile’ workers took place across most of the working day, involved usage of a variety of different spaces and mainly portable devices (e.g. laptop, tablet, mobile phone).
- ‘Communication’ activities related to confidentiality and privacy (e.g. speaking on the phone away from desk – using quiet pods, break-out area, corridor – for privacy) were mostly performed by ‘mainly-mobile’ workers with limited device usage (occasionally portable not plugged-in devices such as laptop, tablet, or mobile phone).

Finally, different types of workers have different technical understanding and knowledge of the relative energy processing profiles and energy consumption of devices, as well as working under different organizational rules. An important distinction relating to device usage is that:

- Different workers from case office site <50m^2 (except for one ‘mainly-mobile’ worker) had a limited understanding of device energy consumption, and there were no organisational rules on how devices are used with respect to electricity consumption on this site (at the time of the study). In this case office site, devices provided included a desktop, two monitors, and mobile phone for each worker, regardless of their role. In addition, depending on the role of workers and the particular tasks to be completed, a laptop or tablet was also provided. The number of devices provided, in combination with a lack of knowledge on device electricity usage and the absence of organisational rules, may be argued to have had a considerably higher effect on small power energy use in this case office site.

- Different types of worker from case office sites 1,000-4,999m^2 and 5,000+m^2 have shown that they pay some attention to energy consumption, depending the way that devices are used, and also understand the effect that device usage has on the building electrical load. Organisational rules involved security policies on device usage and restrictions on the provision of devices (e.g. two monitors were not allowed to be used in these office sites).

Having reviewed the main qualitative and quantitative findings about variations on small power energy use in the case study offices, the next section discusses how they relate to key literature in this field in order to set the study findings in a wider context. The next section also discusses the contribution of this study to research on small power energy use in offices.

7.2 Understanding How Small Power Energy is Used and What it is Used For

Understanding variability and patterns of energy consumption in offices, and the social origins of those patterns through an examination of their associated work activities and device usage, are important elements to help understand what small power energy is used for. This study shows, based on activity observation and interview data (see Section 6.2 exploring the theme observed work activities), that there are four common categories of energy-consuming work activities in the office sites studied. The first of these is 'routine process work' (containing a wide range of activities, e.g. budgeting, auditing of logbooks, project process development, working on web-based software). The second category consists of 'concentrated work' (e.g. reading and reviewing documents/contracts, developing reports). Thirdly there are 'communication' activities (e.g. emails, collaborative work, interaction through formal meetings or informal meetings, teleconferences, phone calls). Finally, the fourth category consists of 'extracting/organizing document' activities (e.g. printing, scanning, photocopying, archiving). With respect to activities performed that are not directly related to work (see Section 6.2 exploring the theme other observed activities), these were related to 'preparing/having coffee in the kitchen', 'preparing/having lunch in the kitchen', 'having lunch/coffee at the workstation' or 'having lunch/coffee at a communal area' (e.g. canteen). These activities have been identified in earlier studies (which assessed activities in the workplace) based on: i) observation or feedback from workers (Appel-Meulenbroek, et al., 2011; The Stoddart Review, 2016), ii) user simulation of space utilisation looking at the nature of activity (social, physiological or job related) including individual or group activities and planned or unplanned activities (Tabak, 2009), iii) office activity surveys to identify energy-use-impacting practices (Jaskiewicz and Keyson, 2015), or iv) a combination of observation, surveys and interviews in relation to the performance of office activities (Steen, et al., 2005). However, these studies have not related the identified work activities to small power energy consumption.

Some of the findings of this study on office activities support earlier studies to identify energy savings from office plug loads. These studies have assessed the role of office activities in energy consumption using data obtained through presence of sensors to assess the occupancy of workstations and other office spaces, and the interaction of occupants with office devices (Nguyen and Aiello, 2013; Zhao, et al., 2013). However, these studies have not explicitly indicated measurements of small power use from office activities and device usage, nor have they associated activities in offices with worker mobility. This study contributes to this research area by associating worker mobility with activities performed and device used (from observational data) as well as measurement of small power energy use (monitoring). The findings show that 'static' workers performed mostly desk-based activities, 'mainly-static' workers performed partially desk-based activities and partially 'communication' activities, while 'mainly-mobile' workers performed mostly 'communication' activities throughout the day, regardless of case office site. With respect to small power energy use per working day for different types of worker considering the activities performed and devices used (excluding the standby power[23] of devices), this study shows that 'mainly-static' workers account for more small power energy consumption (0.31 kWh/worker/working day) compared to 'static' and 'mainly-mobile' workers (0.30 kWh/worker/working day and 0.22 kWh/worker/working day respectively). This finding is explained further below. Considering the dimension of timing and small power energy use, this study shows that 'mainly-static' workers consume more small power energy in the afternoon compared to 'static' and 'mainly-mobile' workers. This association of different types of worker with electricity consumption from office devices when work activities are performed also represents a new contribution to the research on small power energy use in office buildings.

This study identified that the average number of devices used by different types of workers in the different office spaces studied was 6.6 devices for 'static' and 'mainly-static' workers and

[23] The effect of standby power in small power energy use has been identified to range from 22% (Mulville, et al., 2014) to 33% (Crowe, 2013) of the total small power energy use, while a more recent study found that standby power may reach up to 75% (Gunay, et al., 2016) of the total small power energy use.

6.9 devices for ‘mainly-mobile’ workers per working day. This is in line with Hafer (2017) who conducted an inventory of plug loads and occupancy density in 220 buildings in a university campus, showing that 6.6 plug load devices are used per occupant. Likewise, Acker, et al. (2012) assessed commercial office buildings of different sizes and found average equipment density to be 6.7 devices per occupant. In contrast, Webber, et al. (2006) studied small, medium, and large offices, healthcare facilities, and education facilities and found an average of 8.9 devices to be used per occupant. The difference between these studies could be accounted for by the different ratio of types of worker and also the different role and work requirements of workers (e.g. healthcare and education workers) in relation to their device/IT intensity. This association of the average number of devices used per type of office worker could help future studies to use this as a basis for planning future energy monitoring and evaluation studies.

The exploration of small power energy use practices helps explain why ‘mainly-static’ workers consume more small power energy compared to ‘static’ and ‘mainly-mobile workers’. This study shows that ‘static’ workers use mainly desk-based plugged-in devices (e.g. desktop computer connected to one or two monitors) for the majority of the working day due to the performance of mainly desk-based activities. ‘Mainly-static’ workers use desk-based devices, as well as plugged-in devices available in other office spaces (e.g. smart hubs and TV screens in meeting rooms), and also portable devices (e.g. laptop, tablet) to accomplish work tasks (e.g. routine process work, formal / informal meetings etc.). In contrast, for most of the time, ‘mainly-mobile’ workers use portable, often not plugged in devices (e.g. laptop, mobile phone) to perform their work activities. These mainly involve interaction with people (through formal or informal meetings) and the use of different office spaces (e.g. meeting rooms, break-out areas), while the amount of time spent at workstation and usage of plugged-in devices (e.g. desktop computer) is limited (two to three hours). This helps explain why ‘mainly-mobile’ workers consume less small power energy compared to ‘static’ and ‘semi-static’ workers. This finding, which associates the type of devices used in offices with different types of worker, represents a further contribution to understanding the dynamics of small power energy use in office buildings in terms of the device use of different kinds of office workers.

For a practice to exist, it requires people's time and regular performance by a considerable number of people (Spurling, et al., 2013), and also spaces where performance of practices can take place. For example, having a formal/informal meeting in offices requires a place where this activity can be performed - such as meeting rooms, workstation, break-out areas, quiet pods, etc. With respect to the office space usage and associated small power energy use, this study shows differences in working practices which impact small power energy use, based on the mobility of workers. At workstations, ‘static’ workers account for the highest small power energy consumption (0.28 kWh/worker/working day), followed by ‘mainly-static’ workers (0.25 kWh/worker/working day) and ‘mainly-mobile’ workers (0.15 kWh/worker/working day). This can be attributed to the variation in work practices undertaken by different types of workers, including the type of activities performed (e.g. desk-based activities or ‘communication’ activities) and associated device usage (e.g. desk-based devices or portable devices). This finding helps inform results from a previous study which estimate that the electricity usage at workstations may account for up to 88% of total small power energy use from office devices and equipment (Junnila, 2007). The result of Junnila’s study (2007) may be attributed to the type of worker involved (e.g. ‘static’ and ‘mainly-static’ workers), whose working practices can have a greater effect on electricity usage than others (e.g. ‘mainly-mobile’) because of increased time spent at the workstation. Previous studies have shown that ‘actual’ utilization of devices by office occupants (i.e. the actual time the device is used to perform a work task rather than the total time that the device runs) can be as low as 43% of total small power energy consumption (Kawamoto, Shimoda and Mizuno, 2003). This low device utilization may be attributed to working practices, including performance of activities and device usage, in association with worker mobility, particularly by 'static' and 'mainly-static' workers. For instance, 'static' workers may perform 'routine process work' and interrupt this activity for interaction with co-workers or have lunch at the workstation, leaving devices on.

Working practices and space utilization (with respect to the time spent at the workstation) have been associated with work roles. A recent study considered different roles such as administrators, middle managers, and top managers from three organizations, and shows that administrators and project staff spend most of their time at their workstations, while managers spend considerable amounts of time in meetings (Boge, et al., 2019). This resonates with the findings of this study which show that those who perform desk-based working practices, spending most of their time at the desk ('static' workers), are associated with process workers (e.g. administrators). Limited use of workstations is related to working practices of senior workers (e.g. senior managers) due to their increased mobility ('mainly-mobile' workers). This observation of office space utilization from different types of worker and related roles influences working practices in terms of 'what' and 'how' activities are performed and 'what' and 'how' devices are used. This study shows that mobility of workers, which is associated with the role of workers, is a key contributor to small power energy use practices.

This understanding of 'how' and 'why' certain working practices are performed in a particular way in specific office spaces (involving (or not) device usage) is informed by the concepts of 'formality', 'informality', 'privacy and confidentiality'. These concepts have been used to understand differences between types of office environment (e.g. effective, efficient, productive, flexible, creative), activities which are encompassed within each type of office, and attributes of activities (e.g. duration, frequency, and importance) (Appel-Meulenbroek, et al., 2011). However, these concepts of 'formality', 'informality', 'privacy and confidentiality' have not been associated with the different types of workers in offices. This study explores these meanings in terms of 'communication' activities, for example, (short or long) formal meetings, informal (short) interaction between workers, private phone calls, (short or long) confidential discussions. This study shows that formality, informality, privacy and confidentiality apply to all types of workers in the different case office sites. The main difference is that 'static' and 'mainly-static' workers mostly referred to formality and informality in terms of meetings and interactions with co-workers. Beyond formality and informality, 'mainly-mobile' workers referred also to privacy and confidentiality, due to their more senior roles and related work tasks (e.g. reviewing confidential contracts/documents), including confidential discussions, private telephone conversations etc. These meanings helped also to improve understanding on 'why' different office spaces were used by different types of workers to perform similar work activities. For example, 'mainly-mobile' workers used quiet pods to do concentrated work (e.g. review of a contract) or corridors and break-out areas to have a telephone conversation, while 'static' and 'mainly-static' workers performed similar activities mainly at the workstation. This observation helps to understand why 'mainly-mobile' workers have a relatively lower effect on small power energy use in comparison with 'static' and 'mainly-static' workers, who perform more desk-based activities and use more desk-based plugged-in devices.

This study shows that organization rules related to device use in the case office sites were mainly focused on the security aspects of device usage rather than reducing the amount of electricity consumption. Energy-saving initiatives in the office sites were focused on end-uses other than small power use, and were directed at 'switch off' behaviour, such as for lighting in certain areas. These organizational rules, either related to security aspects of device usage or to energy saving from switch-off of lighting were found to have an important influence on the practices of workers, regardless of their type ('static', 'mainly-static', 'mainly-mobile'). This study found that workers from two case office sites, where security aspects of device usage were applied, tended to turn off desktop computers after leaving the office (100% of workers), while a number of workers (some 30%) at the case office site without similar rules tended to leave their computers on. This strong influence of organization rules has also been explored by Young, et al. (2015) who argue that organizational culture and policies on environmental initiatives can be effective, influencing the perception of workers and enforcing norms to be socially accepted. The role of office management and organizational decision making has been widely identified as important in creating opportunities to reduce energy usage in the workplace (Zibarras and Coan, 2015; DECC, 2014b; Sawang and Kivits, 2014). However, although energy savings and changes in practices can be cost-effective, they are often seen as secondary priorities to strategic goals and policies, and so may not be pursued by organizations (Janda, 2014). This study shows that organizational rules (e.g. security aspects of device usage) can contribute indirectly to changing energy-consuming activities in office buildings.

With respect to the understanding of device energy usage and its influence on the performance of work practices, this study shows that workers who had some understanding of small power energy use of devices may not be motivated to use devices in a more energy-efficient way nor alter their working practices. Similar observations on household energy consuming activities and device use have been made. These suggest that although household occupants show an understanding of device electricity usage, they are not necessarily motivated to take conscious decisions to save energy by using devices in a more energy-efficient way (Schipper, et al., 2003). This would imply that knowledge through understanding of device energy use is not always sufficient to alter energy related practices. Peer-education (van Dronkelaar, et al., 2016), provision of information regarding energy use (e.g. feedback) (Mulville, et al., 2017), engaging building occupants with energy data (Whittle, et al., 2015), and upgrades on technology and infrastructure (Cox, et al., 2012) may all be effective strategies to achieve reductions on electricity usage in office buildings. However, in the discourse of energy-related practices, technological innovation on its own may not achieve behavioural change and reduction of energy demand (Spurling et al., 2013). A similar complexity has been identified by Janda (2014, p.49), who argues that energy efficiency and conservation opportunities are to be better understood "at the intersection of organizational factors, occupant behaviour, and technology adoption". This study supports Janda's observation by showing that energy-saving initiatives, provision of efficient devices and equipment, and some aspects of organisational rules (e.g. restriction of device provision) reduce small power energy use in the office sites examined. However, it is worth reflecting on the outcome of Janda's study which examines the role of social and organizational factors in energy efficiency adoption by two different types of stakeholders involved: i) occupants and ii) organizations.

By focusing on the efficient behaviour of occupants, Janda argues that short-term gains can be achieved "by inducing occupants to change the way they use technologies and spaces" (Janda, 2014, p.50). She also identifies the lack of established mechanisms (e.g. monitoring energy usage in different office spaces to identify energy waste) to ensure that occupants use technologies and spaces efficiently. From the perspective of Social Practice Theory, this study shows that electricity usage (from device and equipment usage) in offices is also influenced by the different mobility of office occupants and their working practices. This suggests that more detailed exploration of the aspects of practices (knowledge, meanings, routines, and technologies) could lead to further improvements in understanding of how changing working practices might achieve reductions on small power energy consumption.

With respect to organisational factors that focus on implementing and managing efficiency, Janda (2014) discusses the influence that organisational management can have on the identification of energy-efficiency practices as cost effective investments and their consideration as part of the strategic goals of the organisation. This is further dependent on the ‘capacity’ of the organisation to act in favour of energy efficient goals but also the ‘condition’, either in terms of technical or use characteristics, of the buildings that are to be targeted for improvement. This study has underlined the potential importance of organisational factors on reducing energy use in offices and has explored the role of organisational rules in relation to device and space use in particular. Further consideration could be given, for example, to organisational energy-efficiency initiatives (e.g. switch off devices before leaving the office and restriction on device provision to office workers) on the reduction of small power energy use. A wider consideration and exploration of the organisational dimension could potentially broaden the understanding of the aspects that influence small power energy use.

7.3 Social Practice Theory and Small Power Energy Use

SPT views energy as “an ingredient of specific social practices” and “situates energy demand as part of, and as in no way separate from, the dynamics of social practices” (Shove and Walker, 2014, p.51). Examining social practices to understand what people do in offices which affects small power energy use has been shown to be a complex challenge. This exploration of small power energy use practices helped to extend the understanding of ‘how’ and ‘why’ small power energy consumption varies in offices. Mobility, influenced by the work role, was found to be a key contributor to this understanding. Some of the aspects that constitute working practices, which help to explain small power energy consumption, are summarised below.

- *energy-related activities*: performed by different types of workers such as 'desk-based' activities associated with 'static' and 'mainly-static' workers or 'communication' activities associated with 'mainly-static' and 'mainly-mobile' workers,
- *technologies and infrastructure*: devices used by different types of workers (such as desk-based plugged in devices associated with 'static' and 'mainly-static' workers, or portable devices associated with 'mainly-static' and 'mainly-mobile-workers'). Also, office spaces: used by different types of workers (such as single office settings – e.g. workstation – associated with 'static' and 'mainly-static-workers', or other office spaces, such as meeting rooms, break-out areas, quiet pods etc. associated with 'mainly-static' and 'mainly-mobile' workers),
- the concepts related to the element of meanings behind the performance of activities: *formality* and *informality* (associated with 'static', 'mainly-static', and 'mainly-mobile' workers), as well as *privacy* and *confidentiality* (mostly associated with 'mainly-mobile' workers),
- *knowledge of office devices electricity usage*: including *organizational rules* applied in different case office sites (such as provision of a certain number of devices for each worker, restrictions on the number and type of device use, and security aspects of device usage).

These elements of SPT were associated with mobility of workers and give an insight into the complex picture of what people are doing in an office environment with implications for electricity usage. The use of SPT helps highlight some important aspects of working practices with implications for small power energy use (e.g. *organizational rules*, *knowledge of device energy usage*, *energy related activities* as well as *device and space usage*), but also shows the complexity of these practices. If further research is to be focused on changing working practices to reduce electricity demand in offices, the development of organizational rules related to energy-initiatives on device usage has some potential in this regard. This can be further enhanced by improving office workers' understanding of device energy consumption. This, in turn, may alter energy related activities so that they may be performed in a more energy efficient way by different types of workers (who are associated with particular work roles). This study shows that the same types of workers with the same work roles ('mainly-static' workers associated with middle-senior managers) performed similar work activities but used different numbers of devices, which caused variations on small power energy use. For example, 'mainly-static' workers at case office site <50m^2 used a desktop with two monitors in addition to a laptop or tablet and a work mobile phone at the workstation, while 'mainly-static' workers at case office sites 1,000-4,999m^2 and 5,000+m^2 used a desktop with one monitor or a laptop connected to one monitor at the workstation due to organizational restrictions on the number of devices provided (i.e. the usage of two monitors were not permitted at the desk). The exploration of working practices through the performance of activities and subsequent device usage plays an important role in understanding variations on small power energy use for different types of workers, as well as how and why these variations are caused. For example, higher small power energy consumption by 'mainly-static' workers (compared to 'mainly-mobile' workers) is due to a combination of the performance of 'desk-based' and 'communication' activities'. In turn, this is related to usage of desk-based devices and available devices in spaces other than the desk (either plugged in devices or portable, not always plugged in, devices). The use of SPT in this study shows some of the complex aspects of social practices and helps to explain variations in small power energy consumption in office buildings.

However, SPT does not explore individual behaviours (and associated aspects such as personal perceptions, attitude, and preferences) that may influence how work activities are performed and how associated devices are used. Therefore, individual behavioural elements (for example, individual energy habits and perceived behaviour control for switching-off devices / equipment when leaving a work area) were not explored in this research.

Moreover, while the element of '*knowledge*' in SPT helped to explore the extent to which some aspects of organisational rules and processes may influence the use of space and technologies, and thus small power energy (see 6.4 above), it did not do so with an explicit focus on organisational matters. Such a focus, with a consideration of organisational structure and management in the foreground (e.g. examining the responsibilities that workers might have for others) could have contributed further understanding about the wider role that organisational aspects could have in small power energy use. However, this was considered beyond the scope of the SPT approach adopted.

Instead, the focus of this study is more on understanding observed work practices in the day-to-day routines and processes of office work, to help understand their effect on small power use in offices and so to address the research question of 'what small power energy is used for'. In summary, this approach allowed an understanding of how small power energy use is influenced by office working practices, which explored through work routines and the meanings ascribed to them, the use of technology in different office spaces as well as the influence of organisational rules and the knowledge about the energy used by devices and equipment. However, the exploration of these aspects of work practices did not give an exhaustive understanding of the underlying behaviour that may be motivating particular practices, or all of the wider organisational context within which such behaviour may take place.

If further research seeks to assist in changing current small power energy use practices to more sustainable working practices in offices, this study provides departure points for further exploration of social aspects to help achieve reduction of electricity demand in offices.

Chapter 8: Conclusions

This chapter presents an overview of the study, including its scope and the theoretical and methodological approaches utilised. The chapter draws conclusions on the extent to which the research objectives have been addressed. It then outlines the theoretical contribution of this study, as well as implications of the study for practitioners and policy makers. The chapter concludes by discussing limitations of the research and suggesting areas for further investigation.

8.1 Overview of the Study

The scope of this study is to investigate variations on small power energy use in office buildings by improving understanding of electricity used in the performance of office work practices. The exploration of working practices through the elements of Social Practice Theory (SPT), including habits/routines, technologies (e.g. the electrical devices) and the associated infrastructure (office spaces) used to support them, helped to interpret the variations in small power energy use seen across the office sites examined. As such, the use of SPT provided a useful mechanism to understand complex interrelationships between the different elements of small power energy use practices. One of the main contributions of this study is to shed new light on these variations beyond the results of more quantitative approaches which identify small power energy use in relation to the total electricity consumption of an office building, or which compare device electricity usage of multiple buildings and attempt to predict small power energy use. This allows important insights in understanding effective ways for achieving energy savings from electricity consumption in offices.

This study has taken an unconventional approach by using quantitative and qualitative analysis to understand the use of small power energy in offices and what it is used for. Findings from this study are based on three different case office sites using data from energy monitoring (of device electricity usage) and observation (of activities performed and associated device and space used) of 32 participants over two different working days per worker. Where observation was restricted, this data is supplemented by interview data from a short self-completion questionnaire and also by in-depth semi-structured interviews, both of which help to understand what work is being performed when energy is being used. Although the sample of workers included is relatively small, and cannot be claimed as representative of a wider population of office workers (and therefore results cannot be generalised), this study has yielded some rich insights with respect to working practices and associated small power energy use in offices of different sizes and for a range of different types of office workers.

Having reviewed the literature and identified factors which cause variability of small power energy use (e.g. differences in definitions and scope of studies, methods used, as well as building characteristics and use characteristics of office buildings), it was argued that variations in small power energy use in offices can be better understood by looking at the relationship of energy-related work practices involving activities of office workers, available office spaces, and office equipment used across time (i.e. over a working day). To understand small power energy use and associated work practices, a mixed method approach was used to combine observation of work and other activities and device usage in different office spaces with measuring of device electricity usage. Elements of SPT were used to help explore the quantitative analysis on small power energy use further in terms of office work practices.

In contrast to findings of current studies on small power energy use which are mostly dependent on the number and size of organization as well as occupancy density of office workers (e.g.

Tetlow, et al., 2015; Menezes, et al., 2011; Dunn and Knight, 2005), the key findings of this study show that small power energy consumption is also dependent on the type of office worker and their associated work roles. Overall, ‘mainly-static’ workers, associated with ‘middle-senior’ workers (such as middle-senior managers) are found to consume more small power energy compared to ‘static’ workers (associated with ‘process’ workers, such as administrators, lawyers, data analysts), and ‘mainly mobile’ workers (associated with ‘senior’ workers, such as senior managers, heads of department, directors). Considering the dimension of temporality, ‘mainly-static’ workers were found to consume more small power energy in the afternoon in comparison with ‘mainly-mobile’ workers.

This understanding of the relationships between worker mobility, the dimension of temporality, and the work roles of office workers on variations of small power energy use is of importance in assessing small power energy use in office buildings (and can be used further for more appropriate estimations of the capacity of energy systems, such as HVAC, in offices). Moreover, the findings of this study help explain why there has been such variation in previous studies which examined small power energy use in offices. Different energy-consuming activities performed, and subsequent associated devices used, mobility of workers, and associated work roles all account for variation on small power energy consumption in the office sites examined. This holds the potential to establish new parameters for future research on the design of energy systems in offices, given that the current regulations of energy consumption exclude small power energy usage. This may possibly be achieved by estimating small power energy use in office buildings in terms of the mobility of workers and associated work roles.

8.2 Addressing the Research Objectives

Understanding what people are doing in an office environment and how this affects small power energy use is investigated through the four objectives of this study. These objectives are related to the identification of energy-related work and other activities, identification of device usage to perform work and other activities relating the effect of small power energy use by devices (which are used to perform activities in different office spaces), and exploring how working practices shape small power energy use. Mobility of workers was an inherent variable in each of these objectives to understand differences between different types of workers ('static', 'mainly-static', 'mainly-mobile') and variations of small power energy use in offices. A summary of the key findings for each of the objectives of this study, together with an analysis of the role of SPT in this research, is presented below and is followed by a more detailed review.

The first objective - To understand what office work and other activities are performed in different office spaces that use energy-consuming devices and equipment - was assessed through analysis of observational data and interview data. The main energy-consuming activities performed in the office sites studied are related to the desk-based activities (e.g. routine process work, concentrated work), 'extracting/organizing document' activities (e.g. printing, scanning, photocopying, archiving), 'communication' activities (e.g. emails, collaborative work, interaction through formal meetings or informal meetings, teleconferences, phone calls) which take place either at the workstation or in other office spaces (e.g. meeting rooms, break-out areas). Other activities not related to work have also been found to affect small power energy use, such as preparing/having coffee in the kitchen, preparing/having lunch in the kitchen, having coffee/lunch at the workstation. This study shows the number and type of energy-consuming activities performed in the different case office sites and how these vary for different types of workers. While 'mainly-mobile' workers performed a higher number of activities in two case office sites, their small power energy use was lower compared to 'static' and 'mainly-static' workers. This is related to the type of activities performed (more 'communication' activities due to their increased mobility, with lower effect on small power energy use than 'desk-based' activities which have higher effect on small power energy use due to the usage of plugged in devices).

The second objective - To understand what types and quantities of office devices and equipment are used to support the performance of these office work activities - was also assessed through analysis of observational data and interview data. This study shows that the number of devices used to support work activities in different office spaces in the office sites examined does not vary significantly for different types of workers (average of 6.6 devices per working day for 'static' workers, similar to 'mainly-static' workers, and 'mainly-mobile' workers who used an average of 6.9 devices per working day). However, the type of devices used, for example desk-based (plugged-in) or portable (not always plugged in) devices, differs and consequently electricity usage varies considerably for different mobility of workers.

The third objective - To measure what small power energy is consumed by these equipment/device-using activities in different office spaces - was assessed through analysis of observational and monitoring data. This study shows the variability of small power energy use for different types of workers based on their performance of activities and device usage in different office spaces. The key findings of this study have been outlined in the previous section (8.1) and are further discussed below. Significantly, workers who divide their time in the office between the workstation and other spaces (as 'mainly-static' workers) consume more small power energy compared to workers who spend less time at the desk and use different office spaces across the working day to complete work tasks (as 'mainly-mobile' workers).

The final objective - To explore how small power energy use practices shape the usage of devices and the way that work and other activities are performed in an office environment – was assessed though analysis of interview data. This study shows how the exploration of the elements of SPT in relation to small power energy use practices help to explain variations of small power energy use (at a case/organizational level, mobility level, and office space level) and working practices for different types of worker as discussed below. For example, the combination of different types of activities such as ‘desk-based’ activities and ‘communication’ activities (performed by ‘mainly-static’ workers) can have greater effect on small power energy use due to the associated devices used in different office spaces. This compares to the performance of mainly ‘communication’ activities (performed by ‘mainly-mobile’ workers) which may involve portable devices – not always plugged-in – with less effect on small power energy consumption.

The key findings of this study relating to objectives three and four are based on evidence from the analysis of quantitative energy use data and qualitative interview data (to interpret the quantitative analysis). These show differences between worker mobility and small power energy usage in the office sites studied. The quantitative analysis shows that ‘mainly-static’ workers account for more small power energy use compared to ‘mainly-mobile’ workers. This has been identified both by comparing the different office sites examined and by comparing the mobility of workers regardless of the case office sites. In addition, ‘mainly-static’ workers account for more small power energy use in the afternoon compared to ‘mainly-mobile’ workers regardless of the case office site. ‘Mainly-static’ workers also consume more small power energy at workstations in comparison with ‘mainly-mobile’ workers regardless of the case office site. This is despite the smaller number of activities performed and similar number of devices used by ‘mainly-static’ workers compared to ‘mainly-mobile’ workers.

The exploration of small power energy use practices is important and helps to understand these findings. This study shows that ‘mainly-mobile’ workers perform ‘communication’ activities (e.g. collaborative work, interaction through formal meetings or informal meetings, teleconferences, phone calls) for the majority of their working day, with limited time spent at the workstation using desk-based plugged-in devices. They mainly use portable devices (not always plugged-in) while moving to different office spaces to complete work tasks. They also ascribe different concepts (explored through the SPT element of meanings) to their work activities. Examples consist of privacy of a telephone conversation (which takes place in a quiet pod) and confidential discussions (which take place in a meeting room or break-out area). In contrast, ‘mainly-static’ workers perform desk-based activities and also ‘communication’ activities mainly using available plugged-in devices in different office spaces. For instance, ‘mainly-static’ workers use desk-based plugged in devices at the workstation, available plugged-in devices in meeting rooms or TV screens in the break-out area, and portable devices. This helps explain their increased small power energy consumption compared to ‘mainly-mobile’ workers. Considering how timing influences small power energy use practices, ‘mainly-static’ workers account for more small power energy use in the afternoon in comparison with ‘mainly-mobile’ workers. This is due to the performance of more desk-based and ‘communication’ activities (mainly at the workstation) in the afternoon, using plugged-in devices to complete work tasks.

With respect to ‘static’ workers, the data analysis shows that their work practices involve work activities in a single office space (at their workstation). These activities involve mainly process work and also some ‘communication’ activities (such as telephone conversations, informal discussions, communication with colleagues via emails and less often via conference/Skype calls), with interaction (through informal discussions or meetings) mainly undertaken in the same single space (at workstation). The different number and type of devices used by 'static' workers are also mainly used in a single location (i.e. desk-based plugged-in devices), which increases energy usage at the desk. These working practices of 'static' workers help explain why they account for more small power energy use at the workstation compared to 'mainly-mobile' workers.

These findings suggest that 'desk-based' activities and 'communication' activities are key activities which determine the different mobility of workers, as they require either usage of a single location (e.g. workstation) or usage of different office spaces. The performance of 'communication' activities was found to involve the usage of different office spaces, particularly by 'mainly-mobile' workers (and their associated work roles) and is influenced by the layout of the office environment (e.g. open plan office leads to usage of enclosed spaces such as quiet pods for private telephone conversations). This finding on the usage of different office spaces for the performance of 'communication' activities is important when considering office layout planning, in order to facilitate a combination of 'desk-based' and also 'communication' activities for different types of workers and associated work roles.

This study shows that mobility of workers is a key contributor to the variation of small power energy use in the offices studied and it is mainly influenced by the role of workers (requiring or not the usage of different office spaces and devices, which affects small power energy use). 'Static', desk-based workers are mainly process workers (e.g. administrators, lawyers, data analysts), while 'mainly-static' workers are mostly middle-senior workers (e.g. managers) and 'mainly-mobile' workers are mostly senior workers (e.g. heads of departments, directors). The data analysis of this study found that different mobility of workers and associated work roles influence the number and type of activities performed in different office spaces as well as the number and type of devices used. This in turn affects small power energy use. In the office sites examined, the descriptive analysis shows that ‘mainly-mobile’ workers perform the highest number of activities (an average of 12 activities per worker) compared to ‘mainly-static’ and ‘static’ workers (an average of 11 and 10 activities per worker respectively), while the number of devices used are similar for all types of workers. However, small power energy consumption is the lowest for ‘mainly-mobile’ workers compared to ‘mainly-static’ and ‘static’ workers. This finding on variation of small power energy use due to mobility of workers and associated work roles is important in future research to understand working practices of different work roles and associated energy profiles from device usage in different work sectors or hierarchies (e.g. measuring small power energy use from activities performed and devices used for different types of managers in different work sectors).

Regardless of the mobility of workers and associated roles, organizational rules have been shown to play an important role on working practices, even when they are not directly related to electricity savings from office devices and equipment (e.g. security aspects of device usage such as locking computers when workers are away from their desk). This study shows the different impact that organizational rules had on small power energy use in the different office sites examined. This impact is either related to the number and type of devices provided per worker (restrictions on usage of second monitor at the desk, or provision of laptop or tablet based on worker role and work requirements), or related to security aspects of device usage (e.g. locking computers when workers are away from their desk). These rules were strictly followed by office workers. This study has shown that organization rules hold potential to reduce small power energy consumption, for example security aspects of device usage indirectly reduce electricity consumption (from idle/standby power). This was achieved by workers switching off devices when leaving the office in the organizations where rules on security aspects were applied. This is in contrast to the organisation with no rules, where workers tended to leave devices on after leaving the office. This may be an important consideration for organizations when introducing energy-initiatives and rules and could be investigated further to see how it could be incorporated into energy policies to achieve reduction of device electricity demand in commercial offices.

8.3 Contribution to Knowledge

This research contributes to knowledge in a number of ways. Firstly, it synthesizes a new definition of small power energy use, showing that small power energy use can be approached and better understood by considering activities performed and devices used in different office spaces over a working day:

> “the electricity that is used from office equipment and electric plug-in devices distributed across different spaces within office buildings to support office workers’ activities and tasks which are performed across time (i.e. over a working day)”

Second, the use of a framework which uses the theoretical approach of SPT brings new insights to the understanding of electricity usage from office devices and equipment. This approach has not been used by other studies on small power energy use in office buildings. This study shows how working practices are related to time and space by different worker mobility, causing variations in small power energy use in offices. This is an important finding, which helps to identify profiles of high energy small power device users in office buildings. This profiling of workers can be used in helping to understand the potential for developing effective approaches to achieve energy savings in offices, in combination with the more standard approaches of technological upgrades and improvement of workers’ understanding of device energy consumption. The use of this framework included four elements of SPT – habits/routines, knowledge, meanings, technologies/infrastructure – and the exploration of the element of habits/routines has contributed to the development of a new categorization of energy-consuming activities performed in offices, which consists of ‘desk-based’ activities, ‘communication’ activities and ‘other activities’ (not related to work such as making coffee in the kitchen). This study also contributes to the understanding of what small power energy is used for by exploring aspects of working practices through the concepts of ‘formality’, ‘informality’, ‘privacy’ and ‘confidentiality’ (related to the SPT element of meanings). The understanding of these concepts allows association of certain energy-related activities performed in different office spaces with the different mobility of workers.

Third, this study contributes to the methodological development of work in the area of STP, by combining empirical work for non-domestic practices related to small power energy use. Previously, SPT has been based on theoretical development and empirical research in domestic energy practices or in non-domestic practices which focus on end-uses other than small power energy use. This study shows that an interdisciplinary combination of methods within a practice theory approach can be used to improve understanding of energy consumption in office buildings. Measurement of small power energy consumption (through monitoring of electricity use from small power devices/equipment) was combined with observation of work activities performed and devices used, to understand variations in small power energy use. Analysis of semi-structured interviews was used to explore working practices and to help interpret the measurement of small power energy use and associate it with certain work practices.

Fourth, this study contributes to the UK organizational context of everyday working practices and associated small power energy use in commercial offices. Small power energy use is still a relatively new area of research in the UK and this study adds to this domain of knowledge. So far, research in this domain has used mainly quantitative approaches and considered individual perspectives (such as energy savings through feedback and behavioural change approaches). This work can be used to help inform thinking about more efficient energy systems in UK offices by providing more realistic parameters for the design of capacity of these systems (for example, reducing the over-specification of HVAC systems).

Finally, the study's combination of data gathering approaches and its mixture of quantitative and qualitative data analysis leads to an area of significant novelty with regards to the simultaneous presentation of different forms of data for the examination of small power energy use in office buildings. Up until now this type of interdisciplinary approach has been restricted to exploring domestic energy practices. The synthesis of direct observational data (on activities performed, and device and space used) and monitoring data (on device electricity consumption) in the more complex environment of commercial offices is novel. This way of synthesising data gathering and analysis, can be used as a template for further research to improve understanding of other energy related practices in commercial office buildings and, potentially, in other building settings also.

8.4 Implications for Policy Makers and Practitioners

This study has implications for both policy makers and practitioners in the development of approaches to understanding variations in and reductions of small power energy use in commercial office buildings. This is particularly due to its base of empirical data, which sheds new light on the relationship between device electricity usage and working practices of different types of workers. This research has two major implications for policy makers and practitioners.

- Organisations and their use and management of small power energy use

This study explored the important influence that organizational rules can have on device electricity usage and suggests that practitioners (e.g. facilities management teams within organizations) could apply similar energy-saving initiatives in relation to the energy usage of devices. This can be related to either direct energy-savings on small power energy use by restricting the provision of devices, or more indirect rules to save electricity such as applying security aspects of device usage (such as switch-off devices after leaving the office for preventing access of other people on someone's confidential work). These rules could further be combined with energy efficiency investments by organisations as the provision of efficient technologies and training on the improvement of understanding of device energy usage from office workers to achieve reduction of electricity demand in offices. Energy efficiency investments could also focus on identifying mechanisms (e.g. monitoring of energy used from different equipment in different office spaces) to ensure that office workers perform activities and use devices and spaces in an efficient way.

Senior management teams can harness such initiatives and energy efficiency investments to deliver significant cost savings to help realise organizational sustainability goals (e.g. energy savings from small power energy use). Designers (including architects and engineers) would also benefit by considering the number and type of devices used per worker (considering different worker mobility) together with energy-consuming activities performed, when designing the capacity of building energy systems (e.g. HVAC).

- Policy development relating to energy use in offices based on measured small power energy use and different mobility of workers

Given that small power energy use can affect the capacity and operation of building's energy systems (e.g. HVAC), measurements of small power energy consumption can be used as a basis for the calculation of these systems' capacities. This would allow for more efficient system design (i.e. reducing the over-specification of HVAC due to inaccurate estimations of small power energy use). This latter may also allow policy makers to revise current limits of regulated energy systems (e.g. HVAC) in offices and so achieve further reductions on CO_2 emissions.

To achieve this, policy makers can, amongst other aspects (e.g. electricity from other end-uses such as energy used from server and associated cooling demand as well as device standby power), consider measurements of small power energy use based on different mobility of workers (influenced by work roles and associated devices usage driven by energy-consuming activities). To regulate small power energy use in commercial office buildings, policy makers can consider the variability of small power energy use for different types of building occupants based on their mobility in combination with current recommendations relating to small power use allowances (developed as best practices by British Council for Offices). These recommendations associate small power allowances (e.g. $20W/m^2$) mainly with occupancy densities (e.g. $8m^2$/person) and are further considered for the design of the capacity of HVAC. The combination of these recommendations with the mobility of different types of office occupants may lead to the consideration of policies for current unregulated end-uses such as small power use.

8.5 Limits of the Research and Suggestions for Further Work

Without undermining confidence in the findings outlined above, it is important to recognise the limitations of this work. As is common for qualitative studies, the size of the sample is relatively small and so care needs to be taken in drawing conclusions from the results. This is consistent with a practice-based approach, which would advise against such extrapolations as practices are located in their context and may be different at different times or locations in which they are performed. This relatively small sample size was mitigated by ensuring that different mobilities of workers and different roles in different case office sites were included. This variety of sample allowed an improved understanding of variations of small power energy use and how working practices can influence the device electricity consumption.

With respect to the methods used to support the data gathering and address the research questions of this study, direct observations of certain activities (e.g. confidential meetings in meeting rooms) were not always permitted. In these circumstances, video recording was initially considered to obtain data, but this method was not accepted by the host organisations and therefore an alternative technique was developed. This involved short, self-reporting interviews with the participants and electricity monitoring of devices used by them. The particular nature of interview questions, together with the monitoring data, ensured that participant subjectivity did not compromise the gathering of observational data.

Two further limitations are related to both quantitative and qualitative analysis. Firstly, the study did not assess the consumption of standby power from small power devices and equipment; rather it concentrated on small power energy consumption at the time that activities were performed and the associated devices used. Second, the exploration of small power energy use practices was mainly used to interpret the key quantitative findings, without exploring in depth the social aspects related to working practices and associated small power energy use. Both these limitations fell outside the scope of this study and as a result, possible avenues of further work are suggested below.

Another limitation is related to the Hawthorne effect[24] as the participants were being observed with their agreement. This may have been expected to give rise to some bias in the results by, for example, workers acting differently on account of being observed although the researcher took actions to minimise this by observing the study participants from a certain distance discretely without compromising the data collection and allowing them to act normally. On many occasions the participants appeared to forget that they were being observed and only noticed the researcher at the end of the observational day, when the researcher informed them that an interview was about to take place.

In addition, the particular days of the week and the time of the year chosen for observation could also introduce bias and/or peculiarities into the findings. This potential effect was mitigated given the fact that the study was undertaken between September and April, capturing a wide range of working months. Similarly, days for observations of work activities were randomly selected in order to reflect different days of the week and in some cases different months for each participant.

With respect to the areas of further research that could arise out of this work, this study has evaluated small power energy use excluding the effect of standby power from devices left on or standby power in a single location (e.g. workstation) while office workers performed activities in other office spaces (e.g. meeting rooms, break-out areas, common function areas

[24] The alteration of aspects of behaviour by the subjects of a study due to their awareness of being observed (Monahan and Fisher, 2010).

such as printing area). Further research on how working practices of different types of worker affect standby power of office devices would contribute to the knowledge, giving an expanded picture of small power energy use practices in office buildings.

In addition, further research could be based on particular work roles and associated mobility such as middle-senior managers (related to 'mainly-static' workers) or administrators and data analysts (related to 'static' workers), who have been shown to have a higher effect on small power energy use than other types of workers ('mainly-static'). This research could involve a wider range of office buildings and office contexts, as well as a larger sample of office workers, to explore the working practices impacting small power energy consumption of particular work roles and associated mobility of workers in different sectors, thus, creating energy profiles of similar work roles in different sectors. This could be used by organizations to develop tailored energy-saving policies and rules on device usage to keep device electricity consumption in offices to a minimum level. In addition, the findings of this study, which show a temporal effect of small power energy use for different types of workers ('mainly-static' workers consume more small power energy in the afternoon compared to 'mainly-mobile' workers due to desk-based and communication activities performed using desk-based plugged-in and other portable devices), may facilitate the assessment of the demand side flexibility potential in office spaces. This may be investigated by analysing small power energy use at a more detailed temporal scale, considering levels of consumption of electricity in offices at specific times of the day based on the mobility of workers and associated device and office space usage.

Moreover, this research could be used as the basis for exploring how current small power energy use practices of different types of workers and associated roles could change in order to achieve energy savings in offices. Having used some important aspects of SPT to explore 'what small power is used for', further research could build on the findings on this study to examine the potential for developing more energy-efficient working practices for different mobility of workers, in order to reduce electricity demand in offices.

Finally, analysis of interview data shows that the usage of different office spaces is driven by the ‘design of office’ (e.g. open plan office). The design of offices influences the way work activities are performed. For example, open plan offices restrict confidential discussions through informal meetings at the workstation, and therefore other enclosed spaces (e.g. meeting rooms or quiet pods) are used to facilitate the performance of this activity. However, this study only considers the physical aspects of office space design such as floor layout, without explicitly investigating the influence of ‘design of office’ on small power energy use. Further research on workplace design could associate small power energy consumption with physical spaces, virtual spaces, and social spaces. It is only once these further research agendas based on empirical techniques and understandings from individual and social aspects are synthesised that a fuller understanding of the nature of variations of small power energy use can be developed.

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Appendices

Appendix A1: Observational Data on Work Activities from Pilot Study

An example of the data capture in the pilot study is presented in Figure A1 which shows activities performed by one office worker while his/her desktop monitor was in 'on' and 'idle' modes (5-minute observation interval) during a working day, and the different office spaces in which the activities were performed.

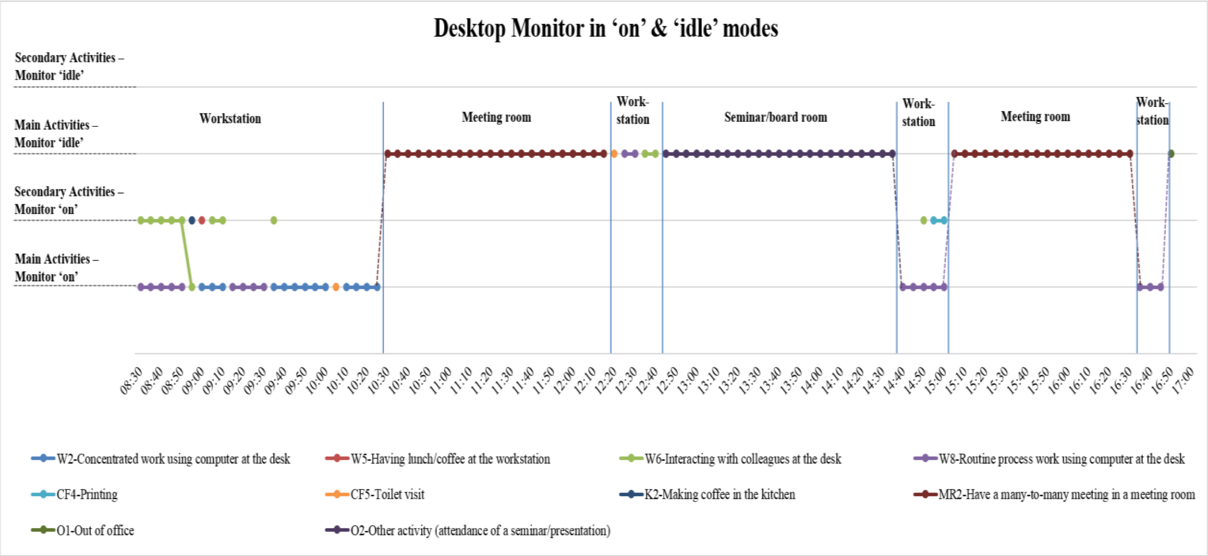


Figure A1. Desktop Monitor in 'on' & 'idle' modes and involved activities during a working day for one office worker

For example, the worker did routine process work (e.g. sending emails, data logging) and concentrated work (e.g. reviewing or developing documents) while interacting with his/her colleagues and making coffee at the workstation between 8:30 and 10:30, having the desktop monitor ‘on’ whether the performance of an activity required the use of a computer or not. The desktop monitor was turned to ‘idle’ mode from 10:31 and 14:40 due to a meeting and attendance of a seminar. Although the worker returned at the workstation from 12:20 to 12:45, the desktop monitor remained in ‘idle’ mode because the routine process work was performed using a laptop. The desktop monitor was used again between 14:41 and 15:05 when the worker returned at the desk after attending a seminar and returned to ‘idle’ mode between 15:05 and 16:35 due to another meeting. The worker used the desktop monitor again from 16:30 and 16:49 to do routine process work and then the left the office.

Appendix A2: Observational Data of Device Usage from Pilot Study

An example of the data captured from the observation of the devices which were available in the office settings accessed by the participants in the pilot study is presented in Figure A2. The observational data of devices identifies what devices were in ‘on’ mode during the observation of an office worker within a working day. For example, shared devices such as multifunction device and mini-fridge remained ‘on’ and/or ‘idle’ all day regardless of the activity performed, while individual devices such as laptop and desktop monitor were in ‘on’ mode in different times of the working day based on the activities performed.

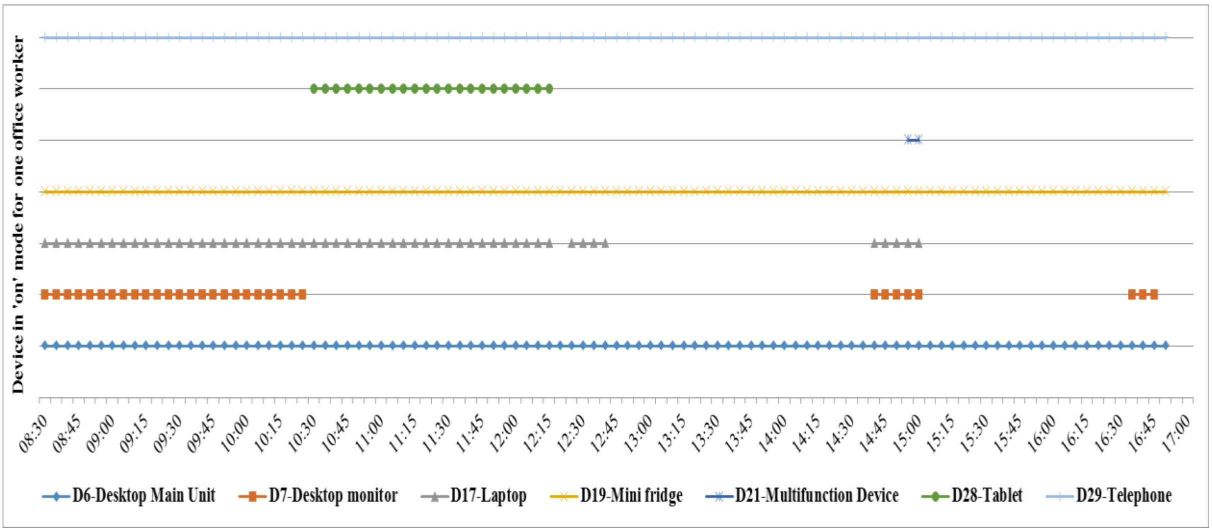


Figure A2. Devices observed to be in 'on' mode during a working day for one office worker

The observational data shows that several office devices can remain 'on' and/or 'idle' during parts of the working day, regardless of the different activities that are performed in different office spaces. Therefore, several office devices can be 'on' simultaneously in different office spaces during a working day (e.g. desktop main unit and monitor, laptop etc.) regardless of whether or not they are used by the office worker observed.

Appendix B: Survey on the Mobility Level of Office Workers for the Selection of the Sample

Survey on office workers' mobility

I am an Engineering Doctorate Researcher in the TSBE Centre at the University of Reading (UoR). I am carrying out research on electricity used from devices/equipment and work activities in office buildings. The study will involve observation of office activities that participants perform in different office spaces, energy measurement from office devices used and short interviews. The aim of this study is to better understand what workers do in different office environments and how this affects small power energy use (i.e. electricity used from plug-in devices and equipment). The first stage of the study is to complete this questionnaire. All the data will be anonymized and stored securely at the UoR central IT infrastructure, following cyber security best practices. The University will process personal data according to the Data Protection Principles set out in the Data Protection Act 1998. Thank you in advance for your time.

*The 4 multiple-choice questions below will take less than 5 minutes to complete.

*Required

Which of the following most closely describes your work activities undertaken inside the office building *

- ○ I perform all of my work activities using a single office location (e.g. desk) for 6 hours or more and rarely use other locations within the office
- ○ I perform the majority of my work activities using a single office location (e.g. desk) for 4 hours or more but some times use other locations within the office
- ○ I perform some of my work activities using a single office location (e.g. desk) for 3 or 2 hours but often use other locations within the office
- ○ I use multiple work settings to perform my work activities and rarely base myself at a single location within the office

Gender *

- ○ Male
- ○ Female
- ○ Prefer not to say

Age *

- ○ Under 25
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65 or over
- ○ Prefer not to say

What best describes your occupation? *

- ○ Managers, directors and senior officials (e.g. Chief Executives, Production Managers & Directors; Functional Managers & Directors, etc.)
- ○ Professional occupations (e.g. Science, Research, Engineering & Technology Professionals; IT & Telecommunications Professionals; Conservation & Environment Professionals; Research & Development Managers, etc.)
- ○ Associate professional and technical occupations (e.g. Science, Engineering and Production Technicians; Information Technology Technicians; Business, Finance and Related Associate Professionals, etc.)
- ○ Administrative and secretarial occupations (e.g. Administrative Occupations: Finance/Records/Office Managers and Supervisors; Secretarial and Related Occupations, etc.)
- ○ Sales and customer service occupations (e.g. Sales Related Occupations; Customer Service Managers and Supervisors; Customer Service Occupations, etc.)
- ○ Elementary occupations (e.g. Elementary Administration Occupations; Elementary Security Occupations; Elementary Construction Occupations; Elementary Sales Occupations, etc.)
- ○ Other (occupations)
- ○ Other: ____________

If you are happy to participate in this study, please provide your name and email address (which will only be used for the duration of the study)

Your answer ____________

SUBMIT

Never submit passwords through Google Forms.

Appendix C: Self-observation Short Questionnaire Used When Direct Observation Were Restricted

Short activity diary

Subject ID: …………………………………………………………………....

1. **Please tick what activities performed while you were away from your desk**:

☐ Collaborative teamwork in a meeting/training room (MR1)
☐ Have a many-to-many meeting in a meeting room (MR2)
☐ Have a many-to-one meeting in a meeting room (MR3)
☐ Have a one-to-many meeting in a meeting room (MR4)
☐ Have a one-to-one meeting in a meeting room (MR5)
☐ Activity outside of your normal office (AOO1)

- If activity outside of your normal office, please specify the location and the activity performed

……………………………………………………………………………

……………………………………………………………………………

☐ Other activity (OA1)

- If other activity, please specify the activity performed and the office space within the office building

……………………………………………………………………

……………………………………………………………………

2. **Please tick what devices / equipment used during the performance of the above activities**

	Device Off	Device Idle	Device On: Use for 5-15 min	Device On: Use for 15-30 min	Device On: Use for 30-45 min	Device On: Use for 45-60 min	Device On: Use for more than 1 hour	Device On: Use for more than 2 hours	Device Plugged in	Device Not plugged in	Device Not in use
Desktop Computer											
Conference phone											
Projector											
Information display											
Laptop											
Laptop charger											
Tablet											
Mobile phone											
Mobile charger											
Other device											

- If other (device), please specify

…………………………………………………………………………………

- Activity start time:

…………………………………………………………………………………

- Activity finish time:

…………………………………………………………………………………

- Number of people involved:

…………………………………………………………………………………

Appendix D: Interview Questions to Identify Small Power Energy Use Practices

Sample Interview questions

1. **Element on knowledge: Identifying participants' knowledge, considering the questions below.**
   - Identifying 'verbal/theoretical/tacit knowledge' and/or level of knowledge through the question: **What do you know about the difference between energy used in offices or at home. Do you normally use the available devices in a similar way in both settings?** Can you provide me any examples of device or equipment settings to avoid waste of energy?

   - Identifying 'way of understanding' through the question: **Do you agree or disagree that energy use of devices varies depending on the way that devices are used?**

   - Identifying background/technical knowledge through the question: **Would you be able to estimate the difference in electricity consumption between in use and standby devices?**

   - Identifying rules applied from the organisation related to the device use through the question: **Are there office procedures to guide to use the office devices in a certain way? For example, use a mobile charger to charge your phone and not a USB to charge your phone from your laptop/desktop computer?**

2. **Element on habits/routines:** To identify routine working practices in office buildings, the following are examples of the interview questions that will be used to understand: (i) to what extent the observed activities and associated small power use are typical in comparison with the routine activities performed and devices used most of the time by each participating worker, (ii) to what extent small power use is affected by the performance of activities within different available spaces and the availability of devices within these office spaces.

   - **Part a: Questions related to the routine activities are as follows:**
     - **Could you describe me a typical working day and what activities are involved?** *Please tell me about your routine activities within a working day*

and how similar they are in comparison to the activities you have performed today?
    - If there are any significant differences, please explain what they are and why you think they have occurred.
- **Could you describe to me what devices you normally use to support the performance of your work activities in different office spaces?**
    - How similar are they in comparison to the devices you used today?
    - If there are any significant differences, please explain what they are and why you think they have occurred.
- **Could you please tell me about the work activities you performed, and the devices used while working outside of your normal office** (e.g. while travelling to another place of work; having a meeting at another premises, etc.)?

- **Part b: Questions related to the routine activities performed are as follows:**
    - Could you please tell me which activities do you perform most frequently within the following office spaces:
    - Workstation,
    - Kitchen,
    - Meeting room(s),
    - Corridor,
    - Break-out area(s),
    - Common function (CF) area – considering this Table?

Activities	**Office Spaces**					
	Desk	**Kitchen**	**Break-out area**	**Corridor**	**CF areas (e.g. printing area / mail room)**	**Meeting room**
Concentrated work						
Routine process work						
Interacting with colleagues						
Informal meeting(s)						
Collaborative work						

	Desk	Kitchen	Break-out area	Corridor	CF areas (e.g. printing area / mail room)	Meeting room
Formal meeting(s)						
Telephone conversation						
Preparing / Having Lunch						
Preparing coffee/ Having coffee break						
Reading						
Writing						
Photocopying						
Printing						

3. **Element on meanings: To identify meanings, answers on activities that performed in more than one space, further investigation is required. Example questions below:**
    - If ‘informal meetings’ take place in different office spaces, could you please tell me why you think this has occurred?
    - If ‘collaborative work’ takes place in different office spaces, could you please tell me why you think this has occurred?

4. **Element on technologies: Questions to identify use of technology/devices in offices are as follows:**
   Could you please describe me what devices you normally use when you are:
    - Working at your desk,
    - Using the kitchen,
    - Using the common function areas (e.g. printing area, etc.),
    - Locating in the corridor,
    - Using the break-out area(s),
    - Using meeting room(s).

Appendix E: Ethics Forms for Pilot Study and Main Study: 1) Information Sheet and 2) Consent Form

1. **Information Sheet – Mary Pothitou – Ethics Submission**

TSBE Centre
University of Reading
Whiteknights
Reading, RG6 6AW

Research Title: Small Power Use & Working Practices in Office Buildings

Researcher: Mary Pothitou; m.pothitou@pgr.reading.ac.uk

Supervisors: Prof John Connaughton, j.connaughton@reading.ac.uk & Dr Jacopo Torriti, j.torriti@reading.ac.uk

<u>Observation Information Sheet</u>

My name is Mary Pothitou and I am an Engineering Doctorate Student in the Technologies for Sustainable Built Environments (TSBE) Centre at the University of Reading.

I am carrying out research on small power use and working activities in office buildings. The aim of this research project is to better understand what office workers do in different office environments and how this affects small power energy use (i.e. electricity used from office devices and equipment, excluding heating, ventilation, air-conditioning (HVAC), and lighting).

If you are willing to participate in this study, you will be asked to be observed for a period of no more than two days. The study will observe office activities that individual participants perform in different office spaces (e.g. workstation, kitchen, meeting room, break-out area, printing room, corridor etc.), and will monitor the small power devices/equipment used during each activity. In particular, the observation will not involve any examination of detailed work undertaken but will focus only on general activities and how they relate to small power use. For example, the researcher will record if the participant is working using a desktop/laptop at the desk, but not what work is being carried out on that device. Please be assured that the researcher will respect your privacy and confidentiality, and will not under any circumstances seek to identify specifics such as if the participant is sending an email, its content, or if the participant is working on a (confidential) document. In addition, please note that this study is not an audit of work productivity or performance.

You will also be asked to participate in an interview for about 30 minutes in order to discuss about the availability of office devices and spaces and their association to your office activities. With your permission, I would like to record the interview that will then be transcribed. Copies of the transcript will be available on request and any changes which you ask for will be made. You can choose not to answer any questions.

If you agree to take part in this study, you will be free to withdraw from the study at any time. At every stage, your identity will remain confidential. Your name or any identifying information will NOT be included in the Excel form which will capture data related to the observation of office activities and power monitoring of device usage. Similarly, NO personal information will be included in the written transcript of interviews. My supervisors and I will be the only people who will have access to this data. The data will be kept securely and destroyed when the study has ended, which will be a maximum of 3 years from the completion of this research project. The data will be used for academic purposes only.

Copies of any outputs, such as articles or presentation slides, will be available on request. If you have any further questions about the study, please feel free to contact me or my supervisors at the contact details provided at the top of this information sheet.

This project has been subject to ethical review, according to the procedures specified by the University Research Ethics Committee, and has been given a favourable ethical opinion for conduct.

Signed (by the researcher): ….…………………………………………………………………..

Date: …………………………………………..…………………………………………………

2. Consent Form – Mary Pothitou – Ethics Submission

TSBE Centre
University of Reading
Whiteknights
Reading, RG6 6AW

Research Title: Small Power Use & Working Practices in Office Buildings

Principal Investigator: Mary Pothitou; m.pothitou@pgr.reading.ac.uk

Supervisors: Prof. John Connaughton, j.connaughton@reading.ac.uk & Dr. Jacopo Torriti, j.torriti@reading.ac.uk

Consent to Participate in Research

1. I have read and had explained to me by Mary Pothitou the Information Sheet relating to this project and any questions have been answered to my satisfaction.

2. I understand that my participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.

3. I understand that my personal information will remain confidential to the researcher and his/her supervisors at the University of Reading, unless my explicit consent is given.

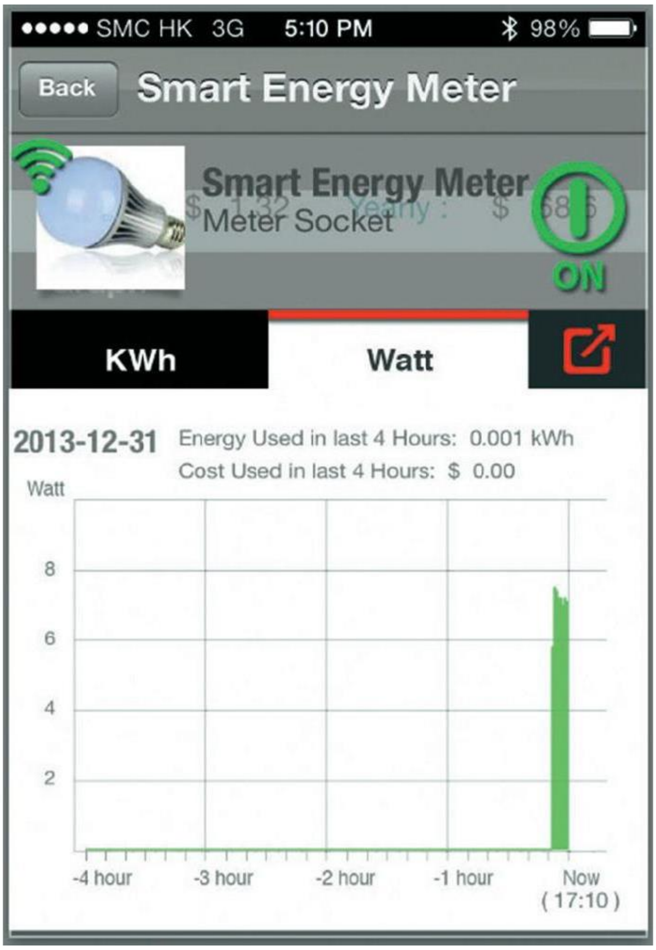
4. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.

Participant Name: ……………………………………………………………………………………………...

Participant Signature: ………………………………………………………………………………………………

Date: ………………………………………………………………………………………………

Appendix F: Smart Monitors Used for Monitoring of Device Electricity Usage



Appendix G: Completed Proforma for the Record of Direct Observation

Observation _ Main Study

1. **Observation Type**
    - Static Worker
    - Semi-static Worker
    - Semi-mobile Worker
    - Mobile Worker
2. **Subject ID** ……………….
3. **Activities:**

Main / Secondary / Not in performance

- W1-Archiving at the desk
- W2-Concentrated work using desktop computer at the desk
- W3-Concentrated work using laptop at the desk
- W4-Routine process work using desktop computer at the desk
- W5-Routine process work using laptop at the desk
- W6-Telephone conversation while sitting at the desk
- W7-Reading at the desk
- W8-Writing at the desk
- W9-Interacting with colleagues at the desk
- W10-Having lunch/coffee at the workstation
- W11-Having a meeting at an enclosed workstation
- CF1- Interacting with colleagues in the corridor
- CF2-Lifting up or down (using stairs or lift)
- CF3-Photocopying
- CF4-Printing
- CF5-Toilet
- BA1-Coffee break in the break-out area
- BA2-Entertainment activity (e.g. watching T.V.) in the break-out area
- BA3-Interacting with colleagues in the break-out area
- BA4-Lunch break in the break-out area
- BA5-Networking with new colleagues in the break-out area
- BA6-'on the move' interaction with colleagues
- K1-Interacting with colleagues in the kitchen
- K2-Making coffee in the kitchen
- K3-Preparing lunch in the kitchen
- K4-Having lunch in the kitchen
- MR1-Collaboative teamwork in a meeting/training room
- MR2-Have a many-to-many meeting in a meeting room
- MR3-Have a many-to-one meeting in a meeting room

- MR4-Have a one-to-many meeting in a meeting room
- MR5-Have a one-to-one meeting in a meeting room
- O1-Out of office
- O2-Other activity

4. **If other activity [O2], please specify** …………………………………………………………

5. **Start Time (Hour/Minutes)** ………………………….

6. **Space**

- Desk
- Kitchen
- Meeting room
- Corridor
- Toilet
- Break-out Area
- Common Function Area
- Quiet pods
- Other
- N/A

7. **If other space, please specify** ....

8. **Type of Space**
- Enclosed
- Open Plan
- N/A

9. **Devices:**

In Use / Not in use _ On / Not in use _ Idle/Standby / Not in use _ Off

- D1-Water tank
- D2-Camera charger
- D3-Computer speakers
- D4-Desktop Main Unit
- D5-Desktop monitor
- D6-Desktop Fan
- D7-Desktop Printer
- D8-Desktop Lamp / Task
- light
- D9-Dishwasher
- D10-Electric convection
- heater
- D11-Fan heater
- D12-Fax machine
- D13-Information display
- D14-Kettle
- D15-Laptop
- D16-Microwave
- D17-Mini fridge
- D18-Mobile charger
- D19-Multifunction Device

- D20-Paper shredders
- D21-Photocopier
- D22-Printer
- D23-Projector
- D24-Refrigerator
- D25-Scanner
- D26-Tablet
- D27-Telephone
- D28-Tooaster
- D29-Vending machine
- D30-Water cooler
- D31-Other device_1
- D32-Other device_2
- D33-Other device_3
- D34-Other device_4
- D35-Coffee machine

10. **If 'other device'_ D31, please specify** ……………………………………….
11. **If 'other device'_ D32, please specify** ……………………………………….
12. **If 'other device'_ D33, please specify** ……………………………………….
13. **If 'other device'_ D34, please specify** ……………………………………….
14. **Number of devices:**

No device / 1 device / 2 devices / 3 devices

- D1-Water tank
- D2-Camera charger
- D3-Computer speakers
- D4-Desktop Main Unit
- D5-Desktop monitor
- D6-Desktop Fan
- D7-Desktop Printer
- D8-Desktop Lamp / Task
- light
- D9-Dishwasher
- D10-Electric convection
- heater
- D11-Fan heater
- D12-Fax machine
- D13-Information display
- D14-Kettle
- D15-Laptop
- D16-Microwave
- D17-Mini fridge
- D18-Mobile charger
- D19-Multifunction Device
- D20-Paper shredders
- D21-Photocopier
- D22-Printer
- D23-Projector
- D24-Refrigerator
- D25-Scanner
- D26-Tablet

- D27-Telephone
- D28-Tooaster
- D29-Vending machine
- D30-Water cooler
- D31-Other device_1
- D32-Other device_2
- D33-Other device_3
- D34-Other device_4
- D35-Coffee machine

15. **Number of People** ………………
16. **Comments**

 ……………………………………………………………………………………………………
 ……………………………………………………………………………………………………
 ……………………………………………………………………………………………………
 ……………………………………………………………………………………………………
 ……………………………………………………………………………………………………

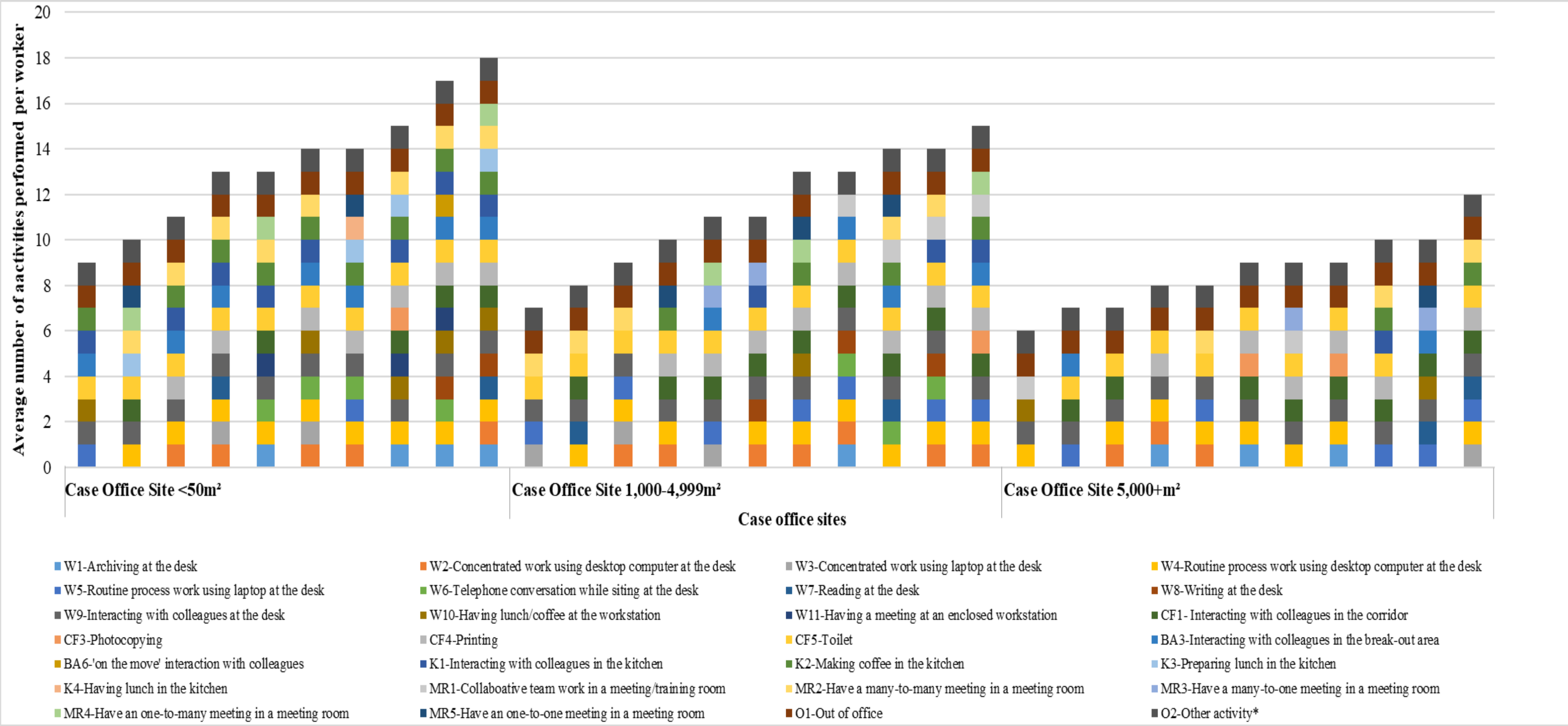
Appendix H: Nodes and Sub-nodes of Semi-structured Interviews

Nodes

Name

- Habits and Routines
  - Observed Work Activities
  - Other Observed Activities
  - Routine Activities
  - Work Activities Outside Office
- Individual
  - Personal Preferences
  - Worker Role
- Knowledge
  - Organisation Rules
  - Techincal background
  - Type of knowledge
    - Theoretical Knowledge
    - Understanding of device energy consumption
    - Verbal knowledge
- Meanings
  - Confidentiality
  - Formality
  - Informality
  - Privacy
- Office design
- Technologies and Infrastructure
  - Office devices
  - Office spaces
- Worker Mobility

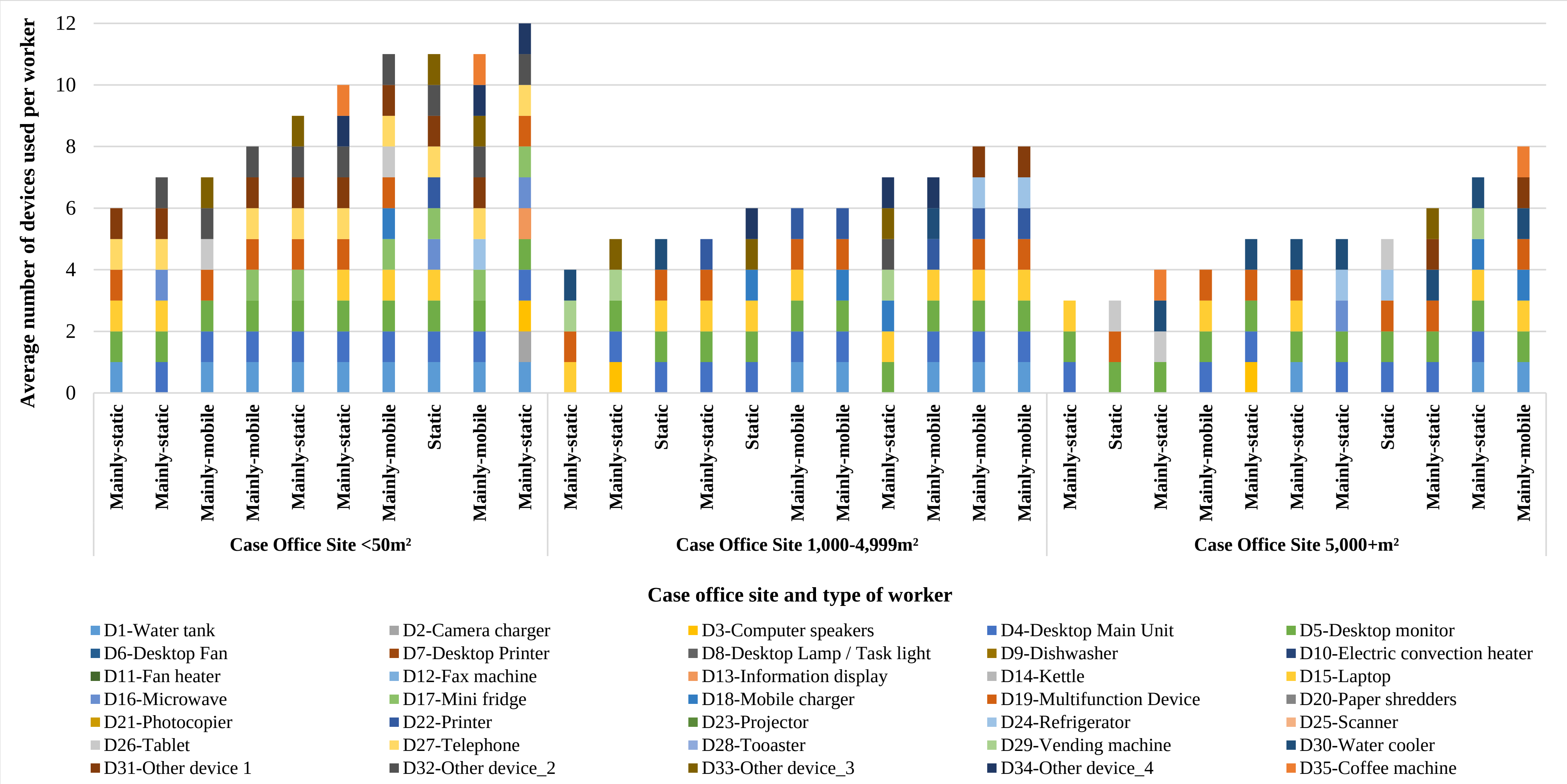
Appendix I. Number of Activities Performed per Worker in Each Case Office Site



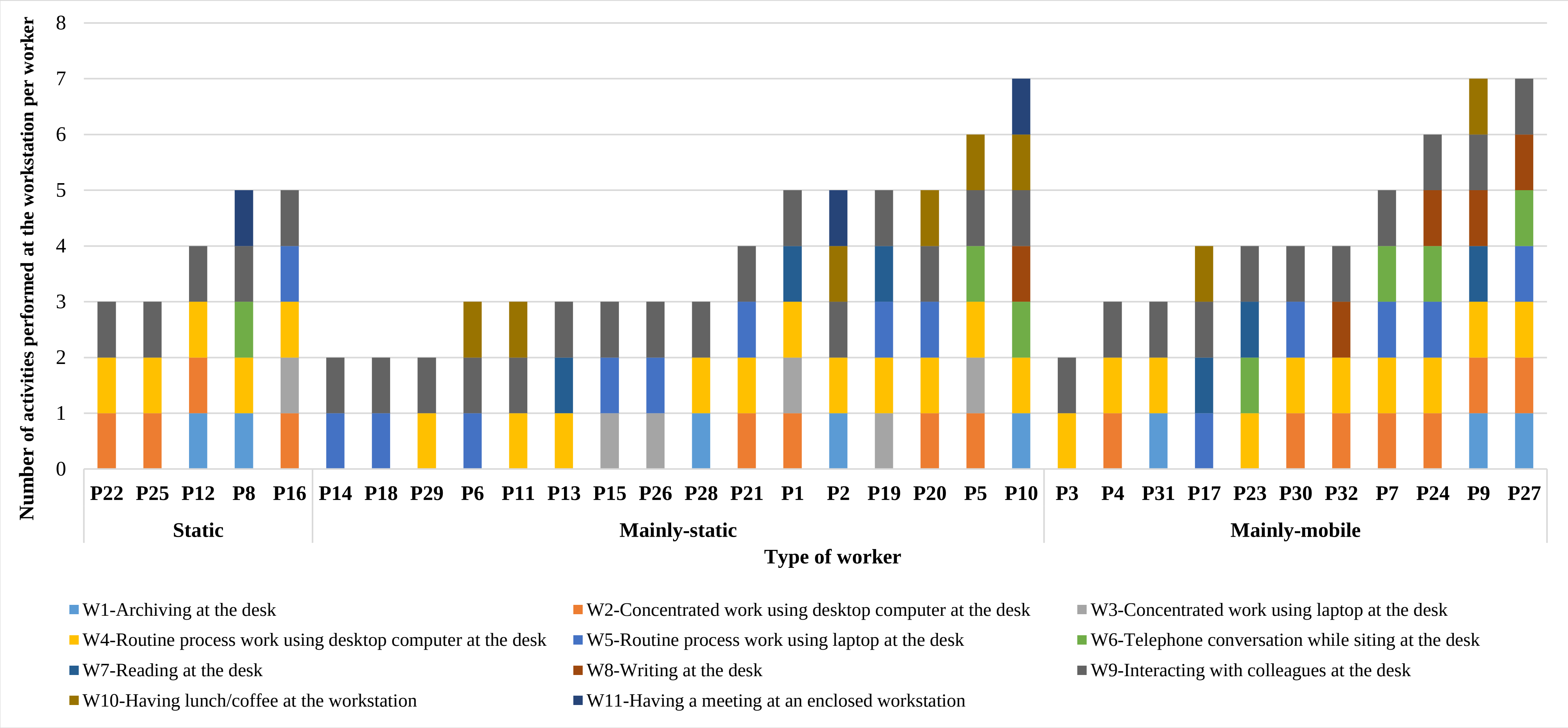
*O2-**Other activity** presented in the Table below:

Office Spaces	O2-Other Activities					
Workstation	Turning on TV in the open-plan office	Have a one-to-one informal meeting at the desk	Collaborative teamwork at the desk			
Kitchen	Filling a glass of cold-water using water dispenser	Making a cold drink using water boiler	Preparing breakfast using water boiler	Buying a snack from a vending machine	Filling a bottle of water using water cooler	Telephone conversation in the kitchen	Getting food from the refrigerator
Common Function Areas	Scanning	Shredding hardcopies	Archiving in a storage cupboard				
Corridor	Telephone conversation in the corridor	Informal discussion in the corridor					
Break-out area	Telephone conversation at the break-out area	Have a one-to-one meeting at the break-out area	Informal meeting at the break-out area	Collaborative teamwork at the break-out area			
Reception	Interacting with colleagues at the reception	Front-of-house tasks/Covering reception desk	Routine process work using desktop computer at the front desk				
Conference room	Informal discussion in a large conference room	Attending an event/presentation in a conference room					
Cafeteria / Canteen of office building	Have a one-to-one meeting at the cafeteria of the building	Lunch break at the canteen of the building	Coffee break with colleagues at the café/canteen of the building	Have a many-to-one meeting at the café/canteen of the building			
Quiet pod	Having a many-to-many conference call/meeting in a quiet pod	Collaborative work with colleagues in a quiet pod	One-to-one meeting in a quiet pod	Concentrated work using laptop in a quiet pod	Routine process work using laptop in a quiet pod		
Outside of office building	Leaving office to attend an event in another office building						

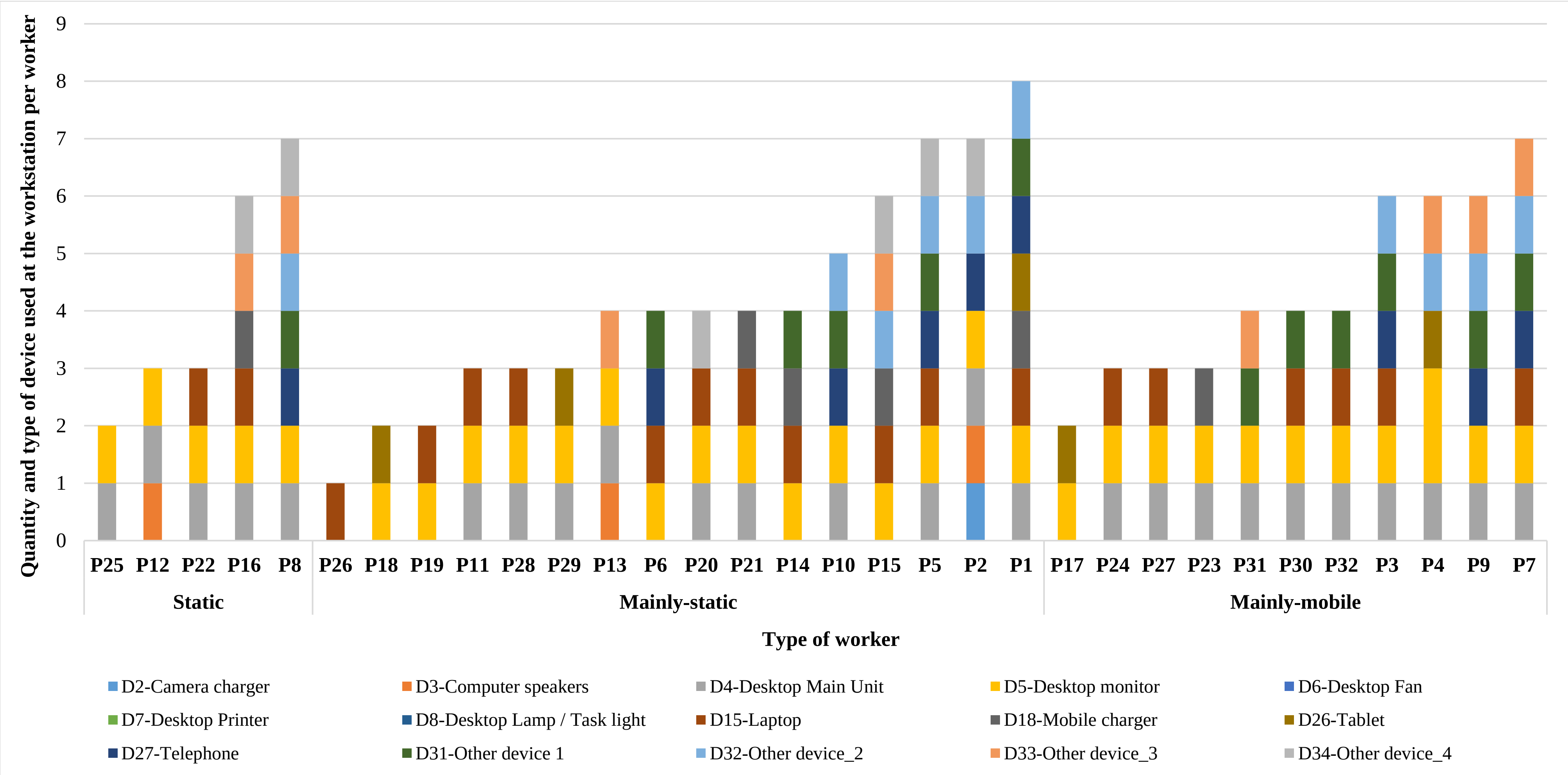
Appendix J. Usage of Office Devices Per Worker in Each Case Office Site



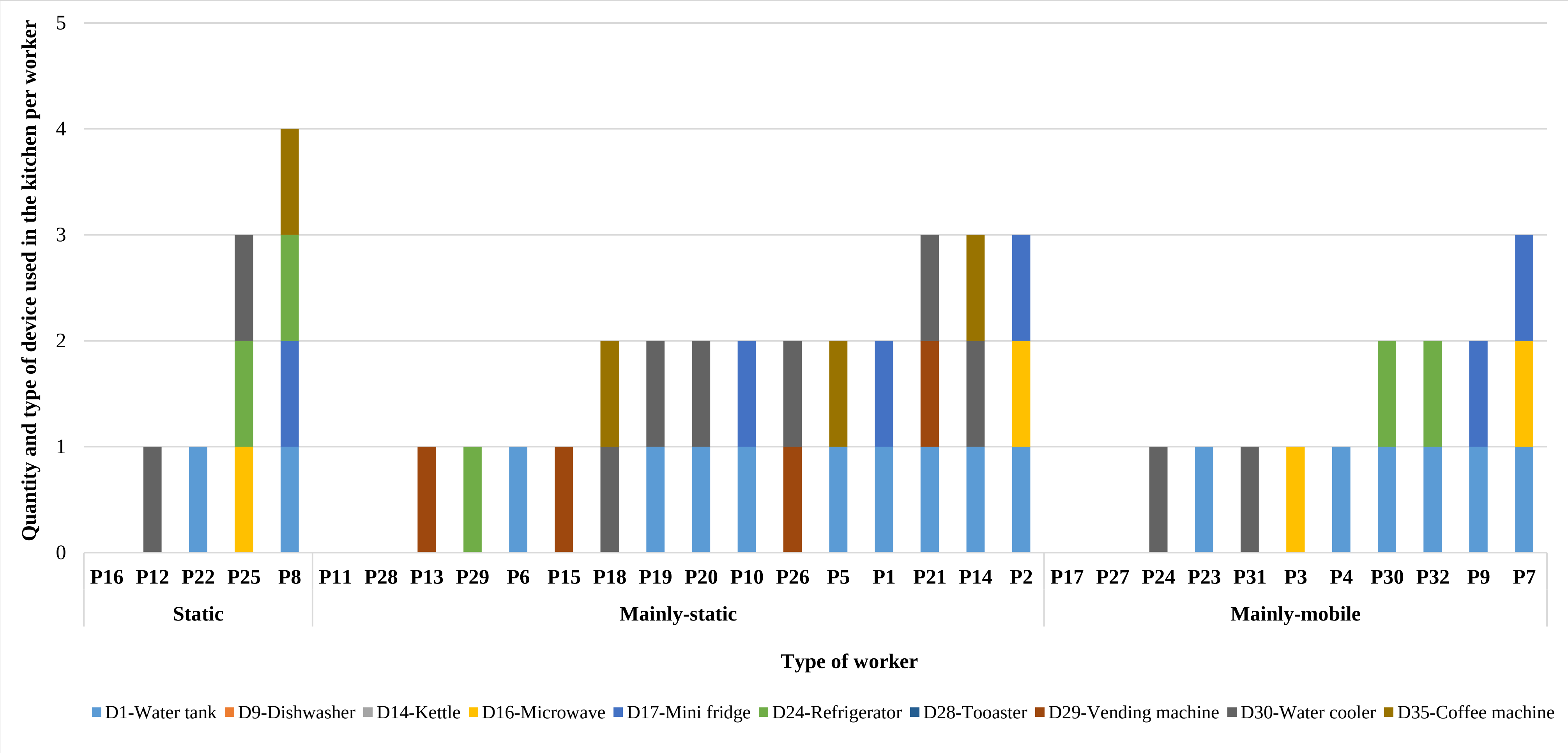
Appendix K. Activities Performed at the Workstation by Different Types of Worker



Appendix L. Devices Used at the Workstation by Different Types of Worker



Appendix M. Devices Used in the Kitchen by Different Types of Worker



Appendix N. Factorial ANOVA – Pairwise Comparisons Between Case Office Sites and Types of Worker

Factorial ANOVA - Pairwise Comparisons

Dependent Variable: Total consumption per working day from devices

Case study offices	(I) Type of persona based on observation	(J) Type of persona based on observation	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Case office site < 50m^2	Static	Mainly-static	.056	.093	.552	-.137	.249
		Mainly-mobile	.137	.095	.163	-.059	.334
	Mainly-static	Static	-.056	.093	.552	-.249	.137
		Mainly-mobile	.081	.057	.169	-.037	.199
	Mainly-mobile	Static	-.137	.095	.163	-.334	.059
		Mainly-static	-.081	.057	.169	-.199	.037
Case office site 1,000-4,999 m^2	Static	Mainly-static	.045	.074	.550	-.108	.197
		Mainly-mobile	.098	.071	.183	-.050	.245
	Mainly-static	Static	-.045	.074	.550	-.197	.108
		Mainly-mobile	.053	.057	.363	-.065	.171

	Mainly-mobile	Static	-.098	.071	.183	-.245	.050
		Mainly-static	-.053	.057	.363	-.171	.065
Case office site 5,000+ m^2	Static	Mainly-static	-.047	.068	.496	-.188	.094
		Mainly-mobile	.106	.085	.227	-.070	.281
	Mainly-static	Static	.047	.068	.496	-.094	.188
		Mainly-mobile	.153*	.068	.035	.012	.294
	Mainly-mobile	Static	-.106	.085	.227	-.281	.070
		Mainly-static	-.153*	.068	.035	-.294	-.012

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).