Assessment of industrial energy use and carbon emissions in the textile industry

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Submitted for the degree of Doctor of Philosophy

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October 2019

ABSTRACT

This study is to design and validate an assessment procedure for energy efficiency of manufacturing buildings. I demonstrated the assessment, based on the detailed energy audit, procedure on a case-study Scottish textile factory. This is to address the recognised need for more energy studies in the small and medium enterprise (SMEs). This heterogeneous and complicated sector inherits a range of energy efficiency barriers, and therefore requires more tailored energy efficiency studies. Over four years, half-hourly (H-H) empirical electricity and gas data, lower-resolution measured data, technology nameplate ratings and operations data have been analysed. The whole-system (site-wide) and key technology assessment assesses the baseline demand, demand variations in response to variables (such as production, weather, and departmental activity), and potential for tailored energy efficiency strategies.

H-H energy data, against weekday activity and shift patterns, was used to produce average daily profiles, with trends linked to production and weather impacts, in turn allowing for identification of periods of energy wastage. Based on the 24-hour peak- and off-peak periods, specific time slots were derived to numerically estimate average demands. Consequently, various demand characteristics like baseload, disaggregation and percentage contribution at activity and departmental level were calculated. Individual key technologies were studied for behaviour- and technology-related energy, cost, and carbon (energy savings when transformed into carbon emissions) saving estimations. The whole assessment showed promising saving opportunities, in a way that can be potentially translated to any similar manufacturing site. As a result of applying this approach to energy analysis, indicative energy, cost, and carbon savings against a base year were estimated to be 33%, 28%, and 28% respectively, with the longest payback period of five-years. Validation for the savings associated with identified measures, through physically installing/applying the measures, was not possible due to funding limitations. Measured and nameplate rating based auditing methods were compared, where possible, to assess their discrete limitations and suitability. The promising energy and carbon reduction methodology and the lessons learnt are adaptable for both textile and the other similar industries. With this transferability, a key part of the work of this methodology in the thesis provides a framework and a series of steps that allows this approach to be taken to SME industry.

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DEDICATION

This Thesis is dedicated to my parents (late) Mr. & Mrs. Agha Muhammad Saleem

DECLARATION STATEMENT

ACKNOWLEDGMENTS

I have been lucky to have this project helped and assisted through two courses of learning — on case-study site and at the University. I would, first of all, wish to thank my academic supervisor Dr. David Jenkins for all his time, help, support, and resourcefulness during this project. I pay my gratitude to my second supervisor Prof Phillip Banfill for his help and support through the course of the project. I would also like to thank Dr Sandhya Patidar and the members of the Urban Energy Research Group who have also provided great support for me during this PhD project.

I wish to thank Johnstons of Elgin for providing funds, data, and the resourceful hospitality onsite. I am excited to say thank you to my onsite mentoring supervisor Mr Michael Mathieson, and the mentor Mr. Robbie Shand for their immense contribution, help, and support throughout the project. There is a long list to pay my gratitude to the friendly and helpful people at Johnstons' factory for their guidance, knowledge sharing, and support. I am obliged to enlist only few due to space constraints. The company's directors Mr Chris Gaffney and Mr Gary Strachan, Paula Ritchie (Human resource), Audrey Gray (maintenance office), and our maintenance team {Chlem, Gordon, Gary, Willie, Paul, Jamie, and Alec}, and all of the departmental/section managers, and the energy representatives. Lastly, I would like to thank my family, especially my elder brother Gohar for his help and guidance, and friends specifically the lost ones, for supporting me over the last few years.

So with every difficulty, there is relief; verily with every difficulty there is relief. (The Qur’an, 94:5−6)

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Key Abbreviations, Acronyms, and Units

Abbreviation/Symbol	Description	Abbreviation/Symbol	Description
1Mtoe	=11,630,000 MWh	HVAC	Heating, ventilation, and air conditioning
AC	Alternating current	IES	Illuminating Engineering Society
AMO	Advanced Manufacturing Office	IESNA	Illumination society of North America
AMR	Automatic meter reading	ILP	Institute of Lighting Professionals
AMS	Advanced metering systems	IOA	Economic Input-Output Analysis
ASD	Adjustable speed drives	IPPC	Integrated Pollution and Prevention Control
BA	Biophysical allocation	IR	Infra red
B2B	Business-to-business	IS	Information systems
B2C	Business-to-consumer	ISIC	International Standard Industrial Classification
BAT	Best available technique	ISO	International Organisation for Standardisation
BEMS	Building energy management system	IT	Information technology
BMS/BEMS	Building (energy) management system	LC	Low carbon
BMW	Box-mean-whisker	LCA	Lifecycle assessment
BREEAM	Building Research Establishment Environmental Assessment Method	LCC	Life-cycle costing
BSI	British Standards Institute	LED	Light emitting diodes
CA	Compressed air	LENI	Lighting Energy Numeric Indicators
CCA	Climate Change Agreement	LHV	lower heating value
CCL	Climate Change Levy	LPD	Lighting power density
CE	European conformity	LPG	Liquified petroleum gas
CEMEP	European Committee of Manufacturers of Electrical Machines and Power Electronics	LU	Land use
CF	Capacity factor	MEPS	Minimum energy performance standards
CO_2	Carbon	MF	Maintenance factor
CO_{2-e}	Carbon dioxide equivalent	M&T	Monitoring and targetting
CoP	Coefficient of performance	M&V	Measurement and verification
CPU	Central processing unit	NACE	Nomenclature of Economic Activities
CRC	Carbon Reduction Commitment energy efficiency scheme	NAC	Normalised annual consumption
CSP	Concentrated Solar Power	NAICS	North American Industry Classification System
CSR	Corporate social responsibility	NEC	Normalised energy consumption
CT	Current Transformers	NGO	Non-governmental organisations
DC	Direct current	NILM	Non-intrusive load monitoring
DEC	Display Energy Certificates	O&M	Operations and maintanance
DECC	Department of Energy and Climate Change	OECD	Organisation for Economic Cooperation and Development
Defra	Department for Environment, Food, and Rural	PAS	Publically Available Standard
DM	Daily metered	PC	Personal computer
EA	Environment Agency	PV	Photovoltaics
EDA	End-use disaggregation algorithm	RE	Renewable energy
EEA	European Economic Area	RF	Radio frequency
EEI	Energy efficiency index	RO	Reverse osmosis
EI	Energy intensive	RoHS	Restriction on hazardous substances
EIS	Energy Information System	SBEM	Simplified Building Energy Model
EM	Energy management	SEC	Specific energy consumption
EMDS	Electric motor driven system	SIC	Standard Industrial Classification
EMDS	Electric motor driven system	SLL	Society of Light and Lighting
EMO	Energy management opportunity/ies	SMEs	Small and medium enterprise
EMR	Electricity Market Reforms	STEM	Short Term Energy Monitoring
EnF	Energy footprint	STM	Short-term measurement
EPBD	Energy Performance in Buildings Directive	TDS	Total dissovled solids
ESOS	Energy Efficiency Opportunity Scheme	Toe	Ttonne of oil equivalent
EU	Eurpean union	TTW	Tank to wheel
EU BREF	EU's Best Available Technique Reference	UF	Utilisation factor
EUI	Energy Use Intensity	UKAS	UK Accreditation Service
FiT	Feed in tariffs	UKSIC	UK Standard Industrial Activity Codes
GDP	Gross domestic product	VFD	Variable frequency drive
GHG	Green house gas	VSD	variable speed drives
GWP	Global warming potential	WBCSD	World Business Council on Sustainable
HE	Heat exchanger	WRI	World Resource institute
H-H	Half-hourly	WTT	Well to tank
HHV	Higher heating value	YOM	Year of manufacturing
HVAC	Heating, ventilation, and air conditioning		

Chapter 1 – INTRODUCTION

1.1 Background

This thesis is concerned about energy management (EM) in the manufacturing (specifically SMEs) buildings. Non-domestic buildings are a major contributor to the rising energy consumption (globally responsible for one-third and 25% for energy and carbon dioxide (CO_2) emissions respectively (Griffin, Hammond and Norman, 2016) and the demand reduction for the trend is a big challenge. Sharing 45% (Ammar et al., 2012) of the total 268TWh final industrial energy use (MacLeay, Harris and Annut, 2014) the UK's SME industry requires considerable efforts to control the demand. In order to reduce the SME sector's energy consumption it is necessary to understand how the industry consumes energy and identify the ways to improve its energy efficiency. For a detailed understanding of energy use in the sector more sub-sectoral in-depth energy studies, for example efficiency opportunities in textile manufacturing are vital.

Whole/individual building- and system/equipment-level macro- and micro-energy-auditing are notably trusted and reliable tools for energy assessments. In addition to estimating baseline energy use these can aid to identify and establish technical energy efficiency improvement strategies. The established baseline demand then can be used variously such as defining/comparing with energy benchmarks or performance indicators (such as CO_2 emissions and specific energy consumption (SEC)), to set targets or predict energy efficiency improvements, and to estimate savings made after retrofitting. Used on high-resolution data, power demand profiles are a useful form of energy data analysis. Propagating an in-sight into investigating and understanding buildings' energy use analysing power demand profiles can define energy end-uses, pinpoint energy waste (diagnose) and saving opportunities. Appropriate measures can then be designed (strategies) to instruct the energy efficiency improvement process. Although both approaches concurrently help to shape an effective EM strategy but the whole process for manufacturing buildings, in practice, is not as straightforward and several issues have been recognised. This is mainly due to varied processes, technology, and their management scheme (or site-specificity) in manufacturing buildings which makes energy assessments difficult to undertake. This eventually results in the need for more appropriately designed, suitable and robust energy assessment methods.

1.2 Understanding and designing energy assessment

Quantifying and understanding energy utilisation is the fundamental step in performance-based building energy efficiency assessments but industry finds it difficult (Giacone and Mancò, 2012). Experience indicates that a framework (a loosely bound structure that allows various tools and practices), is always required to assess (demand/performance/waste), identify (practical suitable saving measure), and then indicate savings (designing/implementing strategies). Achieving this through EM, specifically for larger and complex manufacturing buildings, can be difficult. To simplify this, various systematic assessment programmes (such as operations- and process-management) and standards (such as environmental/energy-management systems i.e. ISO-14001 and ISO-50001) have been designed. Following a specific methodology (strategy of method/s used), these programmes/standards share some common steps from energy audits and surveys (defined in Section 2.4.1) but differences in auditing approach, scope and boundary definition (Helcke et al., 1990; Thumann and Younger, 2007; Capehart, Turner and Kennedy, 2003) means that uniformity in fundamental tools (audits/surveys) and approaches (observations, principles, and assumption) is required (ASHRAE, 2002).

Energy audits and surveys are frequently used for various types of non-domestic buildings' energy assessments. However issues relating to limiting the scope and boundary and their functionalities, particularly when applied on manufacturing buildings, exist. One of the reasons for this can be site-specificity (such as limitations associated with individual site's demand, production processes, onsite activity, production and weather seasonality, and end-uses). To address such factors the first step to focus on is to resolving how site-specific manufacturing energy is? Afterwards, comes learning about the relationship and how congruent it is among different variables on a site. Questioning such prompts, the general design for this research, can only help to understand and identify the energy saving opportunities more comprehensively and thereby tailoring saving strategies accordingly. However in practice straightforward energy audits i.e. based on whole site/system or on a specific system (i.e. building heating system), which can be potentially less useful and robust, are carried out. The exercise generally under-stress the questions like what is going on among (inter- and intra-) systems and what appropriate measures could have been taken to improve their individual and collective performance. As a result, the findings and the saving actions may be compromised. One way to understand the impact of different variables on energy use can be learning the relationships (i.e. consumption, demand disaggregation, and specific services/end-uses) and taking suitable and integrated measures among inter- and intra-systems. These measures supposed to address all the systems/technologies involved in energy procurement, supply, transmission, and transformation and the associated retrofitting. Moreover if ever applied on UK SME industries, for example on textile as detailed energy audits, how detailed and successful these were is seldom reported. Using a UK textile case-study site, this research tries to establish such energy relationships and identify the relevant efficiency improvement measures.

Another commonly observed issue is the inconsistency in auditing procedure resulting in varied results and findings, for example, varied results by different auditors for the same site. This may be associated with variation in scoping as well as the chosen auditing method/s. Moreover, energy audits and surveys when applied to manufacturing buildings and compared with published performance indicators such as energy and CO2 benchmarks/indicators. Significant differences can exist between methods used for determining the former (published values) and the latter (values at the case-study). This can make the process of the whole assessment, when in relation (i.e. comparing) to each other, questionable. Thus improved scoping and robust auditing methods and the tools consisting of pertinent and consistent approaches can help to enhance the process quality. This is to promote consistent and improved energy demand/savings estimation methods. Ideally, it should address and assist the whole EM procedure/s and area/s. This may consist of monitoring, measuring, metering, selection of sound engineering principles, logical assumptions, onsite observations, and data collection and analyses. This array of steps augments the site-specific auditing approaches and their uniformity, energy consumption understanding, culture boost, and efficiency measures and help reducing the gap. Focusing on the key energy assessment tools, this thesis investigates how refinement in the scope and boundaries of the energy audits, and the involved procedures such as assumptions, observations, and rules of thumb can define, ascertain, and improve the overall EM and ultimately deliver savings based on robust method. The outcomes from the suggested data analysis and the other approaches (such as nameplate rating, measured and monitored data, and observations) are compared to identify accuracy, ease of use, and usefulness. Recognising the differing levels of energy auditing, the study also attempts to distinguish, demonstrate, and signify the individual and collective role of each of them.

In order to understand and assess energy performance and saving measures at buildings and systems levels energy demand profiling and quantification is undertaken. Once determined, these attributes such as power demand profiles can help to identify periods of waste. This can help to highlight what is causing the features seen in the data and the resultant information may incite energy savings strategies. With the increasing availability of the high-resolution (H-H in the UK) generic data, power demand profiles against 24-hours analysis is a known practice. Out of numerous objectivities energy benchmarking, diagnoses, and trends and patterns recognition have been reported on different non-domestic buildings. However, due to the heterogeneity of production and operations such assessments for manufacturing buildings may not be as straightforward as for the other non-domestic such as office and school buildings. Analysing suitable combinations of empirical energy data and known practices have provided information about what is causing the features seen in the data for varied scenarios. Such power demand profiles, such as based on H-H data have been used to analyse manufacturing energy. The information gathered through such analyses can help to identify saving opportunities and design efficiency improvement strategies. However, these may be short of detail but if shift patterns and intensity of activity are added, the vagueness can be reduced by visualising the demand and the cause at the same platform. Their use for manufacturing buildings is normally restricted to proprietary software that, due to copyright, generally remains out of the reach of research community. If have been publically witnessed, such analyses are generally based on some proprietary software. Building on energy (electricity mainly) against 24-hours, these profiles are a convincing case of energy diagnosis but at a cost that generally cannot be afforded by the SME industry. Therefore, there is a need of low- to no-cost analytical methods of such high-resolution data based on an easy to understand platform. In addition to that, the method should be repeatable and adaptable and could be performed by employees making such energy analysis a very low-cost undertaking.

This study utilises H-H power demand profiles (electric and gas) for performance evaluations with improved metrics. Drawn against the activity, these highlighted energy trends and patterns help to identify periods of waste, the impact of weather, and production. In addition to performance diagnosis and end-use demand estimation, the method can help to reduce the need for sub-metering installation. Designed on no-cost MS excel platform the suggested method can utilise H-H and other relevant manufacturing activity data for the energy analyses of a variety of SMEs.

The suggested auditing method explores various energy characteristics, along with aspects such as production and weather impacts. The proposed H-H data analysis method can be similarly used for gas, it functions as a single analysis platform for major energy demands. The H-H data can be used to identify specific operation/s versus demand patterns (i.e. increments/reduction) and translated into various empirical values of daytime (peak/off-peak), baseloads, departments, and seasonal energy demands. Findings on similar topics such as total and individual departmental demands through each method are compared and analysed. This is to understand the level of the difference and theoretical and practical precision and accuracy.

1.3 Research design

The aim of the study is to develop an energy assessment procedure. Focusing on energy performance and diagnosis (through improved data analysis) procedure the assessment is, particularly, designed for manufacturing industries. The proposed assessment procedure/method is applied toa vertically-integrated (having control over whole/partial supply chain for example manufacturing and selling textile products) Scottish textile industry. The business is also a composite (a rarely occurring textile manufacturing format in which all or more than one processes are carried out under the same roof) textile factory. Since the study focuses on onsite energy efficiency therefore the assessment is equally useful for other textile industry formats. The suggested carbon emission estimation method is adaptable from organisational only to upstream assessments. Therefore, this unique whole assessment becomes more interesting and useful acting as an energy efficiency framework and series of steps (as individual processing units might have energy culture but share similar technology) for various textile processes and similar industries. Empirical data is used to establish demand and key energy trends and patterns. Performance assessment and diagnosis of individual technologies (where possible) is evaluated through measured data. Upstream and organisational energy data are used for CO_2 assessment. The identified energy and carbon saving opportunities are designed into saving measures and strategies. The objectives of the study are described below.

I. Quantify and identify baseline and key technology's energy demand and behaviour- and technology-change related saving opportunities using top-down and bottom-up approaches

II. Visualise insightful relationships between demand (i.e. H-H) and key variables to diagnose and identify causation in energy characteristics

III. Use the obtained energy and other data to indicate pre-and post-efficiency performance based on such as SEC and CO_2 footprint

IV. Utilise the whole exercise to design energy saving strategies and recommendations to impact manufacturing in SMEs

Starting from a discussion on the global and the UK industrial energy and carbon emissions Chapter 2 discusses existing energy measuring/monitoring, quantification, demand estimation, and data analyses methods. Discussing the existing techniques for H-H energy data analyses, the chapter recognises the need of improved method and its use in manufacturing sites. It further discusses the approaches towards carbon accounting, EM techniques, role and classification of energy audits and surveys to clarify the direction of the study. Chapter 3 reviews the applications and energy efficiency enhancement techniques of the key sector-specific and general industrial technologies including equipment and utilities. It also takes a brief review of energy generation (low carbon (LC) and renewable energy (RE)) technologies. Discussing general textile manufacturing process, Chapter 4 describes the case study site including onsite textile manufacturing processes, inventory of onsite technologies and general energy demand, and the factory operations.

Methods consisting of recording, calculating, and managing data in conjunction with activity (shift-patterns and workload), production, water, and weather to estimate the impact of key variables applied in this thesis are discussed in Chapter 5. How, short time series/high-resolution (H-H), data is utilised for electricity and gas demand profiling against activity along with SEC and CO_2 evaluations is also discussed.

Chapter 6 reviews the results under three key categories: energy cost and data analysis (various forms of high- and low-resolution utility, production, and activity data), individual technology assessment (suggested alterations and saving opportunities based on baseline demand/cost), and carbon footprint assessment, including possible savings based on identified energy efficiency measures. Chapter 7 discusses the findings, future work, and limitations considering site- and the project-specific findings separately. This also includes textile specific technologies, site-specific findings serve both for the site and similar textile industries. It identifies saving measures that may be possible in a range of different textile manufacturing industries (single- or multiple-processes units). Discussing the significance of designing the auditing route for the project, the project-specific findings also discuss assessment procedure, diagnosis, performance indicators, and data analyses. Chapter 8 presents conclusions and recommendations.

Chapter 2 – LITERATURE REVIEW

This chapter reviews world and UK energy and carbon situation for non-domestic buildings. The current energy and carbon evaluation and reduction methods (behavior- and technology-change) used in the manufacturing industry are also discussed to justify the context of the study. The Chapter also compliments the following chapter three, serving as a strong basis of background knowledge and understanding for the other chapters in the thesis, specifically the methodology chapter number five.

2.1 Energy in Buildings

2.1.1 Energy and carbon

Constantly growing population, economic activity, and technology have triggered energy use—doubled compared to 1970's (indicated in Figure 1). Contrary to developing world such as China, the increase in energy demand rate in the developed world (e.g. the European Union (EU)) is relatively low due to multiple factors (such as USA's Energy Star®). Industrial energy, as shown in Figure 2, being the highest in the world energy use. In 2012, total global final energy use was 104,426TWh of which industry, transport, non-energy use, and "others" used 29,552TWh, 29,156TWh, 9,409MWh, and 36,320TWh respectively (International Energy Agency, 2013). Where categories for "non-energy use" and "others" (may also include domestic energy) are not defined.

By 2025, this demand-increasing trend is projected to gradually reduce thus a total 37% increase in global energy demand will result in 2040. This is mainly attributed to improved overall global energy efficiency, energy prices, structural changes in the industry, and leveling off industrial growth of some major economies like China. Of note, industrial energy efficiency improvement in energy intensive (EI) industry is common to both developed and developing world e.g. advanced energy efficient furnaces in African and Asian countries.

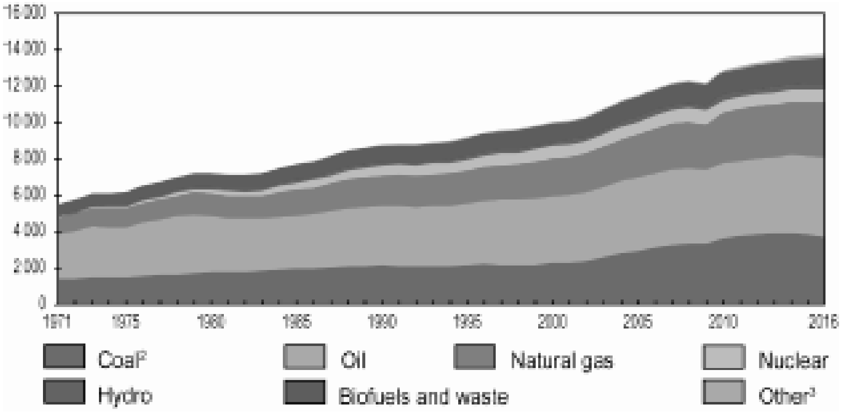


Figure 1 - World* total primary energy supply by fuel, (IEA, 2018)

1 World includes international aviation and international bunkers

2 Peak and oil shale are aggregated with coal

3 includes geothermal, solar, wind, heat, etc.

Described in million tonne of oil equivalent (Mtoe) 1=11,630,000MWh

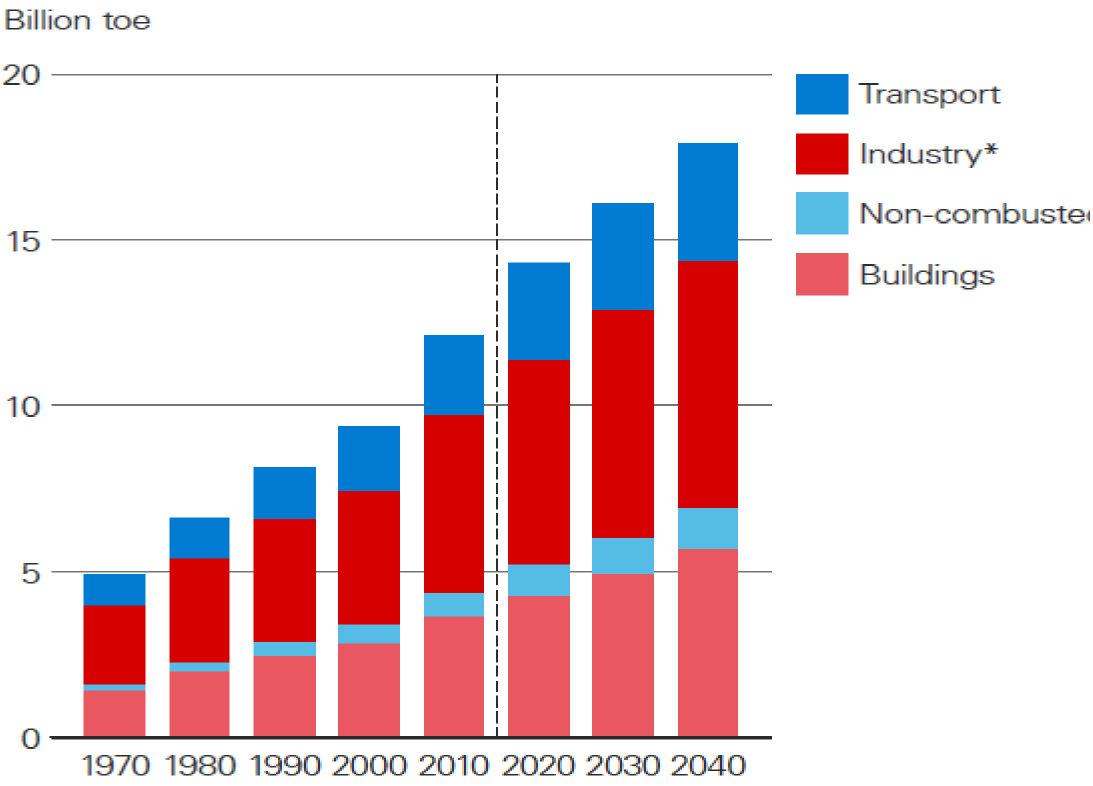


Figure 2 - World historic and projected end-use primary energy, (BP Energy Outlook, 2019)

Primary energy used in the power is allocated according to final sector electricity consumption

**Industry excludes non-combusted use of fuels*

The EU's energy policy has resulted in energy efficiency compliance such as Energy Performance in Buildings Directive (EPBD) and Feed-in Tariffs (FiT). Changes in industrial activity, such as shifting from heavy manufacturing to services and light manufacturing, have also helped in to reduce demand. One half of the savings was contributed by the industry and 10% from structural changes (Odyssee-Mure, 2009). Where structural changes denote a shift from heavy to light industry, part of manufacturing shifted to the developing world, and shifting towards the service industry, etc. In 2009, EU-27's total final energy consumption was 12,956TWh. Where Germany, France, and the UK's demands being the highest as indicated in Figure 3.

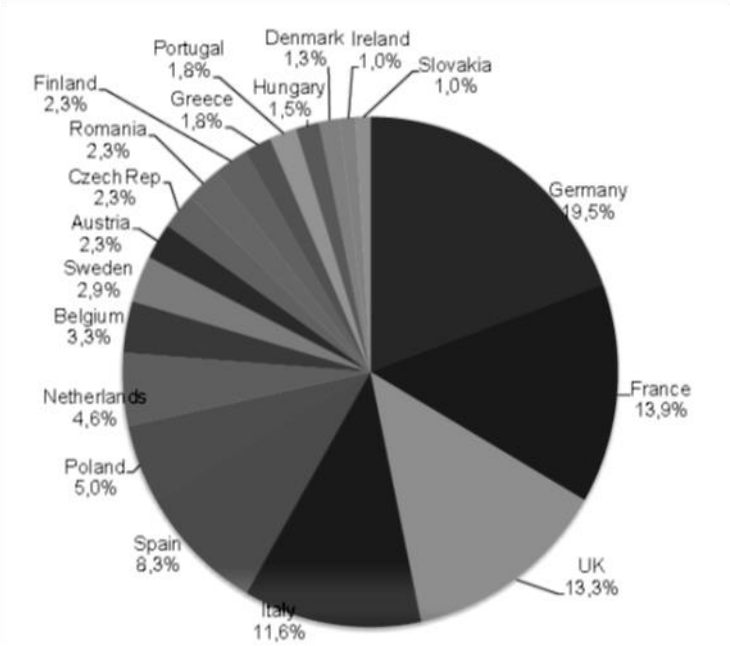


Figure 3 - EU Share of final energy consumption, (Odyssee-Mure, 2009)

In Figure 4, industry and household demand reduction can be attributed to energy policies and overall energy efficiency improvement through technology and management. With discrete final energy demands both regions (World (Figure 2) and EU (Figure 4)) sectoral share is comparable. The EU's significantly reduced industrial and domestic shares can mainly be attributed to the increased energy efficiency. On the other hand, the rise in industrial energy demand and better housing in the developing world should also be noted. The higher share of the EU's transport and service sector may be attributed to affordability of private cars, infrastructure, and travelling habits. The EU's reduced share of agricultural/fishery is due to a shifting to the other sectors e.g. services.

According to the EU projections, there will be minimal growth in energy demand in all sectors by 2030 (Zampou et al., 2009). However, demand growth for industry and transport will be higher than the household and services as indicated in Figure 5. As can be observed, industrial energy is projected to rise (in the rest of industry), specifically in the non-EI sector; this suggests the potential and the need for improvements in this sector.

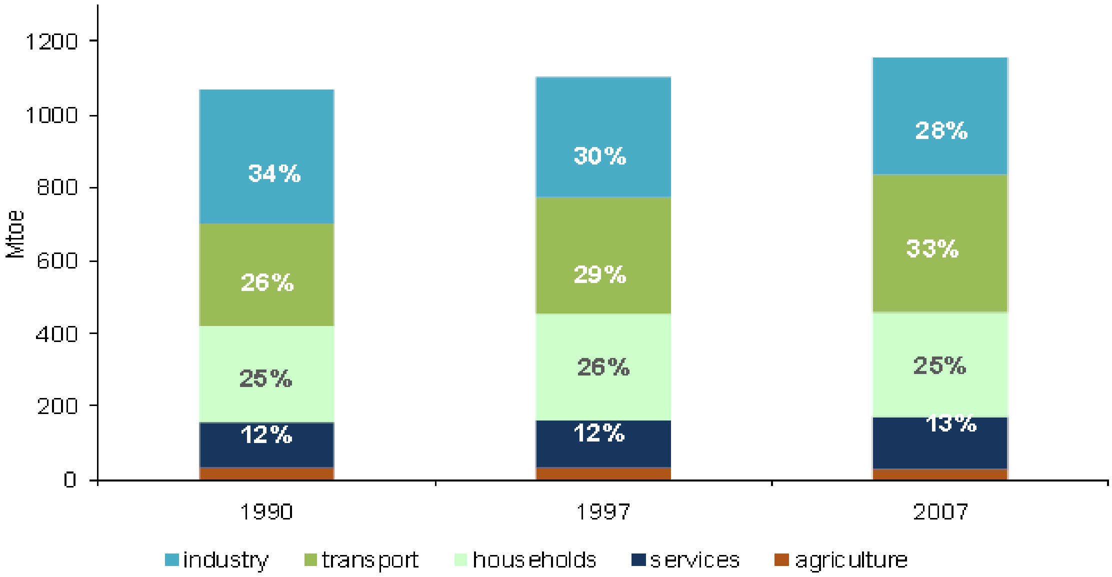


Figure 4 - EU-27 sectoral final energy consumption, (Odyssee-Mure, 2009)

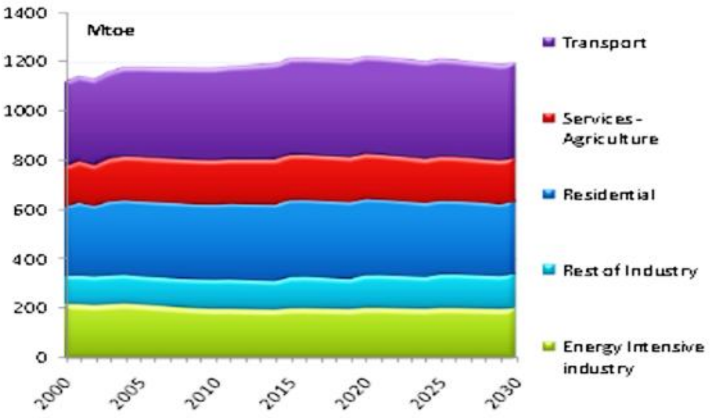


Figure 5 - EU final energy demand by sub-sector, (Zampou et al., 2009)

With a variation in 2000–2005 the UK's final energy demand from 1990's to 2010 has remained constant (143Mtoe/1,650TWh) (AEA Technology, 2012). According to Odyssee-Mure (2009) project, the UK's rate of energy efficiency increase has not reduced from 2000 to 2007. However, the ratio of sectoral share towards final energy use has dramatically changed from the 1970's as shown in Figure 6. A significant rise in transport energy (2013 in Figure 6), has led the country exceeding the EU's 2007 (in Figure 4) and the world (as in Section 2.1) transport-related relative share. This, in addition to more privately owned cars, could be due to a shift towards services including logistics. The UK's higher than the EU's domestic demand can be attributed to several factors such as larger older building stocks with poor thermal performance, user behaviour, and the climate. The significant reduction in industrial energy demand can be attributed to several factors mainly structural change e.g. shift from heavy industry to light manufacturing, and rise in energy efficiency particularly in the EI sector. However, the less-EI sector has comparatively been paid less attention to. Various measures to encourage reducing the energy use in the EI sector has been seen in the UK, for example, the emergence compliance schemes like CRC energy efficiency scheme Energy White Paper 2007 (DTI, 2007). This also includes incentivising such industries for example for renewable obligations scheme for energy intensive industry (EII) in 2015. The scheme has been recently revised as to take more sectors onboard (BEIS, 2019).

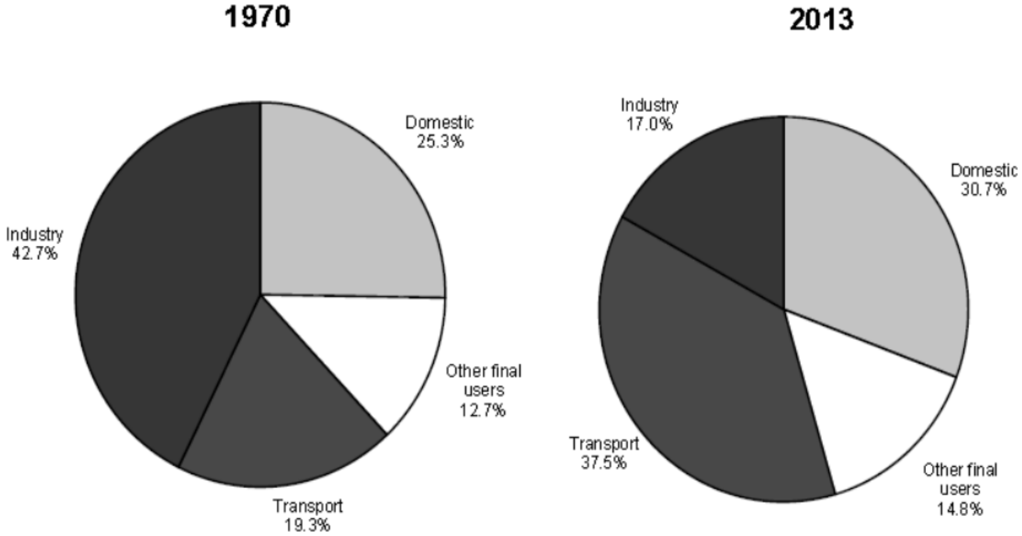
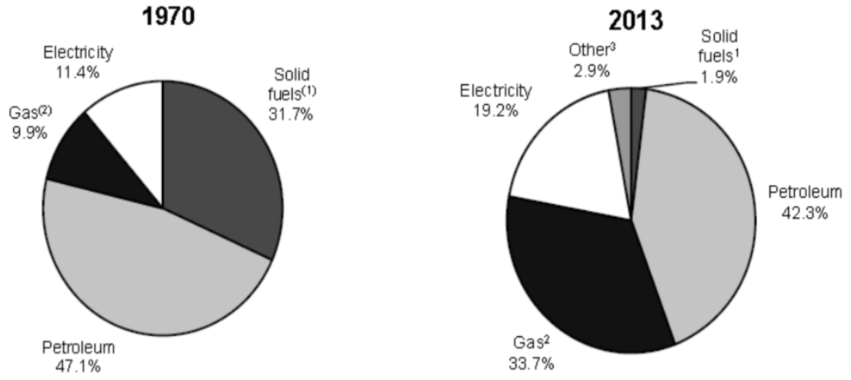


Figure 6 - UK end-use final energy consumption, (MacLeay, Harris and Annut, 2014)

Others include public admin, commercial, agriculture and miscellaneous

Compared to the 1970's, the country's primary energy fuel mix has changed significantly, as shown in Figure 7. The country's relative share of gas, compared to EU's, is found to be greater. Contrary to rising global dependence and the EU's overall consistency, the UK's oil demand shows a fall to 42%. This is similar to the EU's despite increasing demand from the transport sector. This can be attributed to a decline in industrial and agricultural activity and more reliance on gas. During the last few decades, a 50% rise in the country's dependence on electricity is seen.



(1) *includes manufactured fuels and coke oven gas*
(2) *includes town gas*
(3) *includes heat sold, bioenergy and waste*

Figure 7 - UK final energy consumption by fuel type, (MacLeay, Harris and Annut, 2014)

With an average 1.2% annual increase, the global CO_2 emissions in 2012 were 37GtCO_2. In 2010, 90% of the global CO_2 emissions were anthropogenic of which energy, agriculture, industrial processes (non-energy), and "others" (large scale biomass burning, post-burn decay, peat decay) were responsible for 69%, 11%, 6%, and 14% respectively (IEA, 2012). In 2012 coal, oil, gas, and other contributed 44%, 35%, 20%, and 1% CO_2 emissions respectively towards fuel burning (IEA, 2012). Thus, electricity usage becomes a secondary source of industrial CO_2 emissions. Global end-use CO_2 emissions for 2012 are shown in Figure 8.

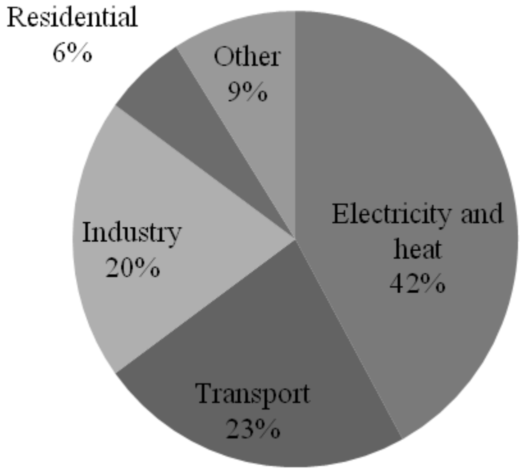


Figure 8 - 2012 world end-use CO_2 emissions, (IEA, 2012)

With variations in the EU's CO_2 emissions between 1990−2007, a total 5% (0.3%/year average) reduction from energy use was recorded in 2007. The 40% of the achieved CO_2 reduction is related to cleaner fuels and the remaining is largely attributed to energy efficiency. The EU's average emission factor for 1toe energy has decreased by 12% (Odyssee-Mure, 2009).

With 82% of greenhouse gases (GHG) emissions being CO_2 in the UK in 2013, total CO_2 emissions were estimated to be 467.5 million tonnes (Mt) (DECC, 2014a). The UK's highest CO_2 emitter, like in the rest of the world, is energy sector, this is followed by transport as shown in Figure 9. After this comes the industry, probably referred to as business.

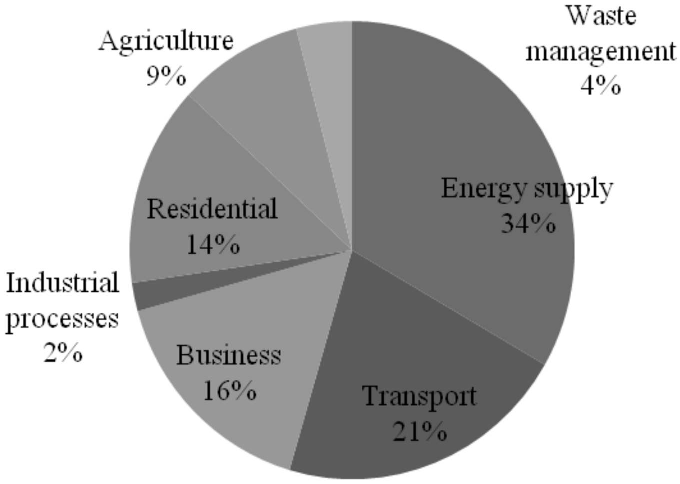


Figure 9 - 2013 UK CO_2 emissions, (DECC, 2014a)

2.1.2 Industrial energy use

The aggregate global energy intensity (consumption/unit of output) specifically in advanced nations has declined. The multiple contributing factors include overall energy efficiency increase, technology/process modification, and improved control and management procedures. In 2004 EI industries (steel, cement, chemical (fertilisers and plastic), pulp and paper, and aluminum) contributed 85% of the global industrial energy demand (Delhotal et al., 2007). Figure 10 indicates the growth in the regional industrial energy use. Showing regional EI industrial energy use Figure 11 indicates higher demands for chemical and steel industry for non-OECD countries. EI industries have remained the focus for energy efficiency improvement due to various, such as higher energy inputs, strategy, and higher technical and capital resource availability, reasons. The final energy estimate use of a selected list of SMEs and small-scale clusters of the manufacturing industry, shown in Figure 12, is between 5,000–8,888TWh (Cong et al., 2012). They also estimated that globally light industries (e.g. textile, food and beverages, and tobacco, etc.) have a saving potential of 3,333–4,444TWh, which can take the total global industrial energy saving potential to 6,111–8,611TWh. However, due to intrinsic (combined and individual) SME energy efficiency challenges, such as lack of skills, investment, awareness, and interest in saving measures, serious efforts are required (Kannan and Boie, 2003). According to another approach by Stich, Brandenburg and Kropp (2012) lack of transparency and information about energy use at plant, production, and machine-level determination of energy efficiency is one of the key challenges in the SME industries. They suggest the need of a holistic approach towards SME's EM needs.

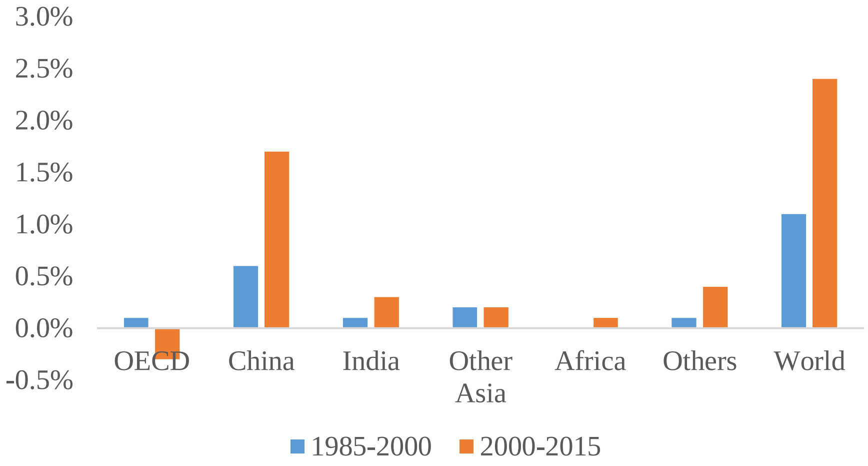


Figure 10 - Regional industrial energy growth rate, (British Petroleum, 2019)

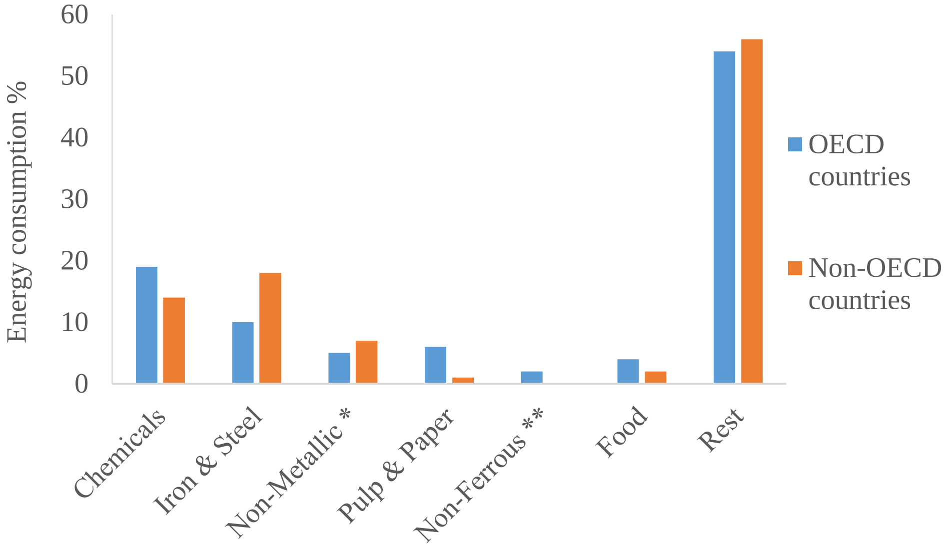


Figure 11 - 2012 world regions energy-intensive industry energy share, (Technology Executive Committee, 2017)

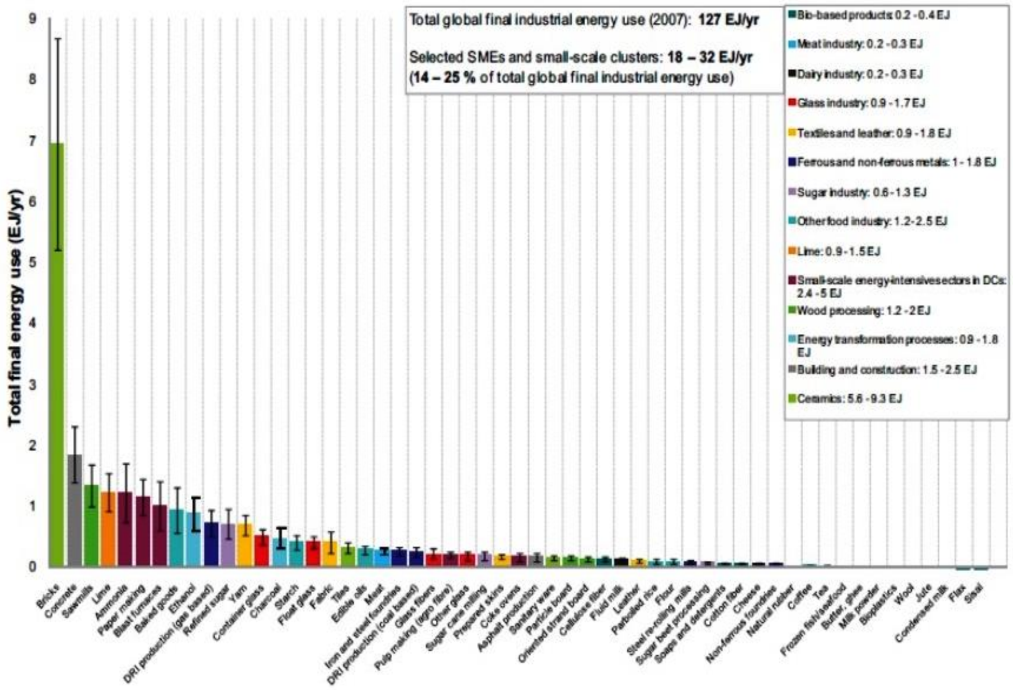


Figure 12 - 2007 estimated global final energy use of selected SMEs and clusters, (Cong et al., 2012)

Typical share of manufacturing energy use by type is shown in Figure 13. It may be assumed that different types of fuels are used for steam/process heating that also satisfies the demand for space heating and space cooling in some cases. Electricity is the next major contributor of motive power and other types of uses.

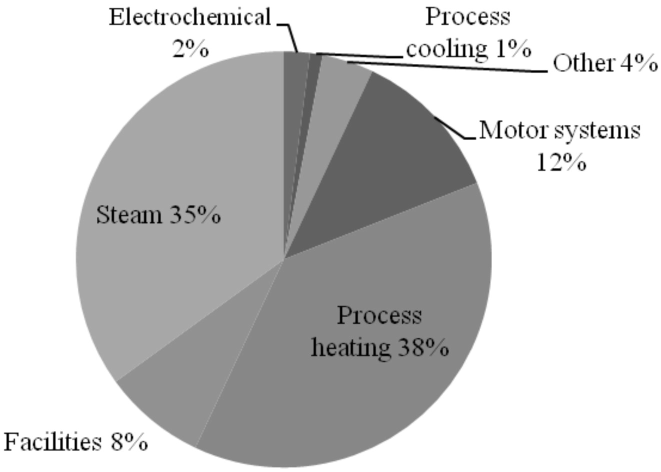


Figure 13 - Typical manufacturing energy use by type, (Cong et al., 2012)

From 1990 to 2007, EU-27’s final industrial energy demand has almost remained unchanged at around 3,700TWh (Cong et al., 2012). This is mainly due to policy and structural changes in major EU countries as well as the use of recycled materials and, in some cases, processes taking place (in part) in countries with cheap labour (e.g. China). However, with a direct impact on the supply chain, this may result in an increasing burden on the transport sector.

By the industrial sector 2012 energy use in the EU is shown in Figure 14 below. The increasing share of EI branches is indicated with a red arrow.

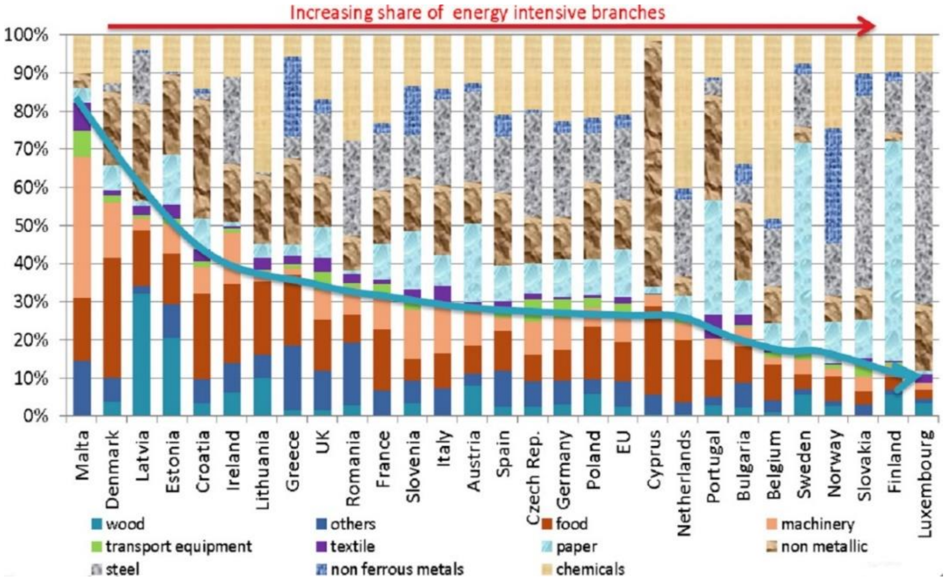


Figure 14 - EU-27 2012 industrial energy consumption by branch, (Lapillonne, Pollier and Samci, 2008)

With a history of industry-based economy, the UK is shifting to the tertiary sector (that is, services such as finance, transport, and consultancy). In 2013, the country's final industrial energy use was 268TWh. The sectoral demand is shown in Figure 15. Energy efficiency improvement in the country's EI industries, which has been a global focus, is one of the prominent factors (Cong et al., 2012). Various publications in the UK (DTI, 2007; HM Government, 2017) recognise the importance of the industrial energy efficiency with specific attention to EI sectors only. The advice for designing, understanding, and implementing appropriate ways for the less EI sector's energy efficiency improvement is confirmed by many (DTI, 2007; Kannan and Boie, 2003; Stich, Brandenburg and Kropp, 2012).

The less EI industries mostly represent the SMEs, which in the UK shares 45% of the total industrial energy use. The realisation that the SME sector lags in EM is intrinsic as well as sector-specific as such efforts have not been well entertained (Ammar et al., 2012). All different types of SME sectors (mostly heterogeneous units) offer various energy efficiency opportunities. Finding economically sound solutions to harness these requires enhanced knowledge and understanding of individual processes/units. However, hurdles like lack of EM-related expertise, resources, and knowledge exist (Ammar et al., 2012). It is generally perceived that the sector largely represents non- or less-EI industries. The sector, however, is also intrinsically linked with some EI industries as indicated in Figure 12. It is important to have a sound understanding of different parameters for defining an SME and the basis on which EI and non- or less-energy-intensive industries are distinguished. This is briefly discussed in Section 2.1.3. Textile as a representative SME and less-EI industry, as discussed in Section 2.1.4, has been chosen as a case-study site.

Global industrial energy related CO_2 has risen from 6.0GtCO_2 in 1971 to 9.9GtCO_2 in 2004 and is projected to reach between 14–20GtCO_2 in 2030 (Delhotal et al., 2007). In 2010, the 26% world share of industrial energy is translated as 18% CO_2 emissions. The EU-15 industrial CO_2 emissions changed from 37% to 30% between 1990−2010. In 2013, the UK business/industry sector accounted for 16% of total CO_2 emissions (21% less than 1990 levels), as shown in Figure 9. The reduction can be related to the downfall of the industry, increased energy efficiency (majorly in EI industry), and the use of relatively less carbon-intensive fuels such as gas. However, a 3% rise in business sector's emissions, between 2012 and 2013, can be due to increased use of manufactured fuels in the steel and iron industry (DECC, 2014).

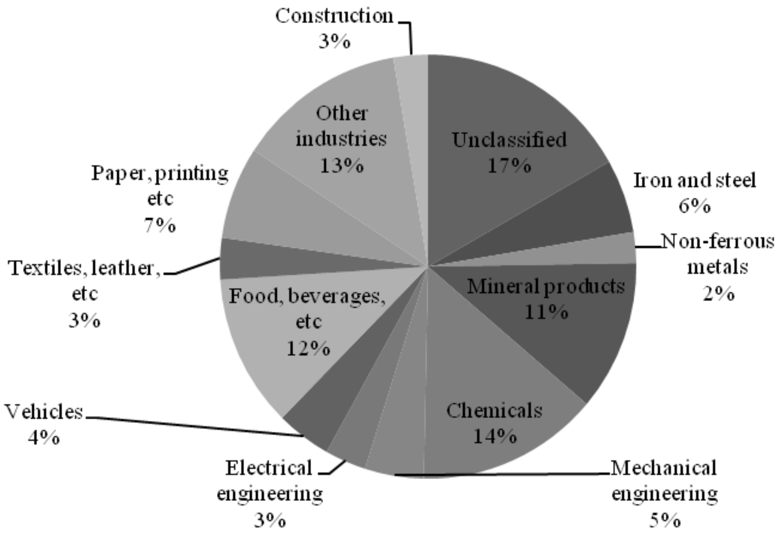


Figure 15 - UK 2013 final sectoral industrial energy, (MacLeay, Harris and Annut, 2014)

2.1.3 Industrial energy efficiency programmes

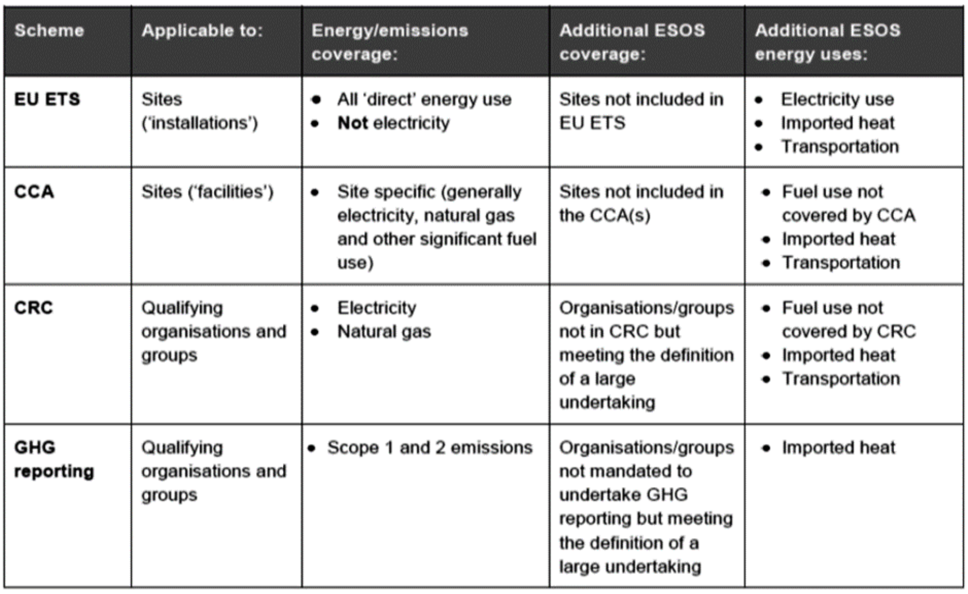
Regional (the EU's EPBD (2002)) and countrywide (the UK's Climate Change Levy (CCL)) industrial energy and carbon reduction schemes and policies, providing clear drivers for change, have been designed. For example, the European Emission Trading Scheme (EU ETS) 2005 requires high-emission industries such as power stations to cap and trade their annual carbon emissions. The EU's energy efficiency directive (2012/27/EU) requires building energy efficiency and the actions of member states to acknowledge this. The Energy Efficiency Opportunity Scheme (ESOS) 2014, discussed below, is the UK's response to it in the non-domestic sector.

In the past 20 years, a number of energy efficiency regimes have been introduced to the UK industry. For example, the tax on energy (CCL) encourages industrial energy efficiency and appreciates industry for a 15% reduction in carbon emissions between 2008−2020, compared to 1995 levels. The UK's GHG reporting, under the Companies Act 2006 (Strategic and Director's Reports) Regulations 2013, requires quoted companies to report their GHG emissions in their directors' report. Where "the quoted companies are the UK incorporated and whose equity share capital is officially listed on the main market of the London Stock Exchange, or is officially listed in a European Economic Area, or is admitted to dealing on either the New York Stock Exchange or NASDAQ" (The Carbon Trust, n.d.). Although a 12-month overview of an organisation's GHG emissions is required, but no particular GHG emission calculation method/standard has been prescribed under the scheme. The emissions should, however, be expressed in per unit of sales revenue or floor space.

Carbon Reduction Commitment energy efficiency scheme (CRC) is a mandatory UK scheme designed to cover emissions that are not covered by EU ETS and climate change agreement (CCA). Announced by the (DTI, 2007) the scheme was a measure to achieve UK's 80% carbon emission reduction targets for 2050. Large non-EI public and private sector organisations (together emitting 10% of UK CO_2) that use 6,000MWh or more H-H electricity data (National Audit Office, 2012) come under the scheme. Organisations that do not qualify would only need to register and disclose consumption to the operator of the scheme. Going slightly further than previous schemes, ESOS confers broader coverage as shown in Table 1.

Designed by the Department of Energy and Climate Change (DECC) and administered by the Environment Agency (EA), ESOS imposes cost-effective energy audits on large organisations (medium-sized and above and their corporate groups as discussed in Section 2.1.4). The scheme consists of three (four-yearly) phases from 2011–2023. The administrator recognises energy audits emanating from Display Energy Certificates (DEC), Green Deal Assessments, and ISO-50001 EM standard and may exempt (full or in part) ESOS. For the first phase, the scheme required a consecutive 12-month reference period (between 1st January 2014−5th December 2015), with data overlapping the qualification date of 31st December 2014. The first complete audit is to be submitted by 5th December 2015. The whole assessment process requires the participants simply to undertake three things: measure total energy, carry out an audit to identify cost-effective energy efficiency opportunities, and report compliance to the EA (DECC, 2014b). The operator estimates a savings of £1.6 billion, most of which will be felt by the businesses themselves.

Table 1 - ESOS and other schemes, scope and requirements, (DECC, 2014b)



Scheme	Applicable to:	Energy/emissions coverage:	Additional ESOS coverage:	Additional ESOS energy uses:
EU ETS	Sites ('installations')	• All 'direct' energy use • **Not** electricity	Sites not included in EU ETS	• Electricity use • Imported heat • Transportation
CCA	Sites ('facilities')	• Site specific (generally electricity, natural gas and other significant fuel use)	Sites not included in the CCA(s)	• Fuel use not covered by CCA • Imported heat • Transportation
CRC	Qualifying organisations and groups	• Electricity • Natural gas	Organisations/groups not in CRC but meeting the definition of a large undertaking	• Fuel use not covered by CRC • Imported heat • Transportation
GHG reporting	Qualifying organisations and groups	• Scope 1 and 2 emissions	Organisations/groups not mandated to undertake GHG reporting but meeting the definition of a large undertaking	• Imported heat

The SMEs and public sector organisations can benefit from the scheme's framework for the audit process. The scope of the audit includes energy from buildings transport and industrial processes within the UK, and at least 90% of total energy use (unlike CO_2 emission accounting frameworks requiring 95% coverage, as in Section 2.3.2) should be accounted for. Measured on expenditure/kWh basis the audit must be approved by a qualified Lead Assessor (internal/external expert/consultant) and reviewed by one of the company's board-level directors. Four out of five audits segments are mandatory, shown in Figure 16. In 2015 an ESOS guide to promoting energy efficiency opportunities has been published by EA (Environment Agency, 2016). According to the third (December 2017) newsletter by the EA, out of 2,400 investigated organisations 240 were issued enforcement notices.

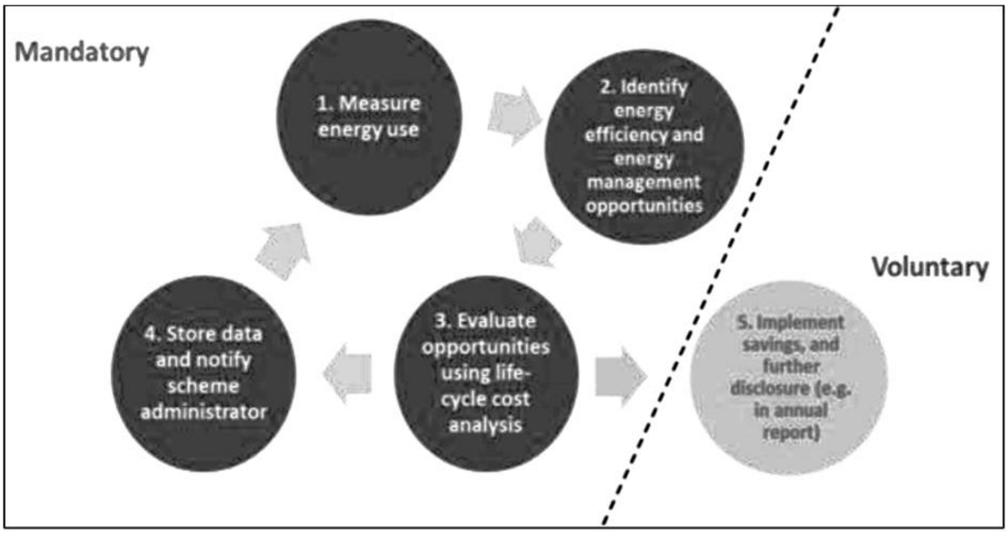


Figure 16 - ESOS compliance steps, (DECC, 2014b)

2.1.4 Classification of the industrial buildings

EI industry, SME or large-size industry, or industry classification codes based on economic activity are frequently used business terms. The classifications, depending on size, economic activity, and energy intensity, are assigned to individual type of businesses. For example, a large-size business does not have to have an EI activity contrary to that small- and medium-sized businesses like ammonia, blast furnace, and iron and steel manufacturing, as shown in Figure 12, do not have to be non-EI. Sometimes a manufacturing activity, perceived to be an SME, can attain a size of large-scale industry e.g. a textile manufacturing unit with fewer than 250 employees. In addition, sometimes non-EI industries can have a large amount of energy embedded into their final products (out of scope). However, determining and distinguishing between these classifications is necessary for energy benchmarking, comparison, and efficiency studies for more clarity, therefore is discussed below.

SMEs are the backbone of manufacturing such as car parts and textiles industries. Representing 50%–60% of world employment, these account for over 90% businesses in the world (Dayo et al., 2006). European Economic Area (EEA) caters 20-million micro-, small-, and medium-sized enterprises. SMEs represent 99% of enterprises in the EU-25 (EU, 2005). Out of 4.9 million UK private sector businesses in 2013, 99.2% were small and only 0.6% were medium-sized. However, large-sized businesses only made up 0.1% of the total but were responsible for 52% of the turnover (BIS, 2013). Although SMEs play a significant economic role, little research has been carried out in to developing frameworks/models (i.e. performance measurement and benchmarking) suggesting how SMEs can improve their business sustainability, profitability, and competitiveness (Cooper et al., 2005). All of this can be related to how that business manages its own energy use. Inconsistencies in defining SMEs in both literature and practice, due to sub-sectoral heterogeneity, exist (Cooper et al., 2005). Definitions for the sector vary; for example, some countries evaluate it on a value-added output basis and in others the number of employees will determine it. However, a typical guideline would be a few hundred employees with a turnover of less than £65 million (Cong et al., 2012).

According to the National Archive (n.d.), the 1971 Bolton report recognises that the size of an SME is relevant to its sector. For the size determination, the report suggested taking the number of employees or annual turnover in the account. This can be seen in the UK 1985 Company Act's section 248 (in which turnover, number of employees, and balance sheet values have been considered).

Amended in 2003, the EU formulated its own first SME definition in 1996. It states that the SME employs no fewer than 250 people and does not exceed an annual turnover or total balance sheet of £36m or £31m respectively, as shown in Table 2. Since it does not take into account the energy intensity, a number of EI industries come under the SME sector as can be seen in Figure 12 above. Therefore, the use of such classification in energy studies may be appropriate within a given sector, but further sub-classifications might be appropriate based on other forms of benchmarking.

Table 2 - Categories of SMEs, (EU, 2005)

Company category	Employees	Turnover (m)	Or	Balance sheet (m)
Medium-size	< 250	<£36		<£31
Small-size	< 50	<£ 7.2		<£ 7.2
Micro-size	< 10	<£1.4		<£1.4

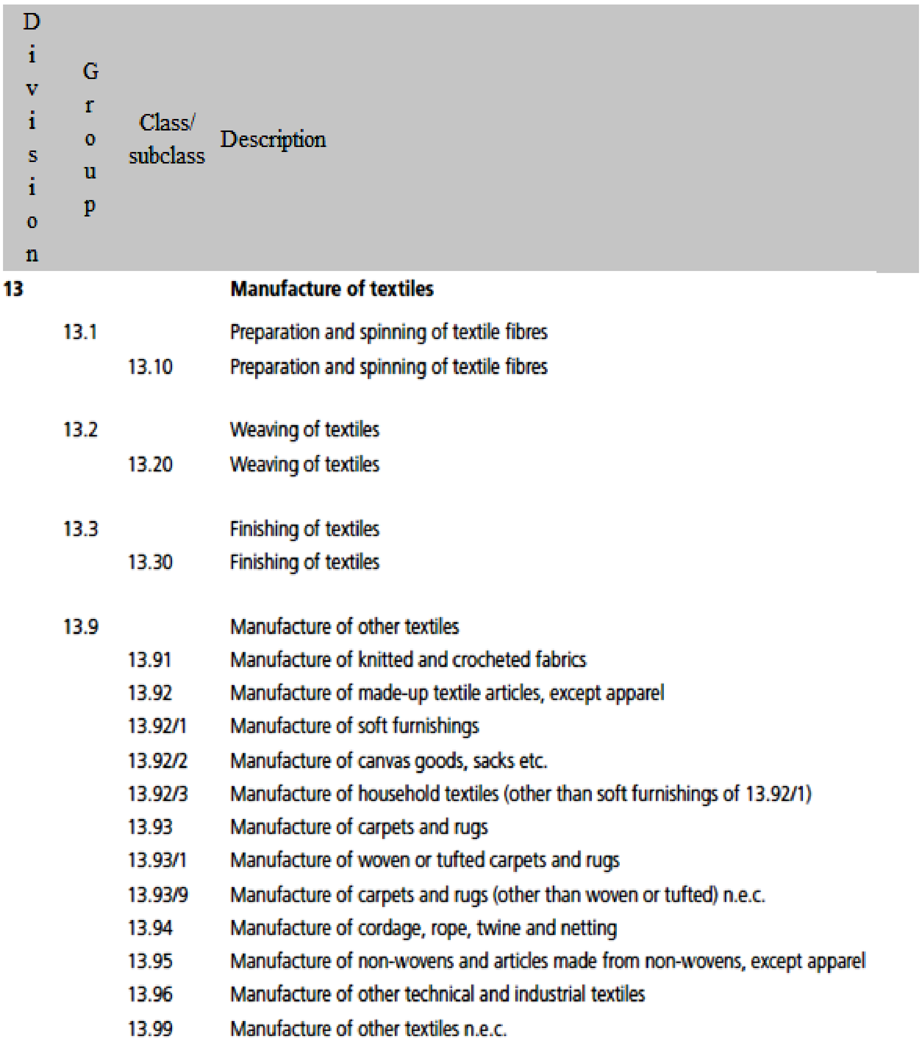
Adopted from € to £ currency where £1=€0.72

SMEs often have a complicated supply chain, which can make complete energy use assessments non-trivial. The supply chain is defined as the network of upstream and downstream (as in Section 2.3.2) linkages of goods and services organisations that add value to the end-customer's products through different processes and activities (Antai, 2010). These businesses can be either standalone independent or may have either vertical or horizontal, or an integration of both. Vertical integration (three types—forward/downstream, backward/upstream, and or balanced) is the form of supply chain in which a business owns and undertakes all or most of the services/process states/goods involved in its supply chain by itself. In horizontal integration, merger/acquisition or buyout takes place with similar organisation(s) for expansion (increase productivity, reduce market competition). The basic definition, according to Delgado, Porter and Stern, (2014), is that these are geographically concentrated groups that are related in terms of skills, knowledge, inputs, demand, or some other common factor. A composite textile-manufacturing plant, on the other hand is the one that carries out all/most of the sub-stage processes under one roof, independently, and or associated with a “mother” textile company (Hasanbeigi, 2010).

Another way to classify industrial buildings is based on their economic activity. Providing a criterion for collection, presentation, statistical tabulation, and analysis of economic activity data, these UK Standard Industrial Activity Codes (UKSIC) were first developed in 1948. Following exactly the Nomenclature of Economic Activities (NACE) codes, the 2007 UKSIC have been revised for contemporaneous changes in NACE codes (ONS, 2007).

This is illustrated in Table 3 with UKSIC codes for textile. The heterogeneity of the textile manufacturing as it has up to five digits (for example 13.92/2) is clearly shown. Other examples of such international standards are North American Industry Classification System (NAICS), and the United Nations International Standard Industrial Classification (ISIC) system.

Table 3 - UKSIC for textile, (ONS, 2007)



Division	Group	Class/ subclass	Description
13			**Manufacture of textiles**
	13.1		Preparation and spinning of textile fibres
		13.10	Preparation and spinning of textile fibres
	13.2		Weaving of textiles
		13.20	Weaving of textiles
	13.3		Finishing of textiles
		13.30	Finishing of textiles
	13.9		Manufacture of other textiles
		13.91	Manufacture of knitted and crocheted fabrics
		13.92	Manufacture of made-up textile articles, except apparel
		13.92/1	Manufacture of soft furnishings
		13.92/2	Manufacture of canvas goods, sacks etc.
		13.92/3	Manufacture of household textiles (other than soft furnishings of 13.92/1)
		13.93	Manufacture of carpets and rugs
		13.93/1	Manufacture of woven or tufted carpets and rugs
		13.93/9	Manufacture of carpets and rugs (other than woven or tufted) n.e.c.
		13.94	Manufacture of cordage, rope, twine and netting
		13.95	Manufacture of non-wovens and articles made from non-wovens, except apparel
		13.96	Manufacture of other technical and industrial textiles
		13.99	Manufacture of other textiles n.e.c.

Another (common) way to distinguish industrial buildings is based on their energy intensity. Energy intensity in terms of physical output is commonly defined as "energy used (e.g. gigajoules, kWh) to produce a unit i.e. one tonne or cubic metre of a product" and is known as SEC (further discussed in Sections 2.2 and 2.3.1). Based on the physical output, industrial buildings are normally divided in to two large families: EI (such as defined above) (Cong et al., 2012) and non-EI. This type of EI industry indexing may be based on fuel type (e.g. oil, electricity, etc), or percentage of energy cost towards the finished goods. Ecorys (ECORYS SCS Group, 2009) tends to declare the remaining industries as non-EI. Some studies refer EI industries synonymous to heavy industries whereas non-EI industries as light industries. This classification is based on their position in the production chain. For example, manufacturing sectors producing intermediate products from raw materials are known as heavy industry. However, assembly and fabrication of basic materials produced by other industries are known as light industry. Including food processing, metal engineering, and electronics industries light industries represent a wide variety of processes. Many a time larger quantities of energy used in this industry contribute towards building services (i.e. Heating, ventilation, and air conditioning (HVAC)) instead of directly for the process (Worrell, 2004). The concept is further enhanced through the classification of strategic (lower-energy-intensity and higher value-added) and non-strategic (low-energy-intensity) industries. Some define EI industries as the ones which are material-intensive too (Ramírez, Patel and Blok, 2005).

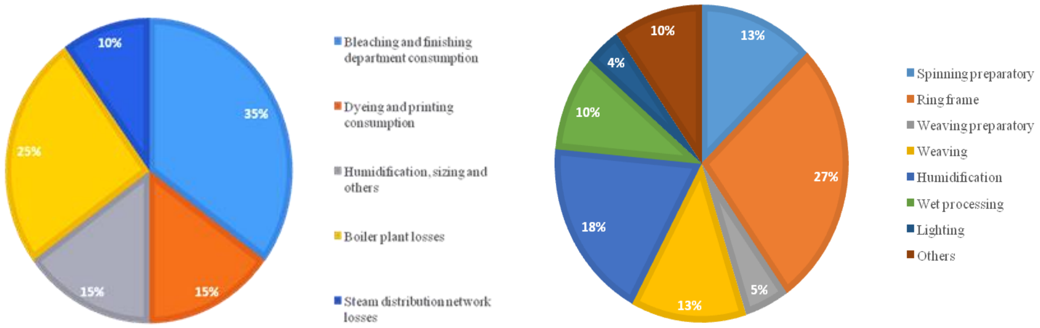
Some other energy intensity determinants can be multiple processes and end-products involved, and the use of multiple production sites causing less quantity/cost of energy used per site. Based on such factors, industries with relatively less or more energy intensity than EI or non-EI respectively are still classed as non-EI, or sometimes referred to as ‘diffused’. For example, office machinery, automobile, and fabricated metal products are a subsidiary of the basic metal industry, whereas pharmaceutical products, pesticides, and paints and varnishes are a subsidiary of the chemical industry (Cong et al., 2012).

As discussed above, factors like climate, energy policy, and structural changes can greatly influence energy consumption in a particular country/region. However, energy intensity based on physical output and monetary values are extensively used for both cross-country comparisons and national benchmarking. Linking such metrics to specific uses of energy within industrial buildings is challenging. Energy use in the manufacturing sector is notably different than other types of non-domestic buildings. The buildings facilitating manufacturing activity are most likely to have higher manufacturing-related energy demand as compared to building services (heating, cooling, domestic hot water). Therefore, methods required for energy estimation for manufacturing buildings should have a more sophisticated approach so that they can estimate and separate manufacturing and non-manufacturing energy use.

Representing a heterogeneous and fragmented SME industry, the textile is a less-EI industry than for example, cement, steel, or chemical. However, it has relatively high energy consumption compared to other SME industries. The textile’s complicated process and supply chain (Hasanbeigi, Hasanabadi and Abdorrazaghi, 2012) makes detailed energy assessments a challenge. Therefore, textile energy studies make a relatively small share of all industrial energy studies (Hasanbeigi, Hasanabadi and Abdorrazaghi, 2012). The industry mostly thrives as small independent individual process/sub-process (such as dyeing, weaving, and finishing) units. Having specific characteristics mainly due to multiphase production processes, with each having different production rates (Karacapilidis and Pappis, 1996) and, therefore have distinct energy requirements. This aspect of manufacturing can have a detrimental impact on the total process energy consumption. This becomes another encouraging factor for more energy assessment studies. Multiple textile country, area/region, and process-specific energy studies (Allwood et al., 2006; Intelligent Energy Europe, 2007; Textiles NZ, 2012; Canadian Industry Program for Energy Conservation, 2007; Koç and Kaplan, 2007; Hasanbeigi, 2010) have been carried out.

In the light of contexts above textile manufacturing energy can be geographically/country specific such as (Allwood et al., 2006; Building Research Establishment, 1997; Textiles NZ, 2012), and process-specific (Koç and Kaplan, 2007; Canadian Industry Program for Energy Conservation, 2007), and general (Hasanbeigi, 2010). Therefore, efficiency opportunities for the sector are similarly specific. However, unavailability of energy studies for one country may lead to rely upon studies carried out elsewhere. Cross-country comparisons, for example as carried out for the whole sector between two countries (Pardo Martínez, 2010) or multiple countries for specific processes such as weaving (Koç and Kaplan, 2007) can also aid understanding. Vertically integrated composite textile manufacturing units (a rarely existing phenomenon) also exist with no visible energy benchmarks or indicators available.

The heterogeneity and complicated supply chain of the textile sector sometimes can create confusion in classification, which acts as the basis for energy benchmarking. For example, large-scale and small-scale textile industries will have site-specific energy demands hence energy comparison or benchmarking among these can be variable. Globally, textile industries exist in a variety of forms such as small units, vertically and horizontally integrated, process-specific sheds, composite plants, and clusters. Due to the nature of the activity energy culture and use at a composite textile plant is likely to have a different scenario, as indicated elsewhere in Figure 17. Having different types of manpower/machinery involved with each type will result in variable fuel resources available and specific energy demands depending on the geographic location. In-depth investigation of a list of such concerns is not the purpose of this thesis. However, defining, distinguishing, and classifying different types and formats used to describe industrial buildings, as discussed above, can be helpful. Distinguishing the textile sector will serve to clarify the existing forms of the industrial and the SME sector based on different characteristics such as economic activity, size, and energy intensity, as discussed above.



A) Breakdown of typical thermal energy

B) Breakdown of typical electric energy

Figure 17 - End-use energy in composite textile manufacturing, (J. Sathaye, et al., 2005)

The UK textile industry uses 0.4% of total national energy and is responsible for the same amount of GHGs (Allwood et al., 2006). The gap and necessity of UK textile energy studies and guides is evident from the few available (Building Research Establishment, 1993; Allwood et al., 2006; Building Research Establishment, 1997). This also indicates the dearth of modern best practice energy efficiency techniques in the industry. Up-to-date UK textile EM practices can play an important role in making the business low-carbon and competitive

UK energy assessment studies can be useful in making sectoral energy and carbon indicators (at the process, unit/factory level) for textile and the associated buildings. The industry-specific energy knowledge can be directly useful for manufacturers to improve and collate other sustainability indicators for the business competitiveness. Nonetheless, having more country-specific studies can suggest more specific saving opportunities as well as will contribute towards benchmarking. This necessity of such studies is for sure as a reasonable number of textile factories still exist in the country.

2.2 Building energy assessment

2.2.1 Energy and thermodynamics

According to Thiede, Bogdanski and Herrmann (2012) energy is “the inherent ability of a system to generate external impact” and is fundamental to carry out any kind of work. Energy is a scalar quantity and is evaluated through thermodynamics (the science of energy and energy transformation and the relationships among the properties of matter) (Cengel and Boles, 2006) indicators. The first law of thermodynamics states that energy can neither be created nor destroyed but transferred from one form to another. Whereas according to the second law exergy "maximum quantity of mechanical work one could obtain from a given heat source" (Ammar et al., 2012) is lost during this transformation (European Commission, 2009). Hence, industries/processes involving radiative and thermal processes are potential candidates for exergy conservation. Although exergy is out of scope of this thesis but conserving radiative, convection, and conduction losses will somehow be addressed.

Heat of combustion of fuels (the energy content) in EM is generally of particular interest as on burning most fuels produce water. The *lower heating value* (LHV) indicates when the water is in the vapour form (some combustion heat is lost as heat of the vaporisation i.e. latent heat). *Higher heating value* (HHV) is when this heat of vaporisation is captured and water is in the condensed form (Cengel and Boles, 2006). The phenomenon is exploited in industrial energy efficiency as discussed in Chapter 3.

2.2.2 Energy efficiency

The phrase energy efficiency is conveniently used to describe the economy (efficiency) of energy utilisation. However, problems arise when attempting to define it on the common basis of measuring it (Langley, 1987). Energy efficiency has a precise technical meaning when applied to some machine. The ISO-50001 energy management standard defines energy efficiency as the ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy. Energy efficiency is defined as "the amount of human activity (e.g. heating a room to a certain temperature, transporting goods over a certain distance, producing a certain amount of steel, etc) provided per unit of energy used" (Phylipsen, Blok and Worrell, 1997). For an industrial process there is no energy output as such thus requiring the basis of energy input relative to some absolute standard as minimum theoretical energy requirement. This leads to the idea of defining energy efficiency on the basis of process specificity. Therefore, different ratios, such as GJ tonne-1 or MJ litre-1 are used to measure energy consumption per unit of output. Energy conservation/saving is "a decrease in energy consumption in absolute terms over some period of time" (Siitonen, 2010). The efficient use of energy, in terms of a system/equipment, depends both on technical efficiency (for example by modifying/replacing the existing equipment) and O&M (operations and maintenance (for example savings based on good housekeeping)), therefore is seen as a quality of system of equipment and operation (Phylipsen, Blok and Worrell, 1997; Siitonen, 2010). Whereas, in terms of an organisation, the use of energy efficiently is hindered by three aspects: economic, behavioural, and organisational (Sorrell et al., 2000). Each of these barriers is however further challenged by economic, behavioural, and organisational aspects (Sorrell et al., 2000). A general review of these has been taken by (Gillingham and Palmery, 2014).

Generally, energy efficiency can be improved through four types of changes—operational, effective maintenance, engineered improvements, and new technologies. These may have individual departments/administrative areas for large organisations—maintenance, operations, research and development, and engineering (Rossiter, 2015). However, for most of the SMEs this will hardly be the case. This thesis mainly investigates system/equipment energy efficiency aspects (Phylipsen, Blok and Worrell, 1997) to improve manufacturing energy efficiency. Since organisational and the operational aspects cannot be completely excluded specifically when dealing with the case study site, therefore, some of these, where necessary, are also discussed.

Energy efficiency in thermodynamics is ensuring minimum energy lost/maximum useful work taken during the energy transfer or transformation process. In manufacturing terms, it is producing more units with less energy. The energy efficiency of a system or technology can be evaluated and compared with similar technology or system. However, such micro-level comparisons are difficult when dealing with large systems/organisations with a variety of equipment, or when benchmarking energy efficiency of one or more processes. For such purposes energy efficiency/performance baseline indicators (i.e. national energy efficiency or SEC standards or measured values in situ) may be determined first, as an approximation, to compare against after retrofitting.

Energy efficiency in mathematical terms has a denominator and a numerator i.e. a measure for energy consumption and activity, respectively. Activity in industrial terms is the output of a given product that is applied to both economic (e.g. value-added) and physical terms (e.g. kilograms produced) (Phylipsen, Blok and Worrell, 1997).

Three widely used energy efficiency indicators: i) energy intensity index/GDP (the ratio of energy input and economic output), ii) thermal efficiency (a measure of efficiency and completeness of combustion of the fuel, iii) SEC, also known as energy consumption intensity or unit energy consumption have been identified (Giacone and Mancò, 2012). The last two are relevant to this thesis. As GDP is a thermo-economic indicator therefore when dealing with the energy it fails to measure underlying technical energy efficiency (Patterson, 1996). Therefore, it may not be good enough for building energy efficiency studies. According to Tanaka (2008) "thermal energy efficiency of equipment is energy output/input for end-use technology and energy conversion technology. For example, in the case of motors, it should be power output divided by input electricity". Thermal efficiency analysis may be carried out to ensure efficient energy performance of a technology/system. Therefore this indicator, to a great extent, is helpful to evaluate micro-level technical energy efficiency, as discussed in Chapter 3. A physical energy index like SEC is a more specific quantity than those obtained through thermal energy assessments. Through this approach, energy comparisons of a broader set of objects from processes, factories, companies, and even countries can be carried out (Tanaka, 2008). Thus an industry/organisation wishing to improve its energy performance as a whole can compare its energy use with existing SEC indicators, as discussed in Section 2.3.1.

2.2.3 Types of building energy performance assessment

Building energy performance—how good the building is performing evaluation is complicated since it depends on multiple variables such as building characteristics, equipment and systems, weather, occupants, and sociological influences (Amiri et al., 2015). The existing building energy performance assessment can be classified into two distinct approaches: namely feature-specific and performance-based approaches (Wang, Yan and Xiao, 2012). In feature-specific approaches (i.e. UK's BREEAM (Building Research Establishment Environmental Assessment Method) buildings are assessed against pre-set features (i.e. building envelop, lighting, HVAC based on good practices). According to Lee, Yik and Burnett (2003) feature-specific type assessments are generally used to carry out building classification. This type of assessment is suggested to have shortfalls like reduced innovation and identified measures being less economical.

Performance-based energy assessments, on the other hand, are based on the audited performance compared against indicators/benchmarks. Although the development of this assessment methods and procedures is more difficult than a feature-specific approach but is preferable (Lee, Yik and Burnett, 2003). EUI (or normalised energy consumption (NEC)/normalised annual consumption (NAC)) is most commonly used energy intensity indicator (kWh/m^2) for the whole (commercial/office) building energy assessments (Xinhua, 2015). This reasonably good approach sometimes may not be a justified method for energy benchmarking/studies. For example, same-sized supermarkets having dissimilar energy use due to geographical location, number of customers, products they deal in, etc. Benchmarking helps to detect faults or identify areas of improvement (Norén and Pyrko, 1999).

Energy performance assessment schemes and methods are mainly used for two main purposes: energy classification and energy performance diagnosis (Wang, Yan and Xiao, 2012). Energy classification (for example BREEAM, and EUI) allows calculating energy performance and carbon emissions assessment in a uniform means. This can be used to establish/encourage building energy performance, to compare with historic or best practice benchmarks for baseline determination, to set targets, or to determine the level of compliance.

The key existing methods for energy performance classification schemes include energy benchmarking, rating, labelling, and certification (Wang, Yan and Xiao, 2012). These types of classifications normally rarely suggest or identify site-specific energy efficiency improvements. This is where energy performance diagnosis takes over to detect building faults and failures and directing solutions to the issues that are causing poor performance. Key areas include prolonged equipment life, and reduced energy use and maintenance costs (Motegui et al., 2004). Allowing diagnosis at different levels the energy improvement opportunities, i.e. at building level, through the method may be identified through a walk-through (based on low-hanging fruits/O&M, as discussed in 2.3.1), or other measures (such as improving technical efficiency as discussed in Chapter 3). For system/technology-level assessments, i.e. a boiler, an analysis of the variance between the total steam produced and the end-user demand, and the coefficient of performance (CoP), will help to identify any improvement measures. The evaluation scope can be further enhanced by adding on more technical evaluations, such as component change or machinery replacement and looking through behavioural aspects within the organisation. The analysis of energy performance data to identify faults and failures is another route towards building performance diagnosis (as discussed in Section 2.2.4). The energy performance assessment method used in this thesis is based on diagnosis. Assessing building energy performance is key for designing effective EM. The process is capable of monitoring, identifying and suggesting improvements for equipment/systems performing poorly, highlighting reasons for underperformance, and identifying priority efficiency improvement areas. This can be equally helpful for existing buildings (through retrofitting) and new building design (CIBSE, 2006b).

2.2.3.1 Energy quantification methods

Being rudimentary to performance-based enquiries energy quantification (measuring) is the very first step towards building energy assessments (Wang, Yan and Xiao, 2012; Giacone and Mancò, 2012). Measuring and monitoring in manufacturing environments, supporting the process control, significantly contribute to energy auditing. Accurate and reliably measured energy flows of system/s alleviate vague estimates and improves traceability of issues influencing system energy efficiency (European Commission, 2009). However, where limitations like unaffordability/unavailability of cost and measured data exists, estimates are relied upon. The EU's Best Available Technique Reference document (EU BREF) identifies different measuring and monitoring techniques under the following headings (European Commission, 2009):

- qualitative techniques
- quantitative measurements, using direct metering and advanced metering systems
- applying new generation flow-metering devices
- optimising utilities using advanced metering and software controls
- using energy models, databases and balances

Three categories of energy quantification methods, namely calculation-based (building simulation models for both dynamic and steady-state quantifications), measurement-based, and hybrid approach have been defined by (Wang, Yan and Xiao, 2012). Based on performance data, the measurement-based approach is the main subject of this thesis. The performance data can be sourced from main meters and energy bills to more detailed data such as from sub-meters, or a BMS (building management system) system. The data can then further be verified/compared with short-term monitoring.

According to Wang, Yan and Xiao (2012) the measurement-based approach has two key types, each having three subclasses (as shown in Figure 18).

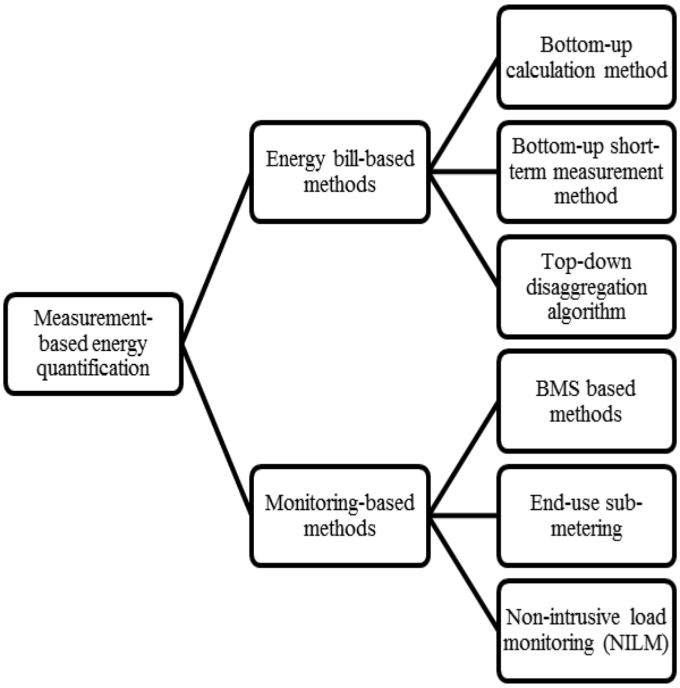


Figure 18 - Measurement-based energy quantification methods, (Wang, Yan and Xiao, 2012)

Energy bill-based methods follow as the name implies. End-use demand indicators such as nameplate rating, and usage factors and patterns are used for bottom-up type estimations, for example, as by Field et al., (1997) in office buildings. The method, when accompanied with short-term end-use monitoring is called bottom-up short-term measurement method. This monitored data is then extrapolated for a certain length of a period, such as a year. The seasonality factor (i.e. for HVAC) is also considered when calculating individual end-use demands. Such a method (short-term measurement (STM) on multiple non-domestic buildings has been applied elsewhere (Robinson and Reichmuth, 1992). Researchers (Wang, Yan and Xiao, 2012) refer the Lawrence Berkley Laboratory's top-down disaggregation algorithm—End-use Disaggregation Algorithm (EDA) as an example of top-down disaggregation method.

Another type is non-intrusive load monitoring (NILM) which utilises sensors on individual devices, mainly on domestic buildings, to avoid the use of multiple metering devices. BMS based methods are another approach classified under monitoring-based measurements. The performance and details of the approach can be further enhanced by using temperature sensors and energy metering devices. Both techniques and methods described by the EU BREF (European Commission, 2009) or (Wang, Yan and Xiao, 2012) discuss sub-metering for measuring. The document (European Commission, 2009) suggests the use of the advanced metering system but does not discuss the data analysis methods, obtained through such systems. Therefore, a dedicated description of building energy analysis is included in Section 2.2.4.

Using intuitive and subjective processes and information, qualitative techniques offer assessments without detailed information. Therefore, depending on the perceptions of the observer, the results may be different. Quantitative techniques rely more on measurable values obtained through different instrumentation and tools e.g. metering. Depending upon the data availability and the nature of the study, a combination of both quantitative and qualitative can be used (D. Yogi Goswami and Kreith, 2007). Hence, this thesis uses some qualitative techniques (i.e. empirical values based on experts' estimates) where no measured/monitored data was available.

2.2.3.2 Measuring building and equipment energy

Appropriate utility metering is key for reasons such as invoicing, EM, and supply/demand side management (CIBSE, 2009; ASHRAE, 2002). Metering based monitoring can result in simple actions that can save 5-10% energy (Jones, 2002) and up to 12% carbon as observed by the Carbon Trust's study (DTI, 2007). However, sometimes it can be expensive hence in addition to regulatory requirements an initial cost-benefit analysis is recommended (CIBSE, 2009). Metering strategies are of two types: direct, (e.g. main utility, hour meter on system), and indirect (e.g. the difference between two-meter readings to generate the third). Three types of measurements: i) spot, (one-off); ii) short-term (regular measurements over one-week to six-months), and iii) long-term, (anything exceeding ii) have also been differentiated (ASHRAE, 2002). Metering, communication technology, and analysis software are used for advanced metering systems (AMS). Having data logging and BMS systems connectivity compatible meters can produce good quality resource for energy analysis.

The traditionally used pulse output meters for high-resolution data recording and communicating to the central system are prone to missing data and other errors (Jones, 2002). Two major forms of errors, zero and cumulative reads have been reported by (Piette, Kinney and Friedman, 2001). Techniques to rectify these missing data and errors are suggested elsewhere (Wright and Brown, 2007) and a range of proprietary and free software can be used for energy profiling such data like Energy Lense's Interval Data Analysis Software (BiZEE Energy Management Made Easy, n.d.). Smart meters and AMS, having analysis software package, are in use to optimise both on-site and on-grid energy use. In addition to H-H consumption data, energy supply companies can provide basic energy analyses for the consumers.

For system and appliance energy measurements, sub-metering is generally recommended (Jones, 2002). Such unit-level energy measuring may be used for different types of energy studies, such as identifying saving opportunities and calculating savings after retrofitting as undertaken for commercial and manufacturing environments elsewhere (Menezes et al., 2012; Gordić et al., 2010). Electronic metering technologies are becoming cheaper however high installation and monitoring costs persist (Field et al., 1997; Jones, 2002). Cost-effective invasive (transducers in direct contact with the flow media), intrusive (transducers extend into the flow) and non-invasive/intrusive alternatives (Leung et al., 2012) are available. These alternatives are tailored and depending on system and situation requirements as shown in Table 4 have been used in different energy measuring and assessment techniques. For example, clamp-on meters used for quick energy demand measurements (Palamutcu, 2010).

A variety of clamp-on meters with inbuilt or auxiliary data logging port such as energy logger kit (Tinytag energy data logger 3 phase power monitoring, n.d.), and integrated data-logging system with multiple CTs (current transformer) (Eltek Specialist Data Loggers, n.d.) are also sold. Producing good quality data can be used for instantaneous short- and long-term energy profiling of whole/individual system/appliances. However, due to the requirement of accessing electric wires/boards/distribution systems, these can sometimes be impractical for certain situations.

Table 4 - Metering technologies with features and installation costs, (Brown and Wright, 2008)

Technology	Approx base cost for hardware, software (£)	Approx. cost per appliance (£)	Notes
Temperature loggers	36	18	Imprecise, post processing is needed
Power meters (plug in)	0	18	Not capable of profile logging but capable of measuring integrated consumption
Power meters (bench top)	18	216	Bulky-lab apparatus used for calibration but capable of logging and very accurate
Current clamps	29	108	Manual data collection required, certain current transformers may not operate at low currents
Magnetic field sensors	18	43	Needs to be positioned close to motor or flourescnet light ballast
Individual appliance monitors	720	86	Extremely accurate and precise, automatic data uploads include integrated consumption

Adopted from € to £ currency where £1=€0.72

From plugging-in to operating, electric appliances generally produce some heat (e.g. 94% heat generated in tungsten bulb) (Patterson, 1996). This may be due to space heating or lighting (baking oven), electrical inefficiencies (as in electronics), magnetic circuits (eddy current heating of transformer cores), or process heat (e.g. refrigerator). Estimating heat produced in an appliance is a well-established method for estimating electricity consumption for the energy assessment and efficiency studies. For example conversion factors based on system characteristics (as calculated by industry-specific organisations) like approximate heat generation figures produced for small power and IT elsewhere (Wilkins and Hosni, 2000; CIBSE Guide F, 2012). These range from office equipment related increase in cooling load and improving motor efficiency by reducing heat and friction losses (IEC-600034 standard), to carrying out equipment health checks, such as lubricating moving parts to reduce friction-related losses. By identifying individual appliance's energy usage patterns through temperature based non-invasive method, for example as proposed elsewhere (Brown and Wright, 2008). With the ability to record computable duty cycles, the method is appealing for individual technology/building systems' energy auditing with detailed energy forensics. However, individual appliance handling and then aggregation for a complete analysis can be difficult for larger buildings. The gadgets used may be inexpensive but for a large number of technologies, the whole project may mean: time, effort, money, and sophisticated data management and analysis tool/s.

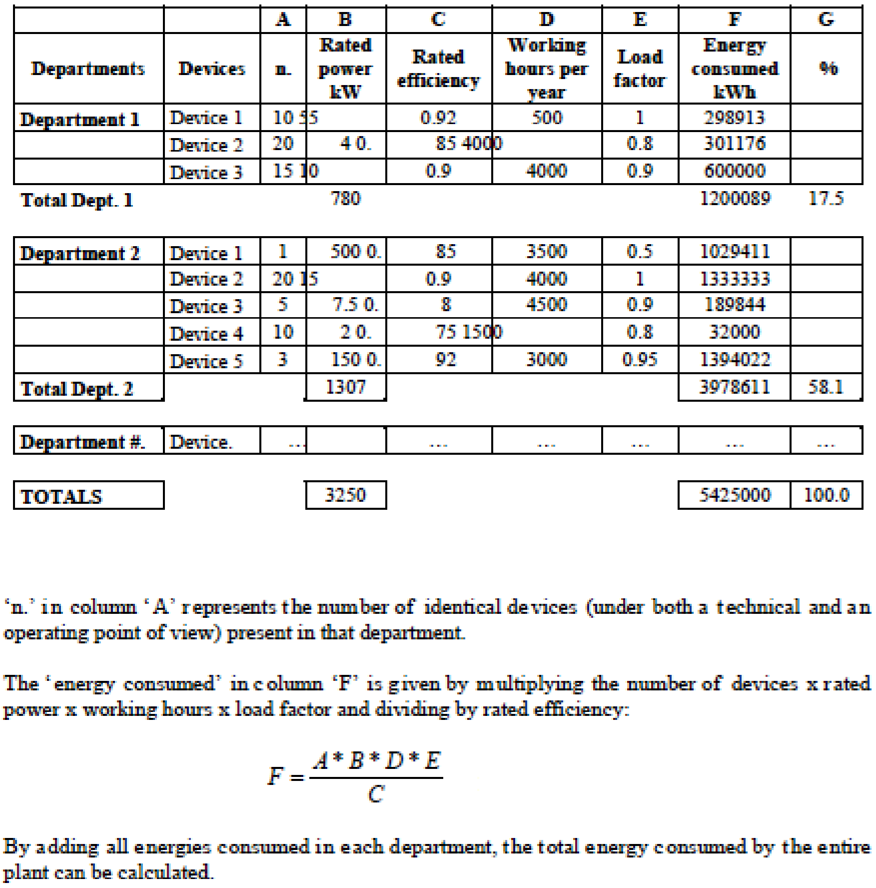
Energy monitoring devices sensing other parameters, such as magnetic fields, are another option. For example, motor/light on-off data loggers are used for automated monitoring e.g. HOBO Motor On/Off AC Field Data Logger (Hobo, n.d.), and HOBO Occupancy/Light (12m Range) Data Logger (Hobo 1, n.d.). Low-cost plug-and-play energy monitoring devices (e.g. e2 classic wireless monitor (E2 Classic, n.d.) can store display hourly energy consumption/cost/CO_2. Remote device controls for domestic and commercial EM using Zigbee internet protocols have also been used elsewhere (Menezes et al., 2013). Handling lower loads and mostly able to monitor individual devices, these meters are more appropriate for domestic/office environments and less for large industrial systems.

Nameplate rating (rated power) when combined with activity duration, i.e. hours/annum, provides an estimated demand, as indicated in Table 5. Other parameters such as rated efficiency and load factors, if available, can enhance the analysis as undertaken elsewhere (Kannan and Boie, 2003). For example luminaires' energy efficiency factors approximated in industry-specific guidelines such as (NSW

Government Australia, 2014), (BSI, 2007), and (CIBSE Part F, 2012). However, rated power assessments are generally suitable for systems lacking sub-metering or where clamp-on meters are impractical.

To estimate total and end user-demand, (Field et al., 1997) suggest a hybrid, using nameplate information along with the clamp-on meters, approach. Another method—STEM (Short Term Energy Monitoring) test, has been suggested by (Bryant and Carlson, 2002), which entails switching on/off energy supply for load estimations of individual buildings' sections. All of the above however has some limitations, for example, devoid of considering transient load conditions rated power is mostly indicative. The more accurate clamp-on meters can pose health and safety risks. With reasonably good accuracy STEM tests are impractical for premises needing a constant supply, and for situations with a variety of applications. The hybrid methods are also subject to limitations inherent to the contributing methods. Energy measuring through monitoring meters such as e2 classic, the heat produced, or magnetic field detection also has limitations as discussed above.

Table 5 - Nameplate and activity information based energy measuring, (European Commission, 2009)



		A	B	C	D	E	F	G
Departments	**Devices**	**n.**	**Rated power kW**	**Rated efficiency**	**Working hours per year**	**Load factor**	**Energy consumed kWh**	**%**
Department 1	Device 1	10 5	5	0.92	500	1	298913	
	Device 2	20	4 0.	85 400	0	0.8	301176	
	Device 3	15 1	0	0.9	4000	0.9	600000	
Total Dept. 1			780				1200089	17.5
Department 2	Device 1	1	500 0.	85	3500	0.5	1029411	
	Device 2	20 1	5	0.9	4000	1	1333333	
	Device 3	5	7.5 0.	8	4500	0.9	189844	
	Device 4	10	2 0.	75 150	0	0.8	32000	
	Device 5	3	150 0.	92	3000	0.95	1394022	
Total Dept. 2			1307				3978611	58.1
Department #.	Device.	...		...	...	...	...	...
TOTALS			3250				5425000	100.0

'n.' in column 'A' represents the number of identical devices (under both a technical and an operating point of view) present in that department.

The 'energy consumed' in column 'F' is given by multiplying the number of devices x rated power x working hours x load factor and dividing by rated efficiency:

$$F = \frac{A * B * D * E}{C}$$

By adding all energies consumed in each department, the total energy consumed by the entire plant can be calculated.

Supplemented by improved measuring devices, such as temperature/pressure corrector meters, primary/generic meters are generally relied upon for gas supply. In the UK premises exceeding 58,600MWh gas are classed as daily metered (DM) sites and for the ones below this demand, H-H metering is advised (Letcher, 2013). The changing concepts of sustainable businesses and the availability of novel low-cost IT and metering emphasises on the importance of gas measuring, monitoring and saving. This results in generating a good quality/quantity consumption data for (performance diagnosis/fault detection) analysis. To help them track their usage, now big suppliers such as Eon and British gas are offering H-H data loggers' installations (free/rental) unlike for the electricity only recently (Brown and Wright, 2008). Although, some gas data analysis techniques have recently emerged (Ferreira, Fleming and Stuart, 2015), more will be needed to address varying data and site situations.

The energy measuring techniques described above are used for EM purposes. The selection of the technique is usually based on the resources, scope, and the design of the EM project. Therefore, in addition to having an in-depth knowledge of these techniques, an energy manager should be well aware of the practical implications of each of them.

2.2.4 Building energy analysis

Analyses of (high-resolution) energy data acquired through intelligent energy networks (i.e. automatic and smart meters) include methods such as pattern recognition, and statistical methods. More analysis methods are required for the increasing amount and nature of such data at both consumption and production ends. For instance, it can be monitoring and diagnostics for end-uses (Ma et al., 2017). Building energy data analysis is key for energy diagnosis (Rabl and Rialhe, 1992) and can suggest improvements like retrofitting, characterisation through benchmarking, anomaly detection, and behavior-change related feedback. The scope of data analysis differs from graphing, forecasting, financial analysis, and benchmarking. These functions range from simple plotting to complex analytical routines (Motegui et al., 2004). Having reliable datasets is essential as data quality, accuracy, and resolution can improve analysis significantly. Numerous software-based information systems (IS) have been designed by IT giant corporations (for example IBM's SAP industrial EM, and Microsoft's Dynamics AX/NAV). These IS can carry out real-time acquisition, analysis, and present end-use energy information. Although these are good for metering integration, monitoring, and management along with footprint data analysis and reporting, they lack sophisticated intelligence capabilities. Standalone IS systems, such as eSight M&T/EMS and EnteGreat's Accelerator Manufacturing EMS have been particularly designed for manufacturing buildings. However, their true functionality is dependent on the presence of a manufacturing execution system (Zampou et al., 2014). Hence, these IS systems for many industrial sites (specifically SMEs) may become too complex and complicated to install, implement, and get benefit from. For EM in small and many medium- to large-size industries (number of employees), improved data analysis solutions can be more helpful. Less complex and easily manageable analysis methods and systems are strongly pronounced for complicated production processes and supply chains.

All forms of energy data (available/recording) have some quality-related risks involved. For example, an energy audit based on a year-long estimate of monthly utility invoices is primarily flawed due to uncertainty in the consumption. However, compared to this, actual invoices or manually taken monthly demand meter readings will be more reliable (Sjögren, Andersson and Olofsson, 2007). Similarly, compared to these, the most preferred data option will be electronic meter readings with increased resolution (number of readings/unit time) e.g. daily, hourly, or H-H. However, even this data can be subject to error as discussed in 2.2.3.2. Building operators are generally not trained on in EM, visualisation, and analysis techniques (Piette, Kinney and Friedman, 2001). Therefore, it is paramount for the data analysers (i.e energy managers) to be aware of all risks involved with different forms and sources of energy data. This is how appropriate precautions and suitable data analysis methods can be designed and applied.

The type of investigation determines the scope of energy data analysis. For example, it can be from simple, such as energy cost analysis, to a more complex problem such as understanding end-use energy variability. For complex probes, this can be further divided into multiple analyses such as summary, energy breakdown, multiple site comparison, normalisation, load duration, and XY scatter plots (Motegui et al., 2004). A general schematic of forms of different data analyses, enquiries, and investigative approaches that may be used is shown in Figure 19. However, each approach may have several forms of methods and techniques that may be uniquely tailored depending on the data and site-specificity. Due to the limited scope, the analytical queries chosen for the thesis can be identified as some individual tasks within Figure 19. The key queries are energy use and cost breakdown, performance indicators, and understanding energy use variability at both the whole site and end-use level in some cases. As there is a variety of specific methods available to understand energy use variability, discrete analysis tools are chosen at various levels. These consist of regression and visualisation techniques, wherein energy line plots/graphs (against time and activity) have been plotted using high-resolution energy data. Some literature background about the key techniques used in this thesis is discussed below in the next section.

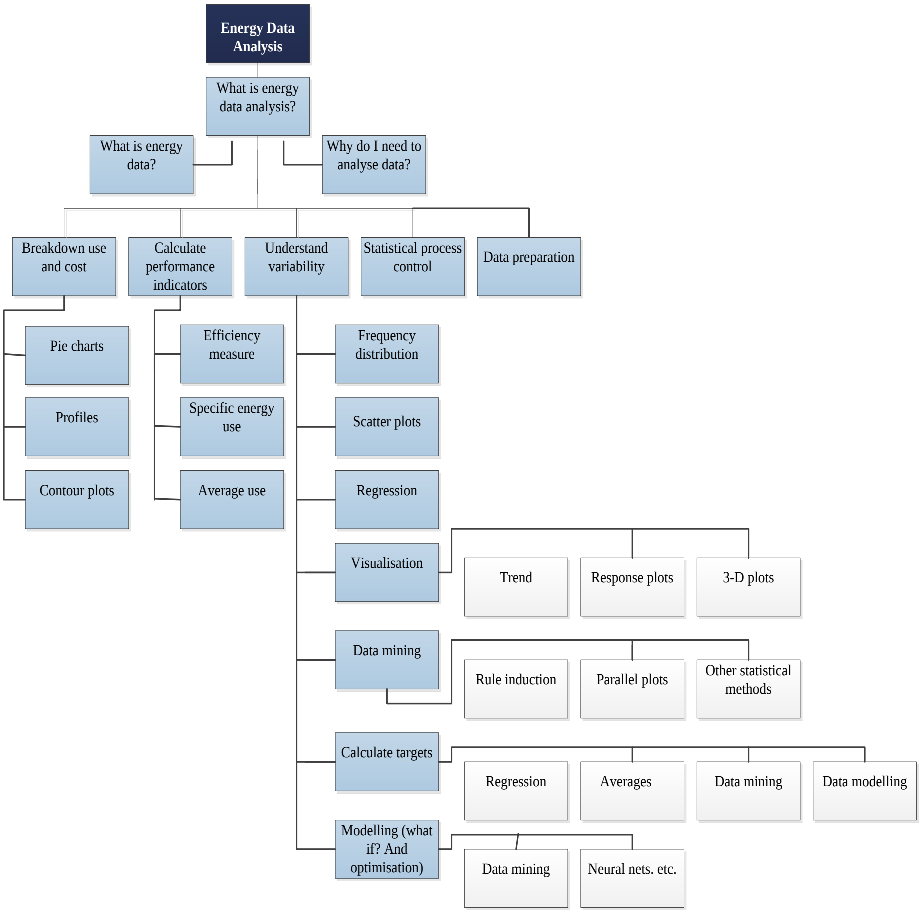


Figure 19 - Key steps and forms of energy data analysis, (Hooke, Landry and Hart, 2004)

2.2.4.1 Establishing energy trends and patterns using high-resolution data

Time-series data, "which consists of a multiplicity of data taken at a single point or locations over fixed intervals of time" (Reddy, 2011b) is in common use for energy investigation related visualisations. These, based on this data, can be of many forms such as daily profile, highs-and-lows, average, and day overlay (Motegi et al, 2003). In many cases, the scheme of high-resolution energy data can be based on time-series, for example, energy data at the case study site. High-resolution data (i.e. H-H) is historically used to design energy demand management strategies (Stephenson and Paun, 2000). Measurement and profiling of this data (for buildings, sites, zones, individual circuit, and plant or machine levels) can generate enough information to realise the demand of individual contributors. The analysis of such profiles along with other available information about the site/technologies helps to understand energy trends and patterns and identify energy efficiency opportunities at a corresponding unit (Stephenson and Paun, 2000). However, a reasonable amount of technical expertise and time is required to decipher the information available within the analysis exercises (even when visualisation tools are used) (Motegui et al., 2004).

Visualising of such detailed data in the form of graphs and charts is a quick and simple way that operators and analysts use to summarise data and assess performance. A number of graphing techniques can be used for building energy data. Christensen examines the history of energy data visualisation techniques and finds out that “Olygye (1963) uses monthly contour plots to understand climatic needs, Milne (1979) designs three dimensional surfaces for monthly building heating and cooling load plotting, and graphics for seasonal design-days is used by Hart, Kurtz, and Whiddon (1980)” (Christensen, 1984). In his study, (Christensen, 1984), utilises hourly climatic data (outdoor temperature) and draws a contour plot to visualise it at a 10 times more compacted form than digital energy maps (as discussed by (Hooke, Landry and Hart, 2004) as shown in Figure 20.

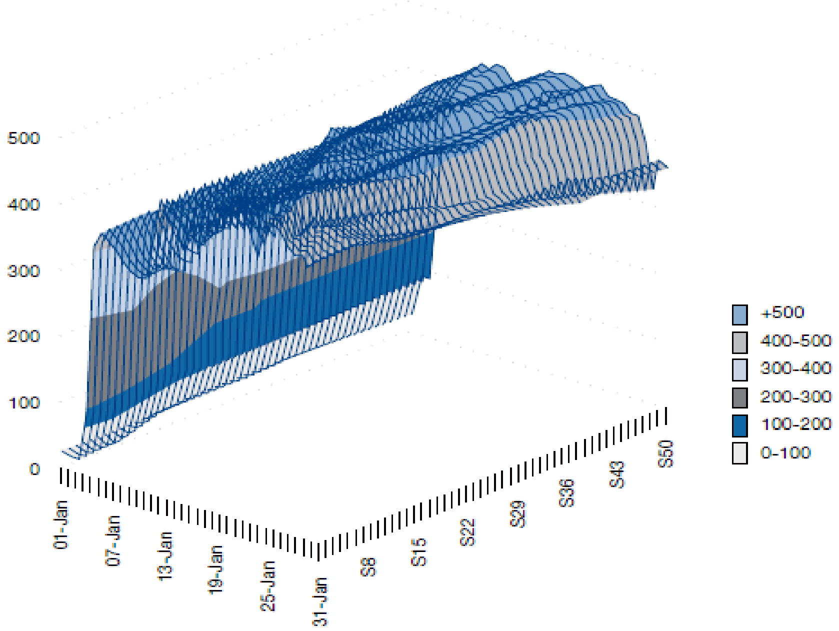
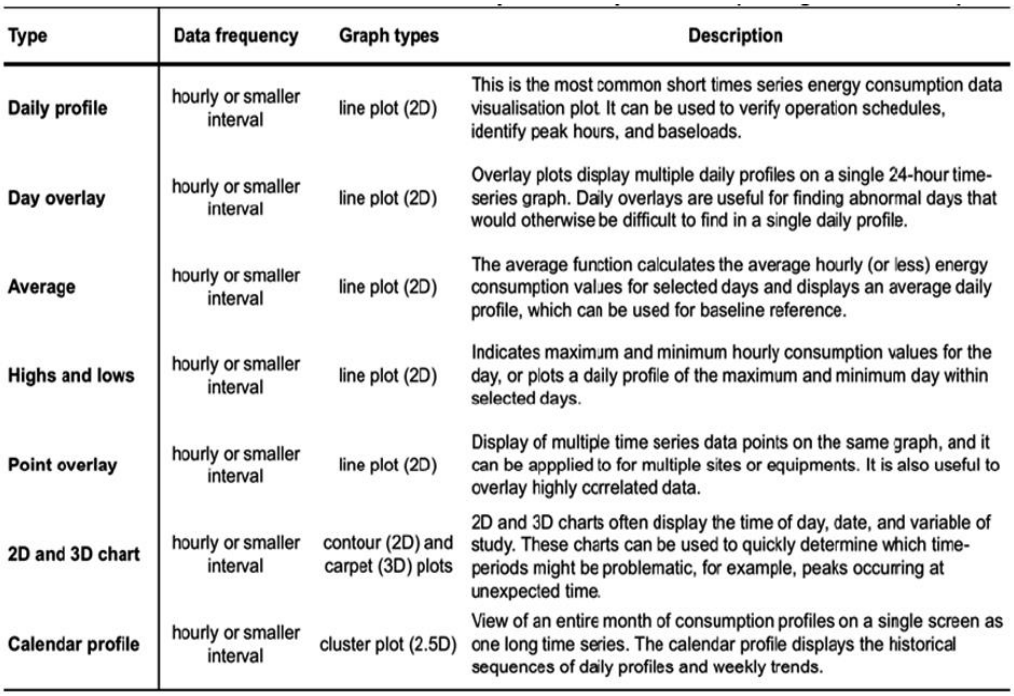


Figure 20 - A typical H-H demand profile as a contour plot (Hooke, Landry and Hart, 2004)

He further describes it to be 100─1,000 times more compact than the then “typical numerical printouts” (Hooke, Landry and Hart, 2004). These energy maps are referred to as colour maps as variation in temperature during the day is represented in variable colours (Christensen, 1984). With the advancing availability of Energy Information System (EIS) improvements and innovations in visualisation techniques have been introduced. Researchers (Motegui et al., 2004; Reddy, 2011a) take an account of prevailing visualisation techniques in the EIS. In his thesis (Ferreira, 2010) suggests a number of time series data visualisation techniques, as shown below in Figure 21, for manual energy diagnostics.



Type	Data frequency	Graph types	Description
Daily profile	hourly or smaller interval	line plot (2D)	This is the most common short times series energy consumption data visualisation plot It can be used to verify operation schedules, identify peak hours, and baseloads.
Day overlay	hourly or smaller interval	line plot (2D)	Overlay plots display multiple daily profiles on a single 24-hour time-series graph. Daily overlays are useful for finding abnormal days that would otherwise be difficult to find in a single daily profile.
Average	hourly or smaller interval	line plot (2D)	The average function calculates the average hourly (or less) energy consumption values for selected days and displays an average daily profile, which can be used for baseline reference.
Highs and lows	hourly or smaller interval	line plot (2D)	Indicates maximum and minimum hourly consumption values for the day, or plots a daily profile of the maximum and minimum day within selected days.
Point overlay	hourly or smaller interval	line plot (2D)	Display of multiple time series data points on the same graph, and it can be appplied to for multiple sites or equipments. It is also useful to overlay highly correlated data.
2D and 3D chart	hourly or smaller interval	contour (2D) and carpet (3D) plots	2D and 3D charts often display the time of day, date, and variable of study. These charts can be used to quickly determine which time-periods might be problematic, for example, peaks occurring at unexpected time.
Calendar profile	hourly or smaller interval	cluster plot (2.5D)	View of an entire month of consumption profiles on a single screen as one long time series. The calendar profile displays the historical sequences of daily profiles and weekly trends.

Figure 21 - Time-series energy data visualisation techniques (Ferreira, 2010)

Each of these has various applications and limitations. For example, (Van Wijk and Van Selow, 1999) use calendar profiles (cluster and contour plots) for consumption trends and patterns on multiple time scales (days, weeks, and seasons) in academic buildings. Raftery and Kean design an innovative technique “carpet-contour plots” using H-H energy data to visualise and understand consumption in buildings (Raftery and Keane, 2011). Researchers (Abbas and Haberl, 1994; Saelens, Parys and Baetens, 2011), elsewhere, connect means of data consumption through box and whiskers (box-mean-whisker (BMW)). The method reveals several hidden energy consumption behaviours of the buildings. Daily profiles (line plots) are commonly used to verify operation schedules, identify peak hours, and base load, seasonal demand variation in school and office buildings (Kilptrick, 2012), and in local government buildings (Ferreira, 2010) as shown in Figure 22.

Using high-resolution data (5-minute) (Firth et al., 2008) attempts to identify energy use characteristics in domestic buildings. The technique can lead to better consumption trends and patterns understanding if the periods to compare are correctly chosen (Farinaccio and Zmeureanu, 1999). The analysis based on these plots helped to identify building system failures and opportunities for energy saving (Piette, Kinney and Haves, 2001). As communication to the end-user is of paramount importance, reflecting the findings of such studies should increase the chances of theoretical savings becoming reality. This study draws energy profiles (including line graphs) to characterise energy demand, trends, and patterns in manufacturing building. The study also pinpoints the energy saving opportunities through the analysis. In-depth energy analyses have been facilitated through regression analyses and other statistical techniques as discussed in the next Section 2.2.4.2.

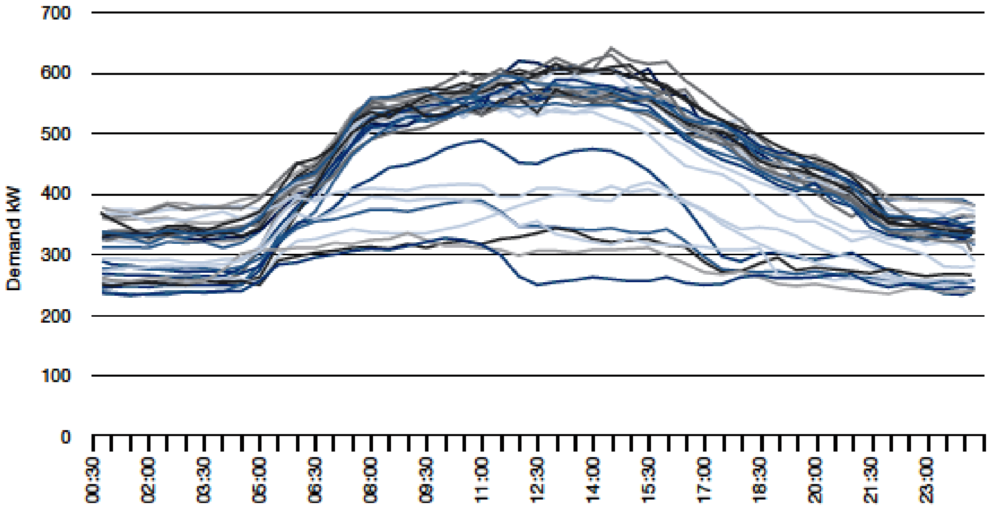


Figure 22 - Typical building energy consumption line graph (Hooke, Landry and Hart, 2004)

Kilpatrick (2012) uses multiple school building and offices half-hourly energy data to identify energy trends and patterns. Based on this analysis he suggests benchmarking for such buildings. In his analyses, he also identifies energy-saving opportunities in these buildings. In addition to generic H-H data he also uses energy monitoring equipment for end-use demand estimation and saving analyses. The main contribution of his research is H-H hourly energy trends and patterns based benchmarking technique in school buildings. Whereas focusing on H-H data analyses-based energy trends and patterns this thesis investigates energy-saving opportunities.

Ferreira (2010) suggests an energy benchmarking method based on primary meter half-hourly energy data analysis of UK municipal buildings together with the outside temperature. This performance assessment method offers novel energy monitoring and analysis techniques based on energy signature and grid electricity demand forecasting. The research focuses more on quantitative parameters than on the visualisation techniques. The method is useful for energy benchmarking and is proposed to be adaptable to various non-domestic buildings. However, how good it can be for a case-study manufacturing building like this will remain a question due to various limitations as his method is based on multiple buildings and the method investigates benchmarking of these buildings. The performance assessment in this thesis however mainly focuses on the identification of energy-saving opportunities.

In their study, (A, Singh,. V. Bansal, 2014) monitored various sites including IT offices, university campus, and manufacturing facilities for energy efficiency and optimisation. They collected varied high-resolution (sub-minute level) data by using extensive sensors and metering. With the help of a proprietary software, they used demand against 24-hours activity through scatter and line plots. This was to identify shift patterns, energy waste, and optimisation opportunities. The saving suggestions for the IT companies consisted of shifting air handling unit (AHU) starting time from 08:00 am to 09:00 am. For university and manufacturing buildings they suggested optimising the scheduling of the chillers and breaks’ starting and finishing times respectively. This data collection and analysis approach is sophisticated and useful for certain savings. However the associated expenses, depending upon the scope, can be costlier for consultancy services and software use and monitoring equipment.

Stuart (2011) used half-hourly energy data of over 300 council buildings from swimming pools, libraries, to museums and designed an energy monitoring and saving method. In his proprietary software-based analyses, he also used the degree-days method and detected abnormal energy loads and identified them as opportunities for energy saving. However, covering a large number of buildings and data sets the method has software-related costs and is demonstrated on a large set of buildings (assuming that is only applicable).

It can be seen that H-H energy data analysis in non-domestic buildings is generally carried out by using costly proprietary analytical software. This is discouraging for most of the SMEs that do not afford to spend on energy consultancy or such services. No-cost and easy to carry out energy data analysis solutions are required if energy efficiency is to be promoted in the sector.

Even if a manufacturing company affords to hire such services and software subscription such analyses are hardly seen in available research. This may be due to data sharing or copy right limitations. Hence, data analysis methods and the findings for manufacturing industry is hardly seen. Therefore, to promote energy and energy efficiency studies the need for free to use and easily comprehendible H-H data analyses tool is inevitable.

Currently available H-H data-based energy analyses for non-domestic buildings mainly discuss schools, universities, public, and office with exceptions of manufacturing buildings. Moreover these analyses are general, as discuss a large set of data from multiple buildings and are not tailored for or focusing on a specific site. Furthermore, the analyses as discussed above mainly revolve around energy benchmarking, trends and patterns, and efficiency opportunities. Using H-H data of individual buildings to tailor-make top-down and bottom-up energy efficiency opportunities will be an interesting avenue to explore and present.

Inspired by and based on the existing H-H data analysis methods, this research designs an analysis method for the case-study manufacturing industry. The suggested method, going beyond the demand calculations against 24-hours, utilises shift patterns for both visual and numeric estimations as discussed in Chapter 5. Giving the liberty from using a subscription-based software, the method in addition to electricity also proposes H-H data analysis for gas on the same MS excel platform. In addition to understanding energy trends and patterns, estimation and disaggregation of total and departmental energy demands, it helps to identify low-hanging fruits. The proposed method working along with individual technology assessment, as discussed in Chapter 3 suggests an improved way of energy auditing covering both top-down and bottom-up energy efficiency opportunities.

2.2.4.2 Techniques to understand performance variability

Regression improves to predict/understand ‘real world’ occurrences. This statistical tool is used to investigate and ascertain the causal effect of one variable upon the other (Sykes, 2007). The equation used is an impression predicting one variable on the basis of the knowledge of the other variable (Hui, 1998). The tool analyses data in ordered pairs or groups. Linear regression, the most commonly used method for energy, is expressed as a mathematical model relating a dependent variable to the independent variable(s). The model in a two-dimensional case is a best-fit curve and the modeling assumption (best-fit line) is computed by the least squares method (Hui, 1998). The least square, as the name implies, is used to minimise the deviations of the points from the prospective regression line (best fit), as indicated in Equation 1. The most commonly used of these methods is the ordinary least square (OLS) method (Reddy, 2011).

Equation 1

$$D1^2 + D2^2 + D3^2 + \cdots Dn^2$$

Where D1−Dn are the observation points

A simple or single variant regression graph is shown in Figure 23 with the calculation script given in Equation 2. When more than one independent variables are involved the model is known as multiple regression, as shown in Figure 24 (Natural Resources Canada, 2010). The simple regression equation can be extended for multiple regression analysis as shown in Equation 3. Multiple regression models have been used to characterise different design parameters affecting building energy performance and simplified equations for building energy standards (Hui, 1998).

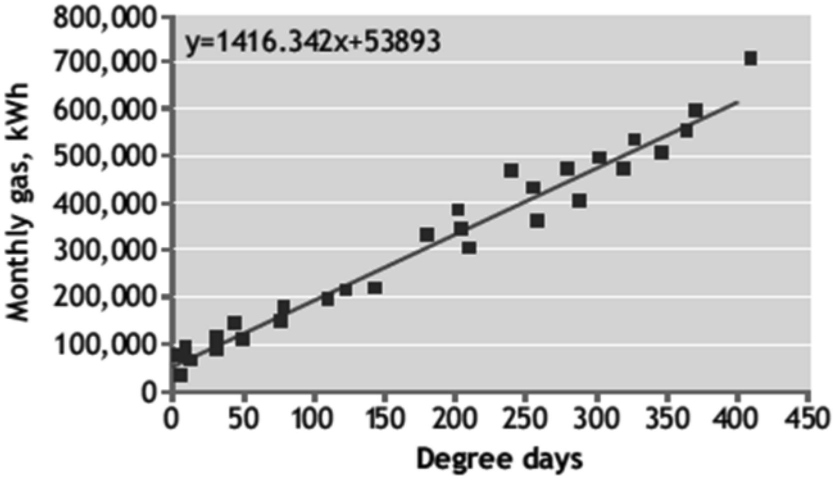


Figure 23 - Simple energy versus degree-day linear regression, (CarbonTrust, 2007)

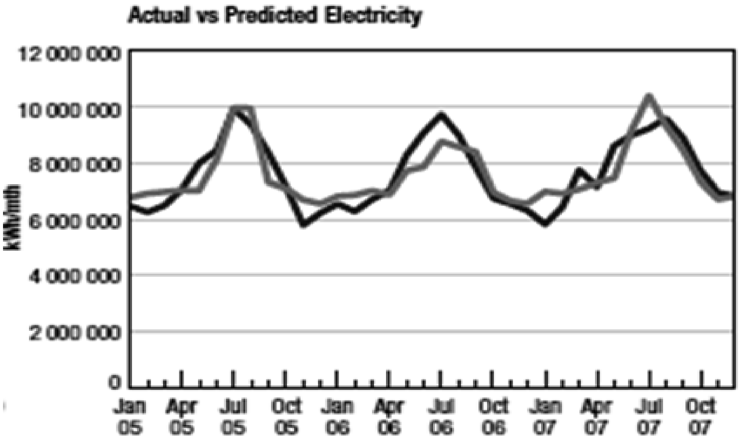


Figure 24 - Actual and predicted based multiple regressions, (Natural Resources Canada, 2010)

Equation 2

$$\boldsymbol{y = mx + c}$$

For energy, y is the energy use, m is the slope (line gradient) and c is the intercept (empirical coefficients), and x represents the dependent variable (production/ weather).

Equation 3

$$y = m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots + c$$

(Hooke, Landry and Hart, 2004)

Regression analyses are usually used in equipment published data to define energy demand characteristics (ASHRAE, 2005). Degree-day method, in which outdoor temperature is regressed against the energy used, is one such technique. For example, the degree-day method, in which outdoor temperature is regressed against the energy used, is one such technique. Based on basic principles, the method is a powerful tool to relating energy such as heating (The Carbon Trust, 2010a) and cooling (Krese, Prek and Butala, 2012) use to weather conditions through degree-days. CIBSE's guide TM41 provides a detailed background and use of degree day for building energy management and designing (CIBSE, 2006a). The method is generally based on 24-hours weather data, determined against a base temperature of 15.5°C (CIBSE, 2006a) for heating in the UK, but can also be calculated for hourly/monthly basis. The simple assumptions used to carry out the calculations make it simpler however based on approximations. The usability and effectiveness to deal with quick results is the key benefit of the technique. The data obtained through the method can be further translated in to Cumulative Sum (CUSum) and control charts, as suggested in (The Carbon Trust, 2010a) and has been utilised by Stuart (2011) as discussed above. However, this is out of the scope of the thesis. The briefly discussed method provides the importance and utility of such quick outside temperature-based methods and energy analyses for building heating load. However, these methods are mainly effective for non-manufacturing buildings where thermal energy is mainly used for building heating. The method may also be effectively used for manufacturing buildings with linear production patterns. The method is considered less useful for the case study site with variable production activity and patterns and is also out of the scope of the study. However, to understand the impact of weather on energy consumption, a simple building heating demand estimation method is proposed.

According to Ashrae (2005) the form of regression models used in energy modeling, for example in empirical/black-box approach, can be purely statistical or loosely based on some basic engineering formulation of energy use in the building. However, no or very little physical meanings can be assigned to the identified coefficients. Regression analyses are extensively used in energy simulation studies for both data generation and calibration purposes.

These have been strongly recommended for the whole building and individual equipment energy estimation for retrofitting projects (Reddy, Kissock and Claridge, 1992). Multivariate regression models have been applied in different energy studies, such as for building energy simulation (Hui, 1998), investigation of air-conditioned office-buildings from different climates, (Lam et al., 2010), as an energy assessment tool in early stage of building designing (Hygh et al., 2012), and energy performance evaluation for buildings (Olofsson, Sjögren and Andersson, 2005). Braun, Altan and Beck use a regression (multiple linear) model to estimate changes in future energy demand of a UK supermarket (Braun, Altan and Beck, 2014). In addition to using general engineering methods, this thesis also uses simple regression analysis. This is to realise the variables' (dependent/independent) sensitivity and identification of the optimum energy use relationship.

Availability of the highest, lowest, and mean values determines the boundaries of the analysis. Percentiles are statistical values that are used to group the set of data into ranks such as 10th, 25th, 50th, 75th, and 90th. Developed by John Tuckey (1970's) box-and-whisker plot (boxplots) is a form of graphical representation of such data. According to Wickham and Stryjewski (2011) these are a compact form of distributional summary, easy to draw (originally/manually). The original (manual) form of these presents less detail compared to histograms or kernel density. However, the use of computers has enabled the presentation of as much information as any other graphics such as histograms. The robust summary statistics they use is always located at actual data points. These graphics (range bar) are specifically useful for comparing distributions across groups. The range bar consists of five elements as shown on the left side of Figure 25. Due to their practicality and broad use, various forms have been designed but only one that is relevant in this thesis is discussed.

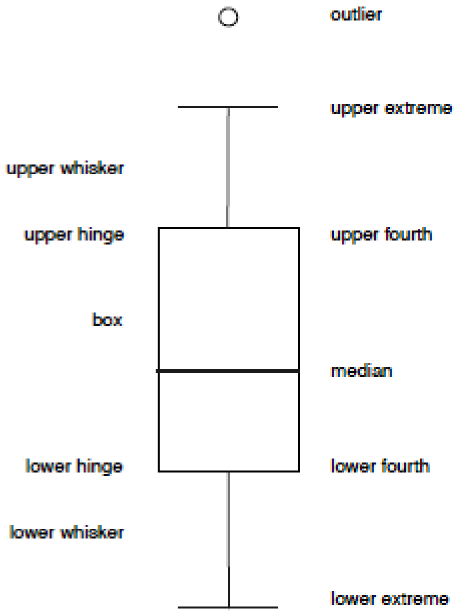


Figure 25 - Components of a box and whisker graph, (Wickham and Stryjewski, 2011)

(labels on the left give names for the graphic elements and labels on the right give corresponding summary statistics)

To calibrate simulation models for building energy use (Soebarto, 1997) uses box-and-whisker plots for 24-hour electricity profiling for total demand and individual building services such as lighting. Elsewhere, Saelen, Parys and Beatens (2011) utilise box-and-whisker plotting techniques to visualise and classify the energy use variation. The data obtained through these exercises helped to understand and contribute towards building energy modeling based on the occupant behaviour (Saelens, Parys and Baetens, 2011). Using five ranks Kilpatrick utilises the same approach for benchmarking in schools (Kilptrick, 2012). Hong (2015) utilises box-and-whiskers plot to assess the distribution of energy performance of UK non-domestic buildings (schools) in different benchmark categories.

2.2.5 Energy management

The term EM is used both for energy generation and consumer sides. Large organisations are devising EM programs to systematically control their energy use

(Krarti, 2012; Kannan and Boie, 2003). The wider implications of EM can be categorised into three main areas, as shown in Figure 26. EM is “the judicious and effective use of energy to maximise profits (minimise costs) and enhance competitive position” (Capehart, Turner and Kennedy, 2003). Although it also serves other objectives (i.e. GHG reduction, improved communication programme for monitoring and energy strategy, and staff training and involvement) but most organisations primarily, focus on cost savings. In industry, EM can cover a broad range of operations including waste minimisation and disposal, equipment design, and product shipment. Therefore, each operation area has specific assessment tools. A comprehensive EM programme can augment organisational sustainability credits.

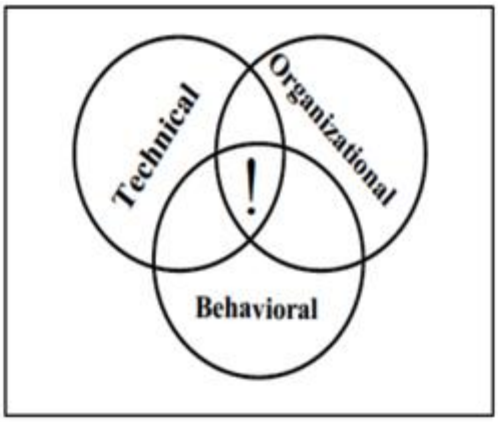


Figure 26 - EM dimensions , (http://www.energy.gov.za/, n.d.)

Organisational energy efficiency improvement can be achieved in several ways and through various investigatory and verification tools/programmes like EM standards/systems (ISO-50001), monitoring and targeting (M&T), and measurement and verification (M&V) (out of scope). Langley suggests four categories of energy efficiency measures: i) management measures, ii) additional equipment measures, iii) replacement measures, and iv) new process technologies (Langley, 1987). Where management measures refer to actions like good housekeeping and maintenance (for example improved heating/cooling), better process scheduling, and regular servicing. These no- to low-cost measures normally have a quick payback. Generally being no- to low-cost examples of additional equipment measures are occupancy and light sensors and economisers’ installation. Replacement measures refer to replacing old technology/components with new efficient ones; something which might be carried out as a matter of course if a technology has reached the end of life. These are medium- to high-cost measures. Being quite similar to replacement measures the fourth category differs when a radical change in process is seen because of technology replacement. For example, change from wet to dry process in cement manufacturing, or continuous casting in steel-making (Langley, 1987).

According to Stich, Brandenburg and Kropp (2012) EM is “the proactive coordination of procurement, transformation, distribution, and consumption of energy within a company”. Thus in an EM programme all the four areas should be thoroughly explored. Procurement, in this context refers to energy-efficient equipment purchasing, is quite similar to Langley’s (Langley, 1987) replacement/new process technologies. Distribution, the way energy is distributed within a system/organisation, can also offer energy efficiency opportunities, for example through voltage optimisation and steam distribution system insulation. A VPO PowerPerfector (Power Perfector Technologies, 2018) voltage optimser, manufactured by iESCo, reduced 10% energy use for Arun District Council, UK. This is comparable to (Langley, 1987) additional equipment and management measures. Transformation is, for example, how energy is transformed into different forms of energy carriers, such as with compressed air (CA) systems, and steam boilers. Efficient transforming equipment ensures energy conservation. This compares with (Langley, 1987) management, replacement, and new process technologies measures. “Consumption” is how energy is used at its source, for example through the use of energy efficient end-use technology as well as reducing waste. This can be compared with (Langley, 1987) management measures. It can be seen that categorising EM measures may have different titles when viewed by different researchers but the objectivity and contents of the measures remain the same. Suggesting the framework for energy efficiency, (Rossiter, 2015) categorises four major areas—operations, maintenance, engineering, and research and development (R&D). The approach effectively defines and categorises the interaction of different disciplines within complex building systems when dealing with energy assessments.

EM is a continuous or live process and requires on-going practical input. Energy investigations, commonly termed as energy audits, to pinpoint structure and provide support to a continuous EM programme. Motiva (Motiva Oy, n.d.) suggests that EM is part of an energy audit, whereas (Natural Resources Canada, 2009) suggests that an energy audit is the key to develop an EM programme. There are various routes to energy audits that are defined by different scopes (physical extent) and levels, as discussed in Section 2.2.5.1. Energy audits and surveys can be termed as the building blocks/tools of EM programmes of all levels. It is arguable, in case of little success, whether it is the practicality of the energy investigation method or the limitations associated with the site or the project that leads towards it.

The simple goal of EM can be achieved through different routes and therefore it is essential to define its scope in a system perspective too. Numerous guides and books have been published on energy efficiency, (http://www.energy.gov.za/, n.d.) as above. Most of these resources focus on technology and component aspects, e.g. replacement or alteration in technology or micro-audit as defined in Section 2.2.5.1. However, in industrial environments, changes in production lines/processes are likely to occur more frequently. Thus, the adapted energy efficiency measures may not remain suitable during this change. Therefore, to resist the fall in energy efficiency due to any such changes, it is better to look into the measures through a system approach as well. The system approach (energy-consuming system) creates a balance between both energy supply side, e.g. equipment and controls, and the demand side such as distribution network, and end uses of a system (Giacone, Mancò and Gabriele, 2008). This could be considered as macro-audit of the system (as defined in Section 2.2.5.1). However, the demand side approach can become the whole building investigation. This, in addition to building facilities and technology, includes building fabric, air infiltration, and other building structure related topics as well. This in this thesis is not entertained due to time and resource limitations. Only utility and technology energy efficiency including, in terms of system configuration, both evaluations—top-down and bottom-up approaches are being considered. The top-down approach for example, in this case, is energy efficiency of a boiler or air compressor which supports end-use energy efficiency too (for example reducing the generation steam/air pressure will reduce the rate of flow/leaks per unit time from distribution through to end-use). The end-use energy efficiency aspect, when resulting in a significant magnitude of energy-saving thus is an example of a bottom-up approach.

2.2.5.1 Energy audits and surveys

One of the highly desired perusals of EM is organisational energy efficiency improvement which can be achieved in several ways. Energy audits are the first step to EM (GPG 316, 2002; Capehart, Turner and Kennedy, 2003). These terms—audits and surveys are frequently used interchangeably referring to the identification of energy-saving opportunities of a building but have also been individually defined by some authors. UK’s Good Practice Guide 316 defines an energy audit as “a study to determine the quantity and cost of each form of energy of a premises, process, or system over a given period, usually a year" whereas an energy survey is "a technical investigation of the control and flow of energy in a premises, process, or system with the aim of identifying cost-effective energy-saving measures" (GPG 316, 2002).

Based on physical investigation, energy surveys rely on both qualitative and quantitative information. An example of the qualitative output is replacing single-glazed windows with double-glazed. However some numerical form, for example double-glazed windows will payback in "x" years, will save "x" CO_2 and cost is always preferred. Based on rules of thumb/engineering principles these estimations play a vital role in decision making at both the auditor and the organisation end. Generally assisted by the site engineer, familiarising with the technology, utility, and services is the very first step of the survey. Information about the technologies/equipment/systems, types and distribution of utility and energy system, type of building structure and fabric, operation, and energy culture of the site is collected. Depending upon the scope, the surveyor may decide to extend the detail of the information, a general condition survey checklist is shown below in Table 6. Normally a walkthrough survey, unless leading to a standard or detailed energy audit as discussed below, requires less detailed information. General energy walkthrough surveys have been offered free-of-cost by the UK's Carbon Trust.

Table 6 - General checklist for a walkthrough survey, (Natural Resources Canada, 2009)

Windows	Heat distribution
Exterior doors	Cooling plant
Ceilings	Cooling distribution
Exterior walls	Electrical power distribution
Roofs	Hot water service
Storage area	Water service
Shipping and receiving areas	Compressed air
Lighting	Process heating
Food areas	Heating and boiler plants

An energy audit is "a process to evaluate where a building or plant uses energy, and identify opportunities to reduce consumption" (Thumann and Younger, 2007). According to another suggestion both terms can be used interchangeably for the same objective of energy-saving and refer to other titles for the same process, such as energy evaluation and energy analysis (Capehart, Turner and Kennedy, 2003). It is clear from the definitions that both terms focus on identifying energy-saving opportunities through approaches including physical and technical investigations. Similarly, different approaches can be adopted to carry out an audit. To simplify the discussion the term energy audit in this thesis would also cover energy survey unless otherwise mentioned.

Energy audits can vary with calculation method, economic evaluation, and scope, all of which can mean different things to different auditors (Thumann and Younger, 2007; Capehart, Turner and Kennedy, 2003). A general illustration of the scope of the energy audit is shown in Figure 27. Comparing different types of audits for the same site can, therefore, produce different results (Helcke et al., 1990). Audits emanating from research projects may be more robust and can identify a greater number of savings options than commercial audits. This can be due to several reasons, including up-to-date field knowledge and there being little or no commercial interest in the projects, as identified in Section 5.2. The cost, quantity of data, and a number of saving opportunities can determine the type of audit (Thumann and Younger, 2007). The type of building facility also plays an important role in determining the audit activity. For example, lighting (with occupancy sensors) and HVAC (with time scheduling) will be the focal areas for an office building audit, as opposed to a manufacturing site where process energy can be of greater importance (Thumann and Younger, 2007). In practice, there can be several additional elements or interfaces around the core energy audit as shown in Figure 28. However, this thesis will mainly focus on EM, energy consumption monitoring, condition assessment, and suggesting implementation of saving measures where necessary.

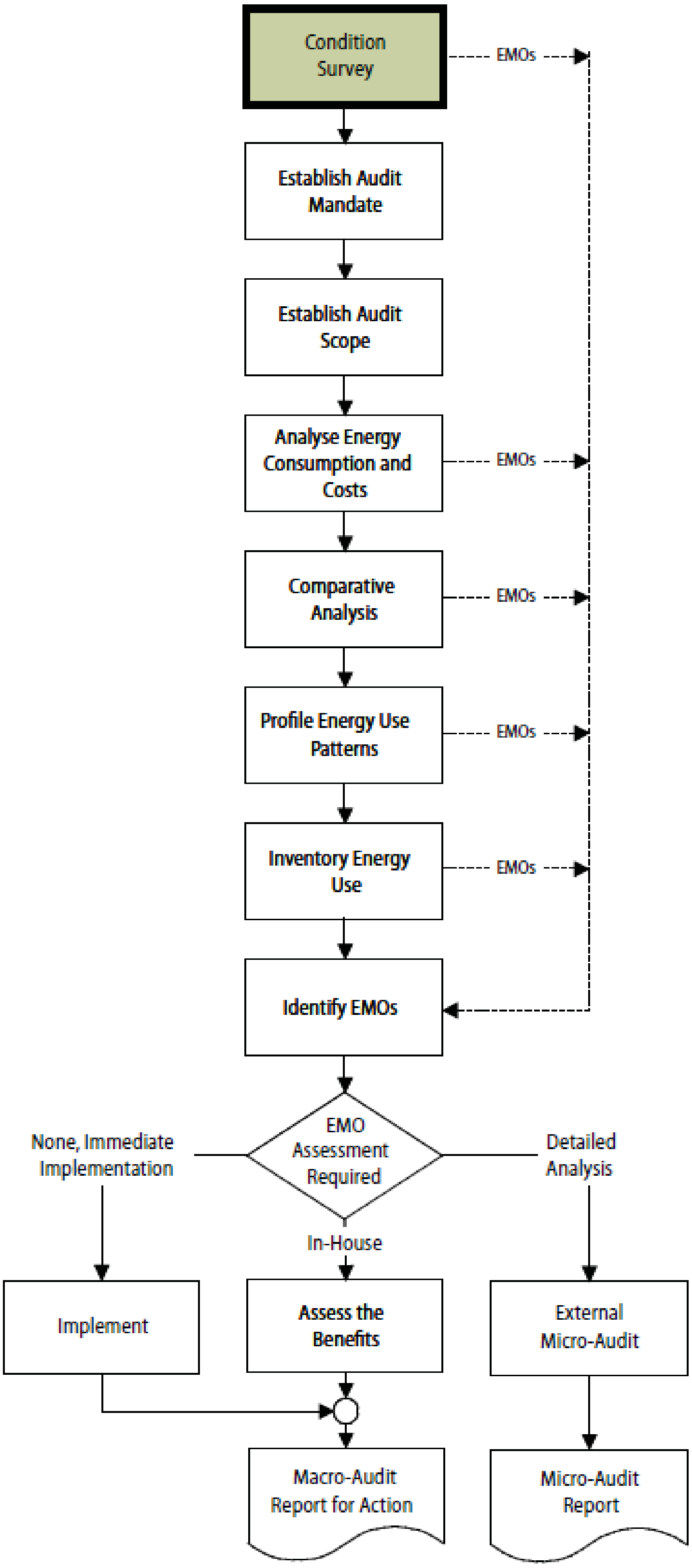


Figure 27 - Key elements of an energy audit, (Natural Resources Canada, 2009)

EMO=energy management opportunity/ies

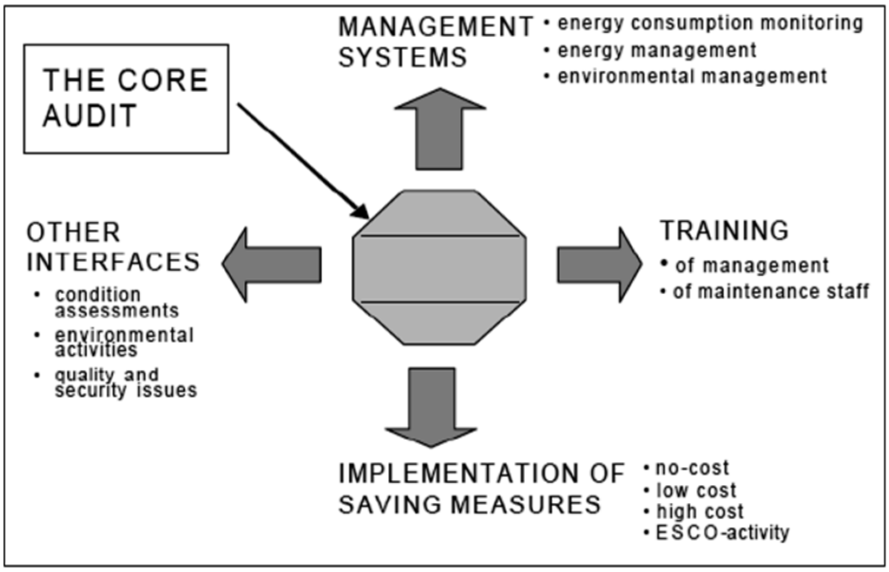


Figure 28 - Interfaces of an energy audit, (Motiva Oy, n.d.)

Krarti recognises four types of energy audits: i) walk-through, ii) utility cost analysis, iii) standard energy audit, and iv) detailed energy audit (Krarti, 2012). A walk-through (condition) survey, as the name implies, is more about physical looks. This is sometimes also referred to as O&M and can include issues such as a broken window, poor insulation of boilers/steam system, or low-levels of lubricating oils in a machine. The total energy usage is also benchmarked with the existing best practice figures (Thumann and Younger, 2007), as carried out elsewhere (Liu et al., 1994), and (Sullivan, Dean and Dixon, 2007). Utility cost analysis identifies saving opportunities in tariffs, based on the peak- and off-peak demand management. It also helps to match appropriate retrofitting measures in line with peak shaving. A standard energy audit, in addition to i) and ii), provides a more comprehensive energy analysis. Developing a baseline energy use, the audit identifies appropriate energy saving opportunities and indicates a likely payback period for given capital costs. These measures are identified through using standard energy engineering calculations (Thumann and Younger, 2007) and simplified tools, such as linear regression and degree-day analysis (Krarti, 2012). As suggested elsewhere (Hasanbeigi and Price, 2010), a detailed energy audit is a more comprehensive form of standard energy modeling, requiring more time and resources. In this approach, monitoring and measuring tools (e.g. handheld and clamp-on instruments) are used to measure certain parameters such as luminance levels and indoor temperatures. Simulation programmes such as bin methods, and DoE-2 (a commonly used dynamic simulation tool) are typically considered, as documented elsewhere (Wright, Oates and Greenough, 2013; Thamilseran and Haberl, 1994) and Simplified Building Energy Model (SBEM) as a typical steady-state simulation model

(Wang, Yan and Xiao, 2012). More detailed economic analysis tools like life-cycle costing (LCC) are also used instead of simple payback methods. Thumann and Younger suggest three types of energy audits i) walk-through, ii) standard energy audit, and iii) simulation (Thumann and Younger, 2007). Both studies (Krarti, 2012; Thumann and Younger, 2007) account for standard energy audit in a similar way, and simulation by Thumann and Younger is what referred to as detailed energy audit by Krarti.

According to another approach, energy audits based on the level of detail can be classed into two categories: “macro-audit” and “micro-audit” (Natural Resources Canada, 2009). The approach also considers the physical extent or scope of an audit (the size of the system) e.g. the number of sub-systems in a system and the components. The macro-type, as the name implies, considers relatively high-level structures of a site/facility and identifies energy efficiency opportunities based on a broad physical scope. This, for example, can consist of monthly utility usage and cost analysis and actions taken, e.g. switch off information technology (IT) equipment and lighting overnight. A macro-audit, according to some authors (Krarti, 2012; Thumann and Younger, 2007) is classed as a walkthrough and utility cost analysis. A micro-audit has a narrower physical scope and involves higher levels of detail and analysis, e.g. equipment-level energy audits. This can include equipment operation, component alteration, energy recovery, and process-level changes. It is convenient to say that micro-audits start from where a macro-audit ends, thus a macro-audit is a key information source to the micro-audit. The micro-audit, as defined by (Krarti, 2012; Thumann and Younger, 2007), may be compared with standard to detailed energy audits or simulation (Natural Resources Canada, 2009).

The classifications discussed above may be considered as indicators that, although somewhat vague, can be helpful in defining the scope of an audit process. Based on these classifications, this thesis can be classed as Krarti’s detailed energy audit as clamp-on and hand-held meters have been used where possible. However, in this research project simulation programmes and advanced cost-benefit analyses are not used.

2.3 Performance benchmarking for industrial buildings

Energy benchmarking simply is a method used to compare the energy use of buildings/processes with buildings/process that execute reasonable similarity. This is carried out under the predetermined characterisation flags such as “typical” and “best practice" or sometimes this may be against historical values for the same subject. This is a useful tool for energy investigations in several ways such as audits, energy efficiency targeting, and energy use comparisons (Motegui et al., 2004).

2.3.1 SEC

SEC is an extensively used industrial energy efficiency indicator worldwide (European Commission, 2009; Siitonen, 2010). For example, SEC for a residential or a commercial building will be in units of kWh/m^2. However these must be adjusted for weather, hot water demand and electrical services, IT, TV, etc. Due to process heterogeneity in manufacturing and agriculture industries, it is applied differently, and is normally measured in energy input/unit mass or volume of product. For industries involving different product lines, it is taken as average SEC$_{\text{Av.}}$ Hence, a reduction in SEC value of a monitored item will imply an improvement in energy efficiency over the period.

In practice, energy efficiency indicators mostly measure the inverse of energy efficiency (Phylipsen, Blok and Worrell, 1997). This, in terms of SEC, can be calculated as shown in Equation 4 (Siitonen, 2010). As different types of fuels may be used, the sum of consumptions of these fuels will be the total energy used as shown in Equation 5.

Equation 4

$$SEC = \frac{energy\ used}{products\ produced} = \frac{enegy\ imported - energy\ exported}{products\ produced}$$

Equation 5

$$SEC = \frac{E_{Fuels} + E_{Steam} + E_{Electricity}}{products\ produced}$$

Once calculated, these values can be compared with existing SEC reference values for the same activity/process (based on BAT, benchmark, or a specified reference period) to determine the energy efficiency index (EEI), as shown in Equation 6. The exercise, in addition to identifying energy trends and patterns, plays a key role to pinpoint energy waste or saving potential.

Equation 6

$$EEI = \frac{SEC_{ref}}{SEC}$$

2.3.2 Carbon management and accounting

2.3.2.1 Carbon footprint current scenario

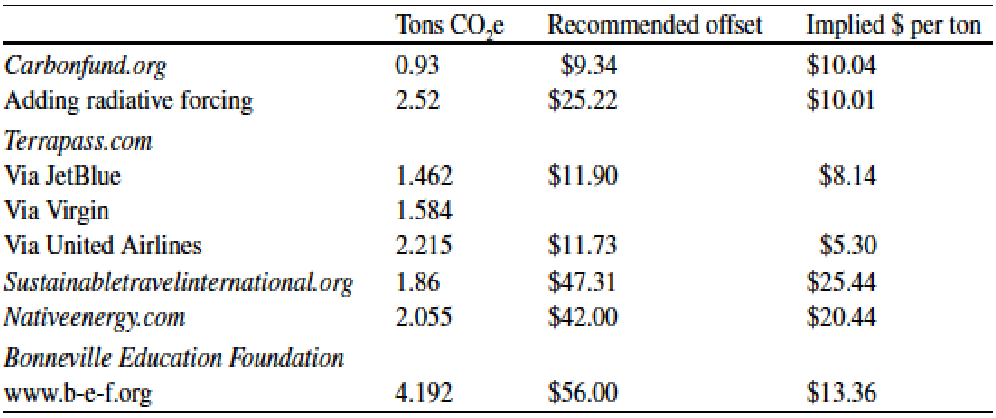
CO_2 emission accounting plays an important role in accounting, regulating, and reducing the human activity-related GHG. When referring to global warming potential (GWP) of some gas/es the term used as $CO_{2\text{-}e}$ equivalent. Carbon emission cognisance is extending to all types of businesses resulting in policies and regulations emergence (as discussed in Section 2.1.3). For clear communication between business-to-business (B2B), business-to-consumer (B2C), or stakeholders CO_2 accounting methods have been designed. A large number of simple and straightforward online carbon footprinting calculators such as (Carbonfund, n.d.; Cotap, n.d.; Myclimate, n.d.) have appeared. These easy-to-use calculators can be good for members of public but not for the organisations having clear CO_2 inventory objectives, as anomalies exist. For example, the results for CO_2-e accounting for the same distance/destinations have been observed and reported to vary widely elsewhere (Wakeland, Cholette and Venkat, 2012), as shown in Table 7. These tools also suffer from many disadvantages such as one-way communication, unknown methodology, and entertain limited data intake for many cases. Hence, for organisational CO_2 footprint evaluations a proper study backed with a decent amount and quality of data can result in improved outputs.

Since carbon footprinting involves money transactions (such as carbon taxes, or consumer choices) consistent calculation methods are necessary for comparability/standardisation (Pandey, Agrawal and Pandey, 2011). Hence, based on the purpose, availability of data, consumer types, and measurement boundaries, different types of evaluation methods can be seen (Weidema et al., 2008), such as based on product/supply chain (Chakraborty and Roy, 2013). Developed in 2008 (revised in 2011), PAS-2050 is such a Publically Available Specification (PAS) for CO_2 evaluations. Suggesting a calculation framework the method addresses and reduces many perceived (BSI, 2011c) problems such as boundary (Weidema et al., 2008), and hence is utilised as a key approach. The specification is branching out into specific investigations such as PAS-2395/2014 (BSI, 2014) for textile products. Product GHG protocol has been developed by the World Resource Institute (WRI) and World Business Council on Sustainable Development (WBCSD). ISO has also developed standards for product CO_2 footprint (ISO-14067/2013). The UK's Defra/DECC has developed a series of publications on systematic organisational GHG accounting for considerably large (Defra, 2009) and small businesses (Defra, 2012).

Defra/DECC has also published industry-specific guidance, such as freight transport, on GHG reporting and calculation methods (Leonardi, McKinnon and Palmer, 2010), backed by annual emission factors. Acting as frameworks these approaches have resulted in the formation of different GHG reporting methods such as the Economic Input-Output Analysis (IOA) model for monitoring all the transition through the supply (Chakraborty and Roy, 2013).

Generally collateral, energy and carbon estimation has profit logic for businesses (Zampou et al., 2014). For the full advantage of CO_2 savings, its monitoring needs as vigilant consistency as for the energy. This is to pinpoint/rectify any energy efficiency measure, at any production/supply chain level, having a negative impact on GHG emissions (Scipioni et al., 2012). However, for most of the traditional EM programmes (unlike ISO-50001) that focus on building energy efficiency (Zampou et al., 2014) extra effort may be required for CO_2 responsiveness. Being less complicated, EM tools/programmes such as audits and surveys may allow CO_2 accounting alongside.

Table 7 - Air-travel CO_2 emissions by various calculators , (Wakeland, Cholette and Venkat, 2012)



	Tons CO_2e	Recommended offset	Implied $ per ton
Carbonfund.org	0.93	$9.34	$10.04
Adding radiative forcing	2.52	$25.22	$10.01
Terrapass.com			
Via JetBlue	1.462	$11.90	$8.14
Via Virgin	1.584		
Via United Airlines	2.215	$11.73	$5.30
Sustainabletravelinternational.org	1.86	$47.31	$25.44
Nativeenergy.com	2.055	$42.00	$20.44
Bonneville Education Foundation			
www.b-e-f.org	4.192	$56.00	$13.36

Where $1=£0.75

This was for a round trip from San Francisco to New York

2.3.2.2 Lifecycle assessment for carbon management

Lifecycle assessment (LCA) is normally used as a GHG accounting approach, as indicated in Figure 29. Individual evaluation methods for complete or part inventory, as suggested in Figure 30, are used. Ecological footprint, which is a frequently used part in the LCA, usually refers to energy footprint (E_nF). Being in use for over two decades, key evaluation steps are given below, E_nF still lacks one single standard approach, (Chakraborty and Roy, 2013);

- Energy consumption is measured in (i.e. gigajoules)
- Energy is converted into CO_2-e emissions (using emission factors)
- Emissions are then converted into hectares based on the forest absorption rate

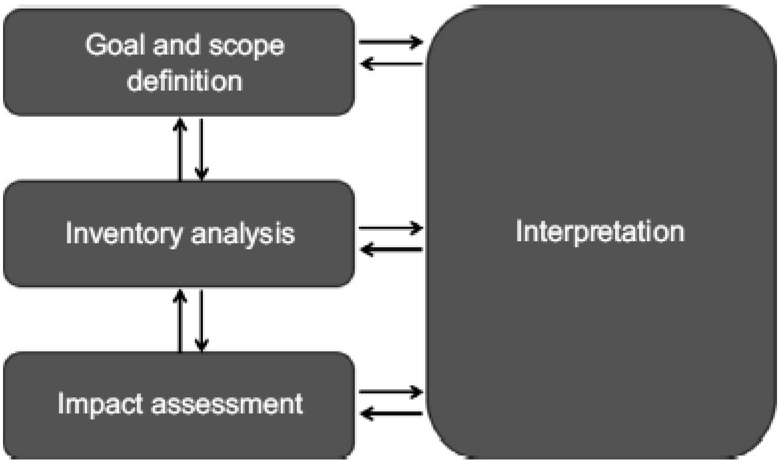


Figure 29 - Steps in carbon footprint process, (Peters et al., 2015)

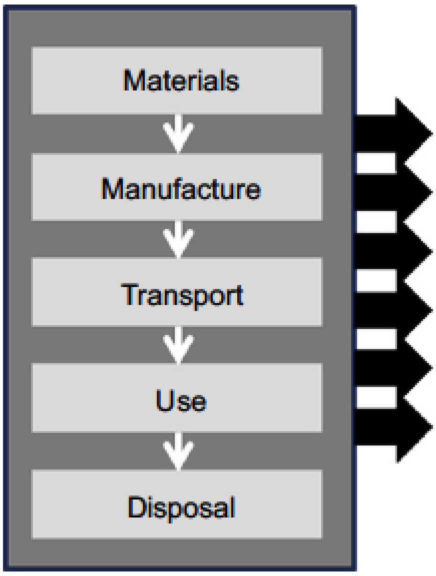


Figure 30 - Inventory analysis steps for CO_2 footprinting, (Peters et al., 2015)

Evolving from the E_nF, the CO_2 footprint concept is gaining popularity since 2005. The tool, however, suffers from methodological inconsistencies i.e. definition and boundaries probably inherited from its parent methods (Chakraborty and Roy, 2013). As this individually and solely aims at CO_2 emissions hence is more focused and robust in terms of GWP studies.

Based on the LCA approach three main emission scopes have been identified (as shown in Figure 31). These are indicated in major GHG calculating methodologies and frameworks. The GHG protocol standard defines these scopes as: Scope 1 is direct emissions that result from activities within the organisation's control such as on-site fuel combustion and other fugitive emissions. Scope 2 is indirect off-site emissions such as electricity, heat or steam purchased and used. Scope 3 is any other indirect emission from other sources outside of direct control such as employee commuting, business travel, outsourced transportation (The Carbon Trust, 2012a). The scopes 1 and 2 are straightforward and generally can directly be associated with the organisation. Whereas generally, complications emerge when dealing with scope 3, for example, freight transportation (whether the related CO_2 emissions be accounted for the organisation itself as scope 3, or for the involved freight service company as scope 1 and 2). This is something that is determined through the scope, purpose, and type of assessment. Defra's guidance on measuring and reporting GHGs from Freight Transport Operations (Leonardi, McKinnon and Palmer, 2010) recommends to include scope 3 emissions when addressing organisations or products (discussed in Section 2.3.2.3). Whereas, PAS-2050 (BSI, 2011c) suggests a $CO_{2\text{-}e}$ intensity-based approach, as indicated in Table 8. According to this approach, identifying the high and low emissions processes and activities is helpful to prioritise key areas within the scopes. The general rule is about 1% equivalent to product dry mass could be omitted or 95% of the emissions should be covered. The low-emission categories, as indicated in Table 8, can be ignored. The textile specific scope 3 emissions are discussed below in Section 3.3.2.4.

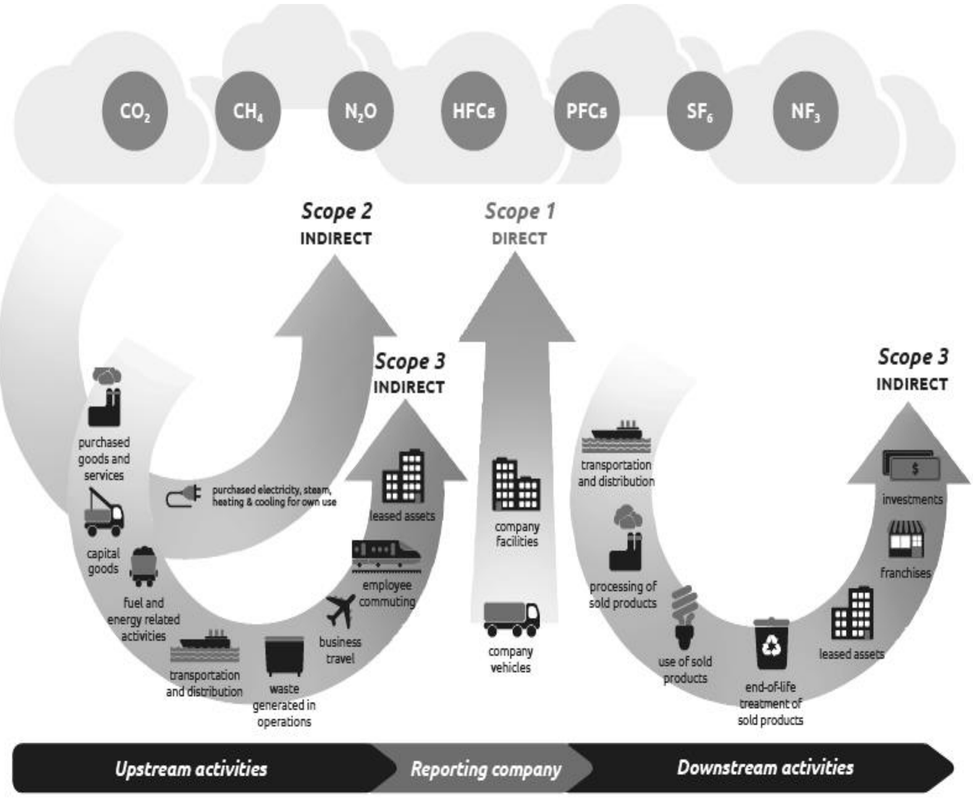
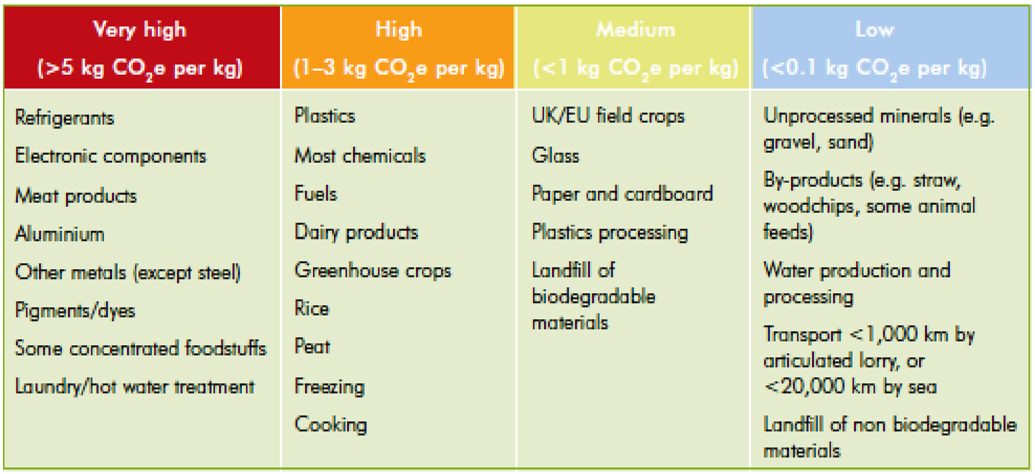


Figure 31 - GHG emissions and scopes across the value chain, (The Carbon Trust and WRI, 2013)

Table 8 - High- and low-intensity CO_2-e based activities and processes, (BSI, 2011c)



Very high (>5 kg CO_2e per kg)	High (1–3 kg CO_2e per kg)	Medium (<1 kg CO_2e per kg)	Low (<0.1 kg CO_2e per kg)
Refrigerants Electronic components Meat products Aluminium Other metals (except steel) Pigments/dyes Some concentrated foodstuffs Laundry/hot water treatment	Plastics Most chemicals Fuels Dairy products Greenhouse crops Rice Peat Freezing Cooking	UK/EU field crops Glass Paper and cardboard Plastics processing Landfill of biodegradable materials	Unprocessed minerals (e.g. gravel, sand) By-products (e.g. straw, woodchips, some animal feeds) Water production and processing Transport <1,000 km by articulated lorry, or <20,000 km by sea Landfill of non biodegradable materials

Though complicated but depending on the nature of investigation/s the scope of LCA modeling can be varied and the adjustments of the calculation method are made accordingly (Bevilacqua et al., 2011). For example (Muthu, 2014a) suggests cradle-to-cradle (or gate-to-gate) inventory as to reduce data-related hurdles and to carry out a well-defined footprinting exercise with a clear assessment boundary, as shown in Figure 32. For company 2 in the Figure, this type of assessment can be termed as (cradle-to-cradle) organisational footprint (within company 2 boundaries though) and if only one product is being produced the assessment will represent product footprint, however, some modifications may be required. This type of assessment will mainly deal with scopes 1 and 2 emissions. In another example (Bevilacqua et al., 2011) carrying out an LCA for a wool sweater exclude buttons and other accessories in the study. To avoid details related complications, they choose standard processes for different manufacturing phases such as yarn, weaving, and finishing treatments. This is an example of product-related CO_2 footprint accounting with a clearly defined boundaries and inclusions/exclusions. However, in addition to that there may be many different types of articles, patterns, and designs of general-wears produced. The examples above indicate that the LCA approach in GHG/CO_2 studies help to simplify the whole accounting process. It also enhances the flexibility in determining the scope of the investigation. This makes the undertaking of projects easier and helps to avoid different data availability, determining the boundaries between organisations, and emission overlapping related constraints.

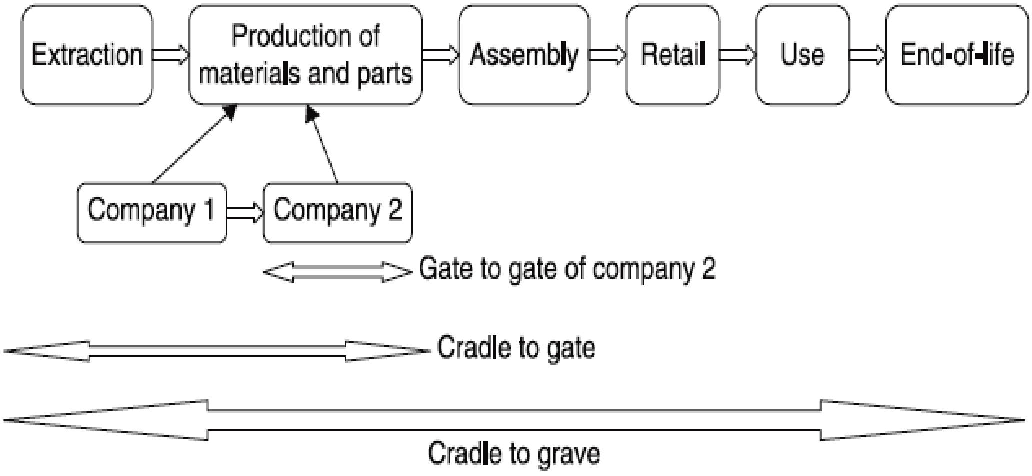


Figure 32 - Different boundaries for lifecycle assessments, (Muthu, 2014a)

2.3.2.3 Organisational and product carbon accounting

In terms of GHG or CO_2 footprint evaluations two types: organisational, and product have been suggested (BSI, 2011c; a), as shown in Figure 33. Both investigations, depending on the scope, target, and objective, have specific data and methodology requirements. The boundaries before and after the organisational footprint are generally termed as upstream and downstream sources respectively. The organisational footprint looks at an organisation’s overall activities and the product footprint calculates the lifecycle emissions of a particular product or service. The former is quite close to simple energy footprint as in point 1 of energy footprint above, and the latter is rooted out of LCA (The Carbon Trust, 2012a). Energy requirements for a good or service are generally estimated through "cradle-to-factory gate" also known as embodied energy, as for in this thesis. In contrast to that the lifecycle approach considers other areas such as use, recycling, and disposal delineating a "cradle-to-grave" timeframe (Lenzen and Dey, 2000), this is quite similar to what is shown in Figure 33 as product footprint (out of scope).

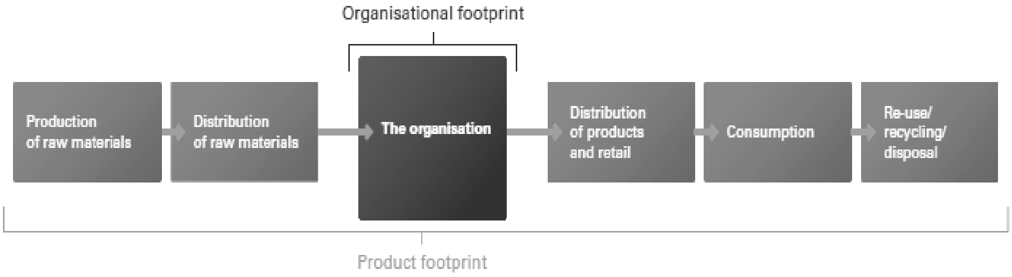


Figure 33 - Levels of boundaries for organisational CO_2 estimation, (The Carbon Trust, 2012a)

Suggesting system boundaries for GHG evaluation for goods and services PAS-2050 identifies establishing an understanding about the key points. These include defining the system boundary, cradle-to-gate GHG emission and removals assessment, material contribution and threshold, elements of the product system, and system boundary exclusions. In the PAS-2050 guide for GHG footprinting for products similar suggestions with slight modifications has been made. The main steps involved in product carbon footprint are shown in Figure 34 (Muthu, 2014b).

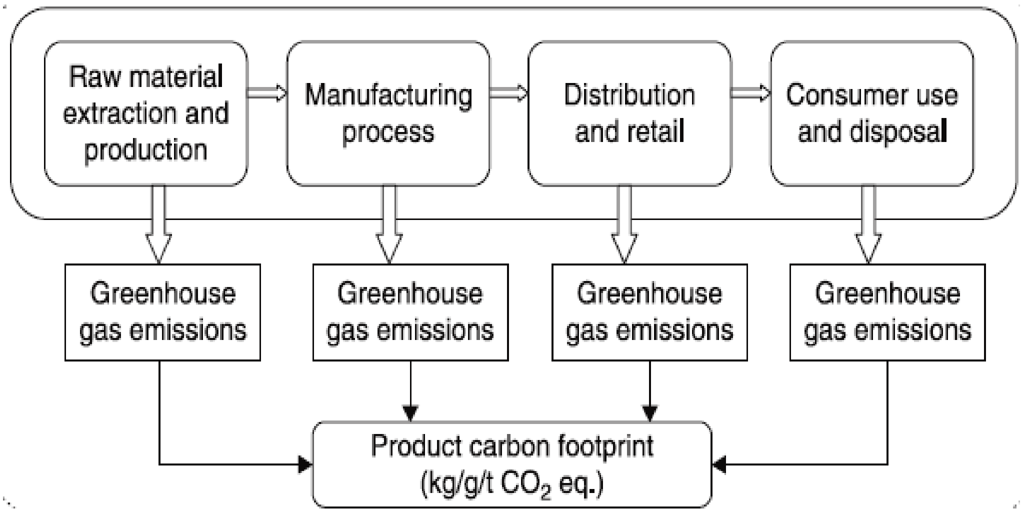


Figure 34 - Key steps for product CO_2 estimation, (Muthu, 2014b)

2.3.2.4 Textile supply chain and upstream scope 3 emissions

Scope 3 emissions categories are complicated hence multiple calculation methods have been suggested. Mainly based on indirect emissions, these categories require extra care to avoid double counting, i.e. transportation of goods' emissions accounted for both supplier and receiver organisations. To cover both up- and down-stream scope 3 emissions, 15 key categories forming a calculation framework have been defined elsewhere (The Carbon Trust and WRI, 2013). Out of these, purchased goods (major raw material) and transportation are the key categories for the scope of this thesis. PAS-2395 identifies key textile lifecycle phases and classifies them in-to three GHG impact levels: low, medium, and high. Table 9 summarises only from material extraction to fabric manufacturing (cradle-to-gate) phases indicating medium- and high-level impacts. This study mainly covers high impact categories.

LCA for materials such as wool production has been evaluated for both CO_2-e and energy use. Animal rearing related LCA inventory (involving a string of individual processes (inputs/outputs)) involving handling, multifunctional processes, and co-products makes the evaluation complicated to handle (Tobler-Rohr, 2011b). According to Henry et al., (2015) data guidelines and requirements for these, though in general, can be found in documents such as ISO-14040, PAS-2395, and (FAO, 2015). These are reasonably helpful to meet standard CO_2 calculation requirements.

Table 9 - Significant GHG emission phases in textile manufacturing through LCA approach, (derived from (BSI, 2014))

Phase	Impact		
	Low	Medium	High
Raw materials sourcing	–	Plant input materials Organic fertilisers Land use Feed processing Land-use change	Nitrogen fertilisers Livestock husbandry Mining for energy and minerals
Textile production	–		Energy use for spinning and texturing Raw material for weaving, knitting Energy use for weaving, knitting, felting Raw materials for finished fabric Energy use for finished fabric
		Raw materials for bleaching	Energy use for bleaching
		Raw materials for dyeing	Energy use for dyeing
Product manufacturing	Generally low except for cutting, knitting, etc.		

Many studies on farming-related LCA's including GHGs and CO_2 emissions and the apportionment to protein (meat, natural fibre/wool) and milk produced have been carried out. Most of these studies discuss merino (a breed of sheep) or the other types of wool, fewer discuss precious fibre like Cashmere (type of goat) (Tobler-Rohr, 2011c; FAO, 2015). Sheep rearing related carbon footprint studies show figures for out in Australia and New Zealand, and some discuss the UK as well. However, ensuring the suitability for the use of these figures is important as there may be different challenges and kg of CO_2/unit of the product (i.e kilograms). These include geographical, regional, and country specificity, rearing methods, and type of animal raising e.g. organic (in terms of agricultural such as crop growing and processing refers to a commitment to practices (that aspire to a "balance with nature") by using materials and methods that have low environmental impact) (Tobler-Rohr, 2011c) (for example, in which no or very little chemicals such as pesticides and fertilisers are used)) and non-organic. For example, when a sheep farming-related CO_2 footprinting study in New Zealand accounts for renewably generated 64% electricity generation in calculations (Barber and Pellow, 2006) the results can be significantly different.

Animal fibre (wool) are the key ingredients of finished woollen articles. The world's 43% wool is produced by China, Australia, and New Zealand (19, 19, and 8% respectively) (Henry, 2012). The UK animal farming (mainly carried out for meat), produces considerable quantities of wool (Wiedemann et al., 2015a), as shown in Figure 35. However, since this being of low quality is only considered as a by-product, and hence is used for other purposes such as insulation materials (Murphy and Norton, 2008). Therefore, the UK along with the other European countries have to rely on imported wool to meet their woolen garment production requirements (Tobler-Rohr, 2011a). Therefore, using animal rearing related GHG figures for the EU countries from Eurasian countries can work as suitable data (as the best available values). China is one of the main hubs of raw wool trade hence it may be convenient to assume that wool bought from China has a mixture of wool imported from different countries.

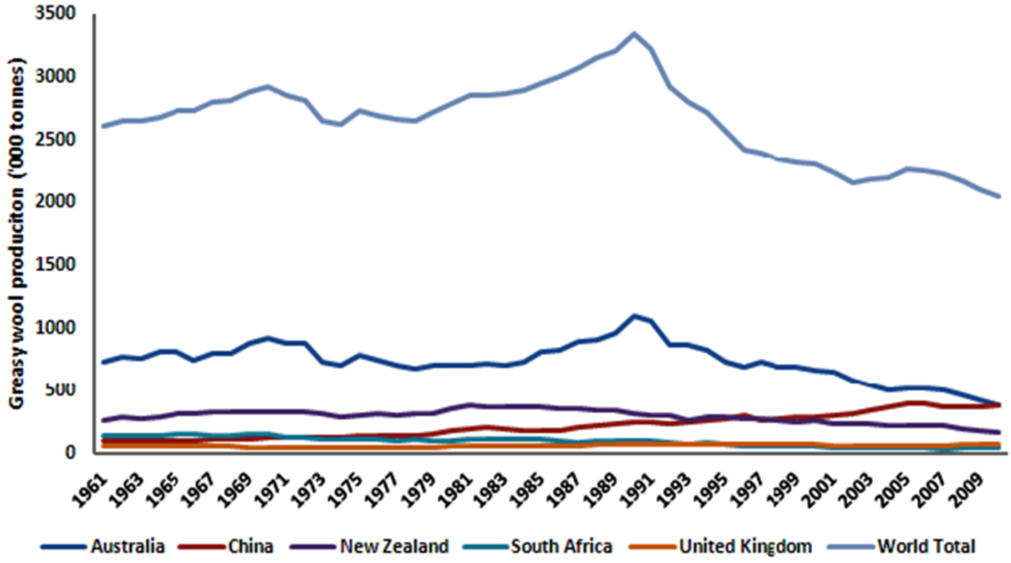


Figure 35 - Global wool production, (Henry, 2012)

Results, considering major farming products meat and wool were found to be highly dependent on the applied allocation methods (Henry et al., 2015). Many studies confirm that there is little impact of regions or countries on GHG emissions or wool types(Wiedemann et al., 2015b). However, the methodology used for handling the co-products can largely affect the results (Henry et al., 2015). For example, (Wiedemann et al., 2015b) use multiple-impact LCA for three types of wool produced in three geographically defined regions in Australia. They come across different results when used different methods for various GHG emissions accounting indicators. For example, when excluding land use (LU) and direct land use change (dLUC) they estimate 20.7–21.3kg CO_2-e/kg. When they included LU and dLUC indicators only 0.3% increase or 0.11% decrease (depending on how the pastures were being managed) were noticed. However, it is not clear whether the wool was greasy or non-greasy in this cradle to farm gate study. Brock et al., (2013) calculated the kg CO_2-e/kg of greasy wool in an Australian case-study farm in Yass region. They estimated a 24.9kg CO_2-e/kg wool for cradle to farm gate. Wiedemann et al., (2015a) use cross-country (New Zealand, Australia, and UK) case-study sites for their study. They apply various methods to calculate GHG emissions and attempt to assess the sensitivity related to them. Using meat and wool as co-products, with 1kg of greasy wool as a functional unit for the study, they use biophysical allocation (BA) indicator to estimate the emissions. Based on this method, they estimate 10-12kg CO_2-e/kg wool however they notice it increasing to 24-38kg CO_2-e/kg wool when they take sheep related maintenance on board. Using the economic indicator (Eady, Carre and Grant, 2012) estimate a 28.7kg CO_2-e/kg wool for the farm to gate greasy wool in Australia. Henry et al., notify that change in farming dominance (prioritised product meat or wool) also have an impact on the relevant CO_2-e/kg of the product. For example, when sheep farming dominance is changed from wool to meat the CO_2-e/kg figure for wool changes from 24.9kg CO_2-e/kg to 14.8kg CO_2-e/kg (Henry et al., 2015). This has been identified in various studies that different factors such as method, region, farming procedures can have mild to medium impact on the kg CO_2-e/kg wool estimations.

For most of the studies discussed above talk about greasy wool however, washing of wool to get clean and dry wool needs some energy. This degreasing process in fact also reduces the weight of the wool obtained, which is another factor that may need to be addressed (out of scope). A study by Murphy and Norton (2008) in the UK estimates the energy used for degreasing as 0.25kWh of electricity and 0.8kWh of gas per kilograms of wool (or 1.15 kWh/kg of wool, collectively). The study also identifies that every 1kg of wool washing generates 5litres wastewater. According to Sing, Carliell-Marquet and Kansal (2012) a wastewater treatment plant can use up to 1.046 kWh/m^3 of mixed (approximately, 50% each gas and electricity) energy. Due to unavailability of data, transportation-related emissions are not being discussed.

2.4 Conclusion

This Chapter completes the first part of the literature review. Discussing global and local energy and carbon situations and the need to understand industrial energy. It explored the importance of energy efficiency in manufacturing. It discussed various topics about the SME buildings' classification to clarify and establish a better understanding of the type of subject building/s. The Chapter defined energy, the other relevant terms, and their significance for building energy assessments through thermodynamics and its importance in building energy engineering. It further established the rudimentary significance of the tools used in the thesis—energy audits and surveys, in EM and the topics like performance indicators and management standards. Discussing various forms of energy monitoring and measuring and the associated drawbacks the Chapter signified the data types chosen for the study (rated power, intrusive, and measured data).

In addition to that, various forms of the existing methods for H-H energy data analysis were discussed. Various forms of H-H data analyses gaps were indicated. Firstly, these analyses were mainly applied on schools, office, public sector buildings with few studies on manufacturing buildings. Secondly, the data used and analysed was generally from larger sets of buildings with the objectivity of energy benchmarking, energy trends and pattern recognition, and efficiency opportunities. Thirdly, these analyses were mainly based on proprietary software with associated consultancy and subscription costs. In addition to addressing these issues, this research has been tailored on an individual site to see how the H-H data can be utilised to analyses such buildings. Based on the SME industry, this project tailors an H-H data analysis method that is free and easy to comprehend and carry out for the industry. Breaking the cost barrier and facilitating better identification of low-hanging fruits (as discussed in Chapters 5 and 6), it offers the SME sector improved H-H energy data analysis technique.

In addition to that, various forms of the existing methods for H-H energy data analysis were discussed. It was found that such data, if have been used, for manufacturing energy profiling was mostly limited to time versus consumption. There was hardly any evidence of such use on gas data. It is realised that if the 24-hour manufacturing activity is categorised into intensity increase/decrease the profiling could be used against the activity. This profiling helps to understand/identify energy and low-hanging fruits in a far better way than ever before, as explored in Chapters 5 and 6. As discussed above, studying individual technology in detail can help in understanding in-depth efficiency opportunities. However, the whole system efficiency is a more robust strategy for energy efficiency in manufacturing. Keeping this in view both aspects, whole-site/system in this chapter and the in-depth understanding of individual technologies are covered in the next chapter.

Chapter 3 – INDUSTRIAL TECHNOLOGY EFFICIENCY

Machines have boosted modern consumerism and manufacturing systems to consume/produce and process at cost-effective and faster rates to the fore. National and regional compliance and policy coupled with increasing energy costs, make a compelling and convincing business case for resource efficiency. As reviewed in Chapter 2, attainable through different routes, energy efficiency is one of the most promising routes to reduce industrial energy use and carbon emissions.

In this chapter energy efficiency/management measures (mainly O&M, good practice, and energy transformation), as discussed in Section 2.2.5, for key textile equipment and utilities (end-use/system level) with a brief review of RE are evaluated. As many of the assessed industrial technologies/equipment are common therefore findings are useful for both textile and allied, and general industries.

3.1 Equipment energy efficiency

3.1.1 Boilers

Sharing similar form and structure boilers and furnaces are a cross-cutting technology and play a key role in combustion-based industrial processes. In 2005, UK industrial steam boilers used 35% of fossil fuels (The Carbon Trust, 2012e). These together in buildings and industry are responsible for 60% of UK carbon emissions (The Carbon Trust, 2012d). Out of various classification bases, identified on designing scheme like shell-and-tube boilers (with two distinct types—fire-tube (mainly discussed) and water-tube) are common in the UK (The Carbon Trust, 2012d). The former runs hot gases through tubes surrounded by water, which is the opposite for the latter. These boilers can have two–three tubes of combustion gas passageways to maximise heat transfer.

Being energy-intensive, the steam and high-temperature boilers are likely to respond to energy waste controlling measures as shown in Figure 36. For example, flue gas heat recovery can save up to 20% energy on boilers (Hasanuzzaman et al., 2012) and strategic actions and advanced component-change avenues can enhance it further. All modern boilers can achieve up to 80% efficiency with the exception of 85% when retrofitted with economisers (The Carbon Trust, 2012d). According to another study, boilers operate at 78–83% (U.S. DoE, 2012c) efficiency and retrofitting economisers can help save from 5% (standard) to 10% (condensing) on fuel (U.S. DoE, 2012m).

Design, operational, and distribution system improvement measures can generally increase up to 10% boiler efficiency (Action Energy, 2004a). Using different saving strategies, shown in Table 10, 20% (or greater) cost saving on steam boilers is possible (The Carbon Trust, 2012d) such accounts have also been taken elsewhere (U.S. EPA, 2010).

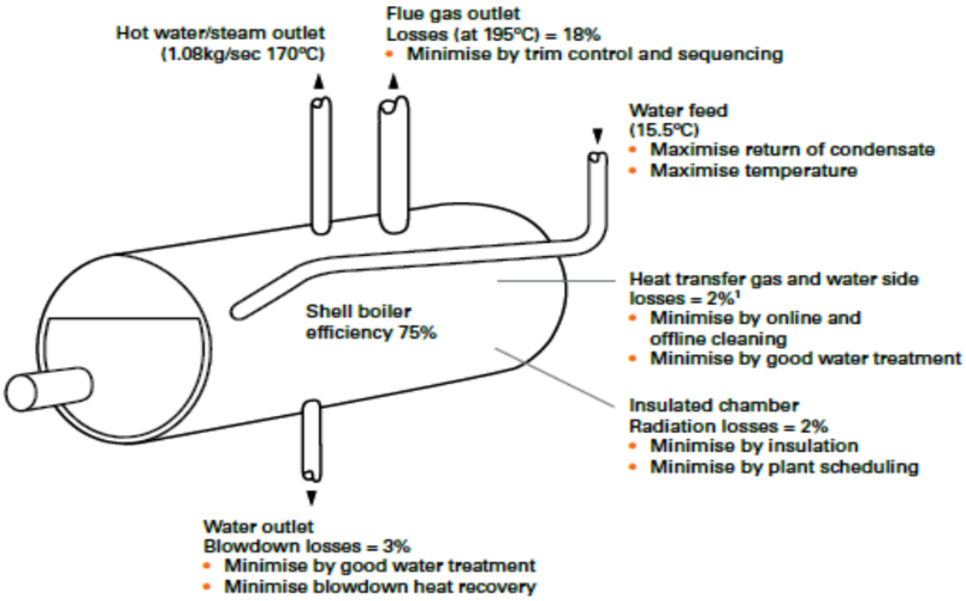


Figure 36 - Heat losses in a shell boiler, (The Carbon Trust, 2012d)

Table 10 - Measures for boiler energy saving, (The Carbon Trust, 2012d; Action Energy, 2004a)

Technique/method	Energy saving potential*
Operation and maintenance of boilers	Up to 5%
Boiler and burner management systems, digital combustion controls and oxygen trim	Up to 5%
Economisers	Up to 5%
Blowdown heat recovery	Up to 4%
Combustion air preheating	Up to 2%
Water treatment and boiler water conditioning	Up to 2%
Total dissolved solids (TDS) control and boiler blowdown	Up to 2%
Flue-gas shut-off dampers	Up to 1%

* Note that the percentages above represent potential saving if only the corresponding action is taken. Implementing several at once will not always result in savings that are a simple addition of both figures.

The combustion efficiency for liquid/gas fuels reported as 99% (Action Energy, 2004) can further be improved as advised elsewhere (U.S. DoE, 2012f). Various efficiency improving aspects through such as controls (Liao and Dexter, 2004), and general strategies, (The Carbon Trust, 2012d) have been discussed. The boiler (thermal) efficiency is the percentage of useful energy output (steam generated) compared with energy (heat) input, as shown in Equation 7. However, the efficiency used for the case-study boilers is pre-determined, as discussed in Chapter 5.

Equation 7

$$Thermal\ efficiency = total\ heat\ absorbed\ /total\ heat\ input \qquad \text{or}$$

$$Total\ heat\ absorbed = total\ heat\ input - total\ heat\ loss$$

The commonly used/advised energy efficiency measures are evaluated as these are easy to understand and implement. The low-cost measures can be realised through energy monitoring, system maintenance, and combustion efficiency by adjusting air-to-fuel ratio through various strategies and technologies, as suggested (U.S. DoE, 2012l; The Carbon Trust, 2012d). Depending on the quality of data, monitoring mainly analyses metered gas consumption data and the steam/condensate produced, as discussed elsewhere (Gordić et al., 2010; Giacone and Mancò, 2012). Flue gas performance diagnosis through monitoring is discussed by (Bhatia, 2012). The information gained through such types of auditing helps to produce baseline efficiency to compare and identify waste/losses, under performance, and setting of improvement targets. For example, for benchmarking the fuel cost for steam generation as suggested elsewhere (U.S. DoE, 2012b). Another important aspect is system maintenance, discussed as O&M in Chapter 2. This, however, has different meaning such as preventing water tubes fouling and establishing suitable water softening system for that, and ash removing from solid fuel boilers, as discussed elsewhere (Action Energy, 2004). Best practice measures can include reducing standby losses (Bhatia, 2012), draught fan controls (Ozdemir, 2004), controlling load swings by installing steam accumulators or by demand-side management (US DoE AMO, 2004), optimising boiler pressure (U.S. DoE EERE, 2005), and scheduling and sequence controlling (U.S. DoE, 2012j; The Carbon Trust, 2008b).

Medium- to high-cost investments i.e. plant's components change can significantly add to energy efficiency. For example, VSD for flame controlling (Ozdemir, 2004; Saidur and Hasanuzzaman, 2009; Action Energy, 2004a). This involves oxygen trimming and heat recovery from the flue gases (Hasanuzzaman et al., 2012; Action Energy, 2004a). Replacing high/low burners with fully modulating burners can save 2%–5% on fuel and suits systems with variable steam demand. Regular controls if replaced with advanced electronic controls can result in 2% fuel savings (The

Carbon Trust, 2012e). Installing turbulators in tubes to convert the developing laminar gas flow into turbulent (U.S. EPA, 2010) for maximum heat transfer. It is cheaper (U.S. DoE, 2004c, 2012d) as demonstrated by manufacturers elsewhere (Brock, n.d.). With a 1% efficiency increase, the measure can replace the need for costly economisers, and or with a quick payback air pre-heaters are another option (US EPA, 2010).

Another tangible saving option is heat recovery at either generation or end-use point (as discussed in Section 3.1.3). Economisers are a type of heat exchanger (HE) are further discussed in Section 3.1.3. Various savings have been quoted for regular economisers for example, between 3%–7% on fuel (The Carbon Trust, 2012c), and 5% as shown in Table 10 (The Carbon Trust, 2012d; Action Energy, 2004a). Condensing economisers can (recovering latent heat) potentially save 5%–9% (U.S. DoE, 2012m; The Carbon Trust, 2012d) as discussed above, somehow agrees with these values. However difficult design/installation terms means that these incur higher than regular economomisers (U.S. DoE, 2012c; d).

Any boilers exceeding 5% constant steam blowdown rate is a good candidate for heat recovery from it (U.S. DoE, 2012k), resulting in up to 4% energy saving, as in Table 10. Blowdown rate typically varies between 4%–8% of boiler feedwater flow rate, though can be as high as 10% (U.S. DOE, 2012). To minimise water tubes scaling, for energy saving, reduction in the dissolved solids levels in the water to the minimum threshold is required. This is achieved through a reasonable water blowdown frequency. Installing an automatic blowdown system with a salt levels sensor is suggested elsewhere (U.S. DoE, 2012h) which can save up to 2% (The Carbon Trust, 2012d; e).

3.1.2 Dyeing, drying, and washing equipment

With reasonably higher thermal demand textile dyeing, drying, and washing are separate processes requiring specialist technologies, as shown in Table 11 (Ozturk, 2005; Büyükakinci, 2012). Common process heating systems can be classed into three main categories: combustion-based, electric, and heat recovery and HE (U.S. DoE, 2004g). Boilers are a typical combustion-based system whereas stenter, in Section 3.1.2.2 being textile-specific such example. The electric process-heating systems have a variety of forms such as direct- and indirect-heating for both resistance and induction types. As discussed in 3.1.2.1, the use of radiant energy is dominant in the textile industry. Thermal processes involve heat exchanging that, in many end-use applications, is often carried out through HE, as discussed in Section 3.1.3.

Table 11 - Key dyeing, drying, and finishing processes technologies

Area	Process	Product form/machine type
Finishing	Desizing	Desizing unit
	Scouring/bleaching	Kier
		Open width range
		Low-energy steam purge
	Scouring	J-box
		Continous hank
	Heat setting	Heat setting stenter
	Drying	Stenter
		Hank
		Steam cylinders
	Printing	Rotary screen
	Bleaching	Jig/winch
	Preparting/dyeing (cotton)	Package/yarn
	Preparting/dyeing (polyester)	Package/yarn
Dyeing	Dyeing	Jig
		Winch
		Jet
		Beam
		Pad/batch
		Continous/thermosol
		Steam cylinders
		Hank

Dyeing requires higher process temperatures (normally 98˚C) as compared to washing (usually 60˚C) (Pardo Martínez, 2010). Dyeing vats, if used as open vessels, are advised for covers (U.S. DoE, 2012e), up to 9% energy of the total requirements can be saved by insulating them (Building Research Establishment, 1997). If liquor is agitated through pumping or CA, efficient motors (as in Section 3.1.4.1), and alternative methods, and efficiently produced CA may be applied (as in Section 3.2.2). Energy from process cooling water can be recovered/reused to save half of the total dyeing energy requirements (Building Research Establishment, 1997). Steam for washing is generally supplied through coils. Controlling losses through insulation and covering, as indicated in Figure 37, can save energy significantly. Heat recovery from wastewater produced by these technologies is discussed in Section 3.1.3.

Figure 37 - Heat balance in a continuous water cleansing machine, (Pardo Martínez, 2010)

Drying can account for 10%–25% of a nation’s industrial energy demand (Defraeye, 2014) and is applied toarray of processes (such as textile, food, and ceramics). Textile has many uses of it in dyeing, pressing, and washing with some process stages given below;

- Mechanical (kinetic (centrifugal separation), and pressure (vapour compression))
- Radiant or non-contact or electromagnetic radiations like microwave, radio or high-frequency (RF) waves, and thermal radiations like infrared (IR)
- Direct heat through convection or direct drying (stenter, hot flue, perforated drum dryer, and yarn package drying)
- Conduction or indirect drying like vaporisation, sublimation, and drying e.g. calendar, and cylinder drying machines

Mechanical technologies are mainly motors (as discussed in Section 3.1.4) based. The radiant and the latter two types, their applications discussed below, are frequently used in the textile industry. Each type has specific energy demand bandwidth for drying 1kg of water, as shown in Figure 38. Specific methods, as discussed above, are used to fulfil the requirements of each stage. For some stages pre-drying is necessary, for example as in stenter (Building Research Establishment, 1997) as the technology is not designed to dry soaking wet fibre/cloth, and also drying such materials would become too energy-intensive. Best practice manuals (Building Research Establishment, 1997; Schonberger and Schafer, 2003) discuss the benefits of such fabric pre-drying (discussed below). For example, a 50%–60% fabric moisture content reduction incoming to a stenter, depending on the type of the substrate, can save up to 15% demand. For textile pre-drying/extra water removal, four types of mechanical drying (dewater) classed as: squeezing between rollers (manglers), suction devices i.e. using an air knife on the fabric, and rolling the item on a purpose-built suction chamber/suction slot, centrifugal i.e. putting in a crudely annular fashion inside a spin dryer/hydro-extractor, and a mix of suction and centrifugal technology are used (Boucraut, 1976; Schonberger and Schafer, 2003). Each specific process/design technology, depending on the type of substrate, is suitably used. It can be seen that these textile processes use a wide variety of technology. Studying discrete technologies comprehensively on an individual basis is not possible in this thesis (recommended for future), but how important it can be is being highlighted through the study.

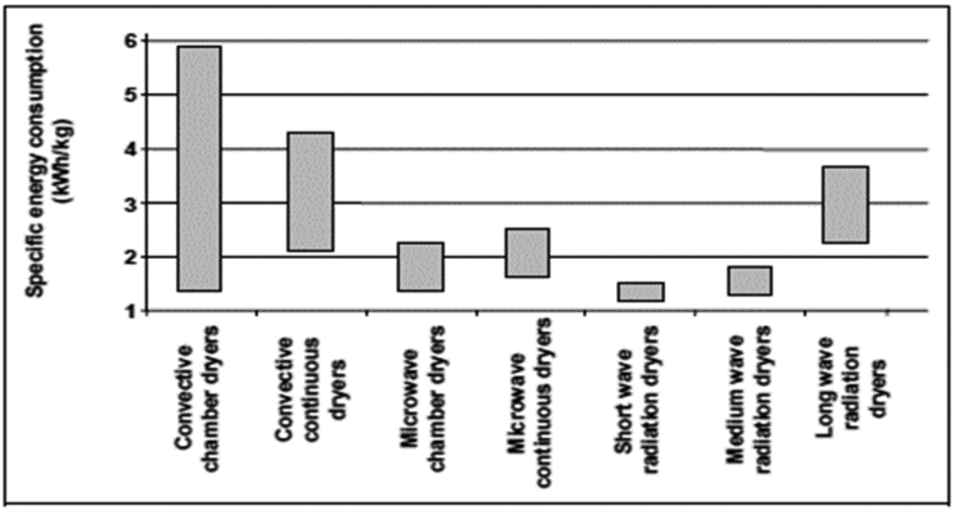


Figure 38 - Various dryers' energy consumption bandwidths (European Commission, 2009)

3.1.2.1 Microwave and radio frequency machines

Microwaves are broad frequency spectrum electromagnetic waves (ranging 1cm–1m and frequencies 30GHz–300GHz) based radiant energy whose electromagnetic spectrum lies between RF and IR. Microwaves and RF dry materials like water through polarisation from the substrate. Microwaves are trusted and applied in many low-temperature (<500°C) industrial applications such as wood curing, rubber pre-treatment and vulcanisation, and textiles. The microwave absorption is assumed to increase kinetic energy by stimulating molecules. The heat produced facilitates water molecules to escape from the substrate.

Microwave technology is preferred for many other benefits including energy efficiency, and uniform and localised heating. Their textile-specific applications are drying, dyeing, pressing, finishing, and thermal setting (Bhat, Kale and Gore, 2009).

Being 50% more efficient than conventional systems, these save considerable amount of energy (Haggag et al., 2014). These systems can process batches quickly, compared to conventional methods, due to reduced warm-up and cooling down.

To expand their scope in textile industry, issues such as inability to create uniform energy distribution need to overcome. These rays can trigger chemical reactions in textile molecules such as polyurethane (PU). An industrial microwave system manufacturer (IMS) however claims to have overcome this problem (Katovic, 2010). Depth penetration—the higher the frequency the lower the penetration, is also another problem (Katovic, 2010). Koral, in response to industrial operational conditions, shows concerns about the leakage of the microwaves creating workers' health issues (Koral, 2008). Katovic et al., find microwaves much better for size setting and warping applications in certain aspects (Katovic et al., 2008). It is not always clear if microwave is more energy efficient than other forms of drying however is widely used in various textile applications. Koral credits microwaves being safer and having lower running costs than the RF and suggest more research for thorough comparison of benefits (Koral, 2008).

With a one-million units sold so far, RF heating and drying has been popular since 1960 (Koral, 2008). In addition to drying bobbins of yarn, these have food and the other industrial applications due to better energy and job efficiency. These are a direct form of heating hence little energy is wasted. An RF system manufacturer (RF Systems, n.d.), claims that his is more efficient as can remove 2.8kg of water/kW from bobbins and yarns as compared to traditional ones (removing 1.2kg/kW).

IR transfers thermal energy through conduction, convection, and radiation. Therefore, its use in the textile industry is broad and both electric and gas IR technologies are available. IR units have been used in pre-drying in stenters. If installed at the cloth feed-in chamber of a stenter, they are claimed to save energy and time and improve product quality. They are also used post curing of coatings and embossing.

3.1.2.2 Stenter

Enabled by motive power, a stenter is a thermal (convective and conductive) conveyor. It utilises high-temperature air (80°C–200°C) for size setting (length/width), heat setting (for synthetic fibres), drying, printing, shrinking and curing. Drying processes represent 50% of the energy in finishing processes 25% of which is used by these. Roughly every textile material is treated at least two-and-a-half times in it

(Borges, Pieri and Henriques, 2011). It is energy-intensive therefore, can offer several saving opportunities.

Different mediums like steam (temperature not exceeding 160°C) (Building Research Establishment, 1997), gas, and thermic oil are used for contact (conductive) drying, which in some cases can adversely affect the quality of cloth e.g. discolouration. A more efficient direct-fired gas method like stenter is used for convection drying, which consists of a large frame having three distinct parts 1) fabric feed-in zone, 2) middle zone or heating chambers (varying from 3─10), and 3) exit zone or plaiter, shown in Figure 39.

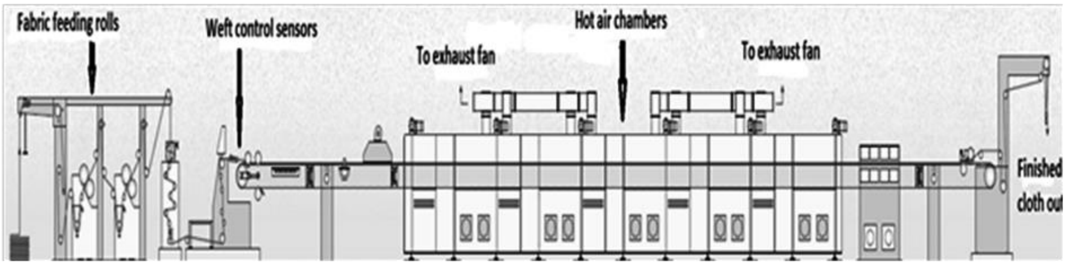


Figure 39 - A schematic of a stenter frame, (Schonberger and Schafer, 2003)

With motorised rollers in the first zone, the fabric is inserted into the middle zone. This zone has pins and clips to hold and straighten the cloth and carries out fixing and curing by firmly stretching. The last chamber circulates fresh air to cool down the cloth after which comes the exit zone (plaiter). With a simple motorised machine, the plaiter is used to spread the fabric into a folded or rolled manner. Depending on the finished fabric requirements, this zone can accommodate additional tools (e.g. selvedge cutters). The energy consumption in an optimised stenter can be 3500kJ–4500kJ/kg of textile (Schonberger and Schafer, 2003). The energy breakdown of the machine is shown in Table 12. Auxiliaries like vacuum extraction, squeezing manglers, and IR have been suggested for energy efficiency improvements (Kocabas et al., 2009).

Table 12 - Stenter energy breakdown, (Building Research Establishment, 1997)

Component	Energy content (GJ/tonne)/(kWh)	%
Evaporation	2.54 /706	41
Air heating	2.46/683	39.7
Fabric	0.29/81	4.6
Case	0.39/108	6.3
Chain	0.09/25	1.5
Drives	0.43/119	6.9
Total	6.20/1722	100

Thermal insulation can reduce 2%–4% heat losses (The European Commission, 2003). In most of the cases, the operator of the machine estimates and manually controls the rate of exhaust airflow, moisture content, and the fabric dryness (Building Research Establishment, 1997). This poor practice often results in exhaust humidity levels of 0.05kg(water)/kg (dry air), which is much lower than the required levels of 0.1–0.15 kg(water)/kg (dry air) for optimal performance. If not monitored, this excessive energy use can reach up to 60% of the total energy. A reduction of fresh air consumption from 10kg–5kg(fresh air)/kg (textile) can result in a 57% energy saving (The European Commission, 2003). Therefore exhaust airflow, temperature, and fabric dwell time optimisation are convincing energy efficiency improvement techniques.

With an additional choice of air cleaning equipment installation heat recovery from the exhaust using air-to-air or air-to-water techniques can be undertaken. Double heat recovery systems may also be designed. A flowchart indicating how it works is shown in Figure 40. The Figure shows a combination of an air/air and air/water heat exchanger along with an electrostatic precipitator. An indicative reference data, as shown in Table 13 is used for such calculations, for example as for Table 14. Air/water HE can recover up to 70% of the exhaust air energy and the obtained hot water can be used for processes (dyeing/washing) (Schonberger and Schafer, 2003). Air/air HE can recover up to 30% heat from the exhaust (The European Commission, 2003), and manufacturers like Montfort confidently claim this. A general return on investment estimation for both system types is shown in Table 14. Heat recovery methods are further discussed in 3.1.3.

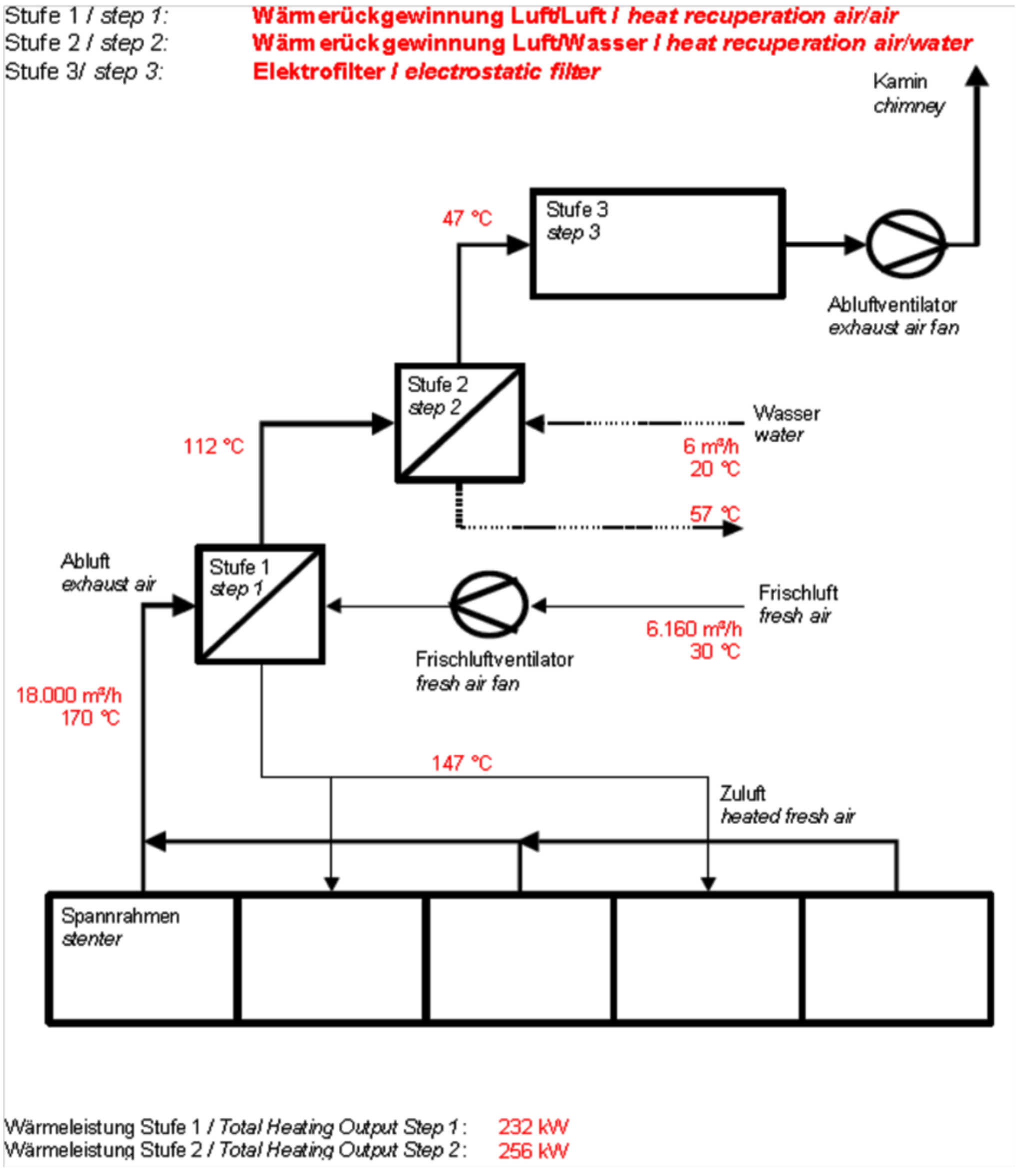
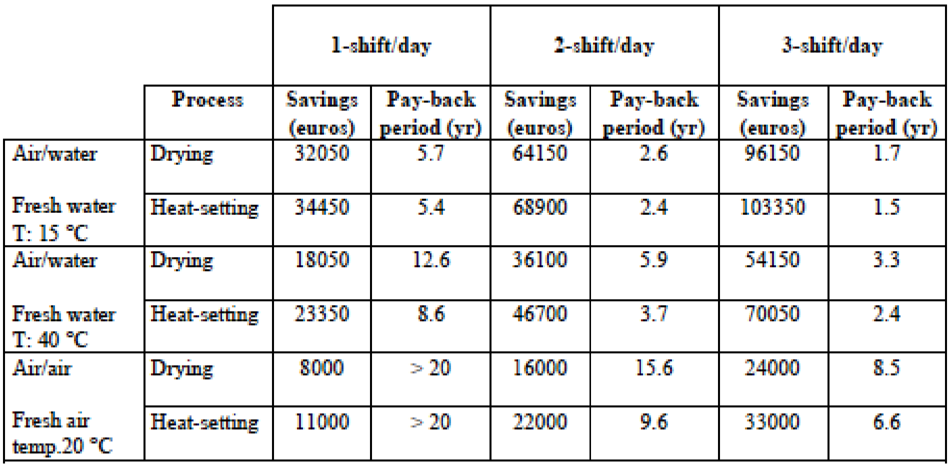


Figure 40 - Exhaust gas and heat recovery, (Schonberger and Schafer, 2003)

Table 13 - Reference data for stenters, (The European Commission, 2003)

Parameters	
Heat recovery system	Counter flow pipes
Drying temperature	130°C
Heat setting	190°C
Off-gas volume flow	15000 m^3/h
Off-gas moisture content “Drying”	70 g/m^3
Off-gas moisture content “Heat setting”	40 g/m^3
Efficiency	70%
Heating value for the gas	9.3 kWh/m^3
Costs for the gas	0.25 $EURO/m^3$
Maintenance costs	1.000 EURO/a
Interest	6%

Table 14 - Return of investment on stenters*, (The European Commission, 2003)



		1-shift/day		2-shift/day		3-shift/day	
	Process	Savings (euros)	Pay-back period (yr)	Savings (euros)	Pay-back period (yr)	Savings (euros)	Pay-back period (yr)
Air/water Fresh water T: 15 °C	Drying	32050	5.7	64150	2.6	96150	1.7
	Heat-setting	34450	5.4	68900	2.4	103350	1.5
Air/water Fresh water T: 40 °C	Drying	18050	12.6	36100	5.9	54150	3.3
	Heat-setting	23350	8.6	46700	3.7	70050	2.4
Air/air Fresh air temp.20 °C	Drying	8000	> 20	16000	15.6	24000	8.5
	Heat-setting	11000	> 20	22000	9.6	33000	6.6

**Assuming different processes, heat recovery systems and working times*

As an indication £1=1.20 euros

Other thermal drying machines like calendars and cylinders are quite similar to the technologies discussed above. Therefore, general saving measures like heat recovery, operative adjustments, efficient motors and enablers, and selecting optimum operating temperatures can be used.

3.1.3 Heat exchangers

HEs have varied industrial applications such as chiller systems, boilers, and steam cooking pots. The heat exchanging is mainly based on two physical processes—conduction and convection. Three types of fluid flows—parallel, counter, and cross are considered for HE calculations. These can be divided into two distinct categories:

thermal and hydraulic calculations (for transfer rates and pressure drops) and for equipment sizing, and mechanical design calculations (for detailed specifications i.e. considerations like stress and tube vibration analyses).

3.1.3.1 Heat recovery

The exact quantity of large-scale recoverable heat from industrial processes is poorly quantified. It is estimated that 20%–50% of the energy used is ultimately wasted through different streams such as exhaust gases/liquids, conduction, convection, and radiation from the equipment surfaces and the products. Some of it must be lost due to the irreversibility of thermodynamic processes exergy destruction (as in Chapter 2). Industrial waste heat in the UK is estimated to be 11.4TWh/yr (Law, Harvey and Reay, 2013). A large amount of this heat can be recovered for direct use, potentially for low-grade (55°C–230°C) heat streams (Ammar et al., 2012). Advanced and improved methods have significantly increased the capacity of heat recovery applications (Ammar et al., 2012). In industry, site-specific conditions and system design/type suitability assessments and optimisation studies are in common practice (Pintácsi and Bihari, 2013). The heat exchanging for electricity generation is also considered. For the sources below 60°C, however, heat recovery is difficult and system design novelty is often required (Law, Harvey and Reay, 2013) which sometimes becomes too expensive.

In general, heat exchanging calculations assume steady-state conditions and the system’s heat losses/gains to the environment are ignored. There is a large variety of HE which can be classified through different criteria. The geometry of construction is one of them and has two commonly used major types—shell and tube, and plate type HE (Ammar et al., 2012). The shell and tube type has been generally reviewed in Section 3.1.1. Plate HE can be far more compact with a larger surface area than the former type hence can be up to 6% more efficient (SpiraxSarco, 2011). Choosing the most appropriate HE for a facility is a common problem (Ammar et al., 2012). Another problem that gradually reduces the efficiency and is difficult to handle is fouling (deposited scale/material on the surface), and thus scheduled cleaning is required that may incur cost and downtime (Ammar et al., 2012).

Commenting about selecting the right type of HE, manufacturers often mention the lack of information about specific application requirements. This is mainly due to the end-user not knowing all or any of the parameters required for the proposed system. For example, details about maximum/minimum flows and the normal HE unit operating conditions are ignored. Installing a duplicate system without a root cause analysis is a common practice to replace a failed HE system. This results in a substandard design, selection, longevity, and performance considerations for correct heat transfer. Determining the process conditions such as maximum- and minimum-pressure and fouling factor, and steam conditions that the end-user may provide to the manufacturers for better system design and efficiency are helpful (U.S. DoE, 2003d). A general 10-year payback criteria taking an account of, initial and maintenance cost, down-time losses, and replacement cost if the unit fails, can be suitable to apply (U.S. DoE, 2003d).

Increasing heat transfer rates warrants optimum HE performance. Such investigations may use experimental, numerical, and analytical approaches and other applications or natural systems. To thoroughly understand HE, Goldstein et al., (2010) take a comprehensive account of the literature. A relevant example is a study, in which HEs were used to competing with the EU's IPPC (Integrated Pollution and Prevention Control) energy reduction requirements in the textile industry (Kocabas et al., 2009). Elahee proposes different methods of textile energy recovery using HE (Elahee, 2010).

Heat transfer characteristics of a rotating cylinder with a lateral air impinging jet have also been documented (Jeng, Tzeng and Xu, 2014). Fins are used to increase the HE's thermal resistance, but they tend to enhance the pressure drop problem, requiring a balance between the two. Finned-type HE have also been studied to maximise performance through solar applications to support thermal textile processes (Muneer, Maubleu and Asif, 2006). Project-specific analyses have been undertaken to optimise HE performances elsewhere (Cipolla and Maglionico, 2014).

This study uses real-time empirical observations made in dyeing and wet finishing units of the case-study factory as discussed in Chapters 5 and 6. The whole exercise in this thesis is helpful for the textile industry to understand basic design methods, heat recovery guidelines, and energy benchmarking for the dyeing and wet finishing operations.

3.1.3.2 Heat pumps

Heat pumps are utilised to increase the temperature of a waste-heat (otherwise be wasted/rejected) source to the level where this waste heat becomes useful (U.S. DoE, 2003c). This, however, is carried out at an expense of some thermal or mechanical, as shown through a vapour compression heat pump example in Figure 41 below (European Commission, 2009), (normally electric) energy. The characteristic contributes towards reducing energy transformation cost as can utilise low-grade/non-useable RE- or waste-heat sources into useable energy. Hence, this has reduced carbon emissions and becomes an attractive application even for industries like textiles. Each type, out of many, offers specific characteristics providing a choice of best-fit selection for a specific process. The main types of these are: closed-cycle mechanical, open-cycle mechanical vapour compression, open-cycle thermo-compression, and closed-cycle absorption, as discussed elsewhere (U.S. DoE, 2003c; European Commission, 2009).

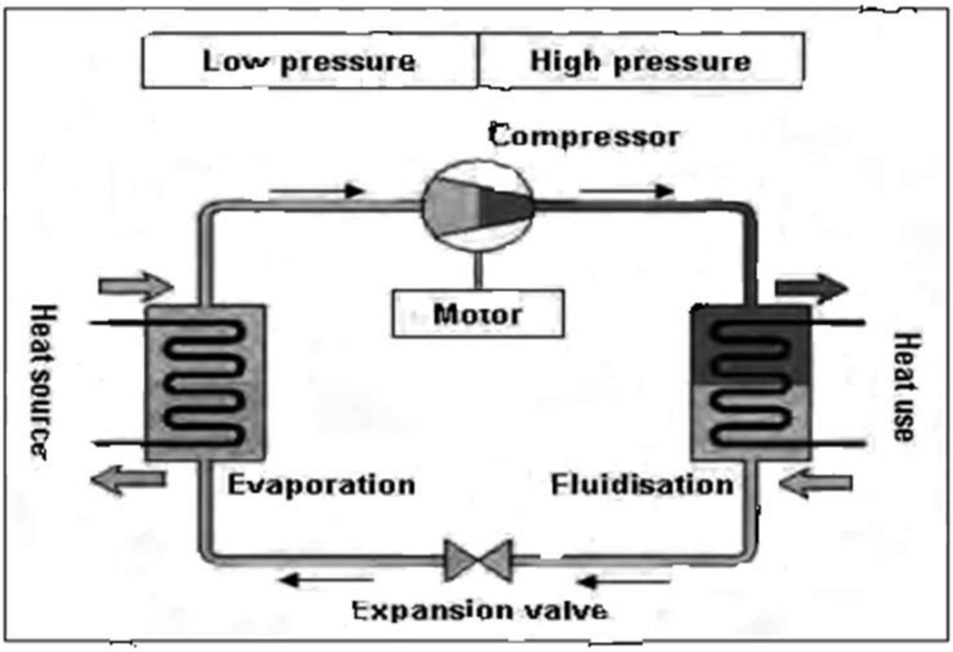


Figure 41 - Functioning of a compression heat pump, (European Commission, 2009)

Heat pumps have been used for multiple objectives in industry, for example for process integration (Becker and Maréchal, 2012). For process design methods such as cascading heat utilisation in difficult multi-process systems i.e. batch systems. Two different process integration methods for waste heat recovery through heat pumps in a case-study cheese factory has been suggested elsewhere (Becker, Spinato and Maréchal, 2011). Ammar et al., suggests low-grade heat recovery options in multiple industrial processes and applications and, if technically feasible, is another potential energy efficiency application (Ammar et al., 2012). A brief introduction of these devices indicates their potential in the industry, however, their textile-specific applications have not been evaluated due to time constraints.

3.1.4 Electric motors as prime movers and enabling technologies

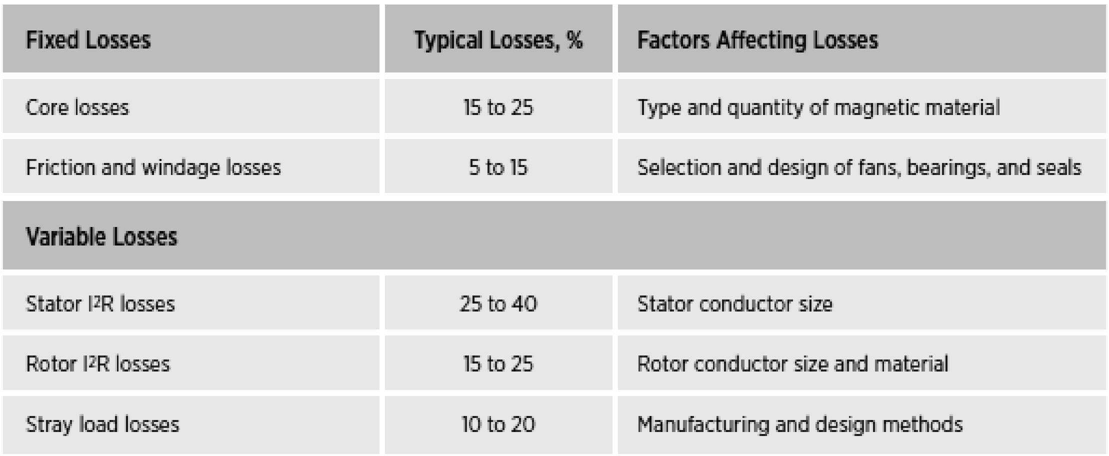
Motors convert electricity into mechanical power (Waide and Brunner, 2011) and have wider applications such as pumps, fans, and motive power. Some textile-specific examples are shown in Table 15. Motors are classed into two distinct types—AC (alternating current) such as induction motors and DC (direct current) motors, each having some sub-classes. The AC induction motors are a frequent choice hence motor efficiency standards mainly target them. The relationship of motor torque (a force that tends to cause rotation), output, and corresponding speed are useful terms to understand a motor's capacity.

Table 15 - Some motor-based textile process technologies, (Goswami, Anandjiwala and Hall, 2004)

Fabric/fibre sheet making process		Machine
Weaving		Automatic loom with shuttle
		Shuttle less looms
		Rapier
		Projectile
		Air-jet
		Multiphase
Knitting and hosiery		Circular knitting machine (wide)
		Warp knitting loom
Non-woven bonded fabrics	Dry method	Stitch bonding machine
		Short fibre carding, non-woven card
		Long fibre carding, garnetting
		Tufting machine
		Aerodynamic web-making machine
		Spun-bonding machine
	Wet method	Rotoformer
Paper manufacture		Paper-making machine (high powered type)

An electric motor driven system (EMDS) or packaged equipment, only uses a fraction of power to control functions and the other ancillary circuits (Waide and Brunner, 2011). Motors need more power than the rated output due to the associated losses. These, mainly affecting the motor efficiency varying from motor to motor, are associated with four major categories: power, magnetic core, friction windage, and stray load (stator/rotor resistance) (U.S. DoE, 2014). The percentage of each towards total loss is shown in Table 16. Mainly depending on the motor design, these losses/efficiency can be accounted for by applying them to Equation 8.

Table 16 - Different types of motor losses towards total (U.S. DoE, 2014)



Fixed Losses	Typical Losses, %	Factors Affecting Losses
Core losses	15 to 25	Type and quantity of magnetic material
Friction and windage losses	5 to 15	Selection and design of fans, bearings, and seals
Variable Losses		
Stator I^2R losses	25 to 40	Stator conductor size
Rotor I^2R losses	15 to 25	Rotor conductor size and material
Stray load losses	10 to 20	Manufacturing and design methods

Equation 8

$$\text{Efficiency}, \% = \frac{Watts\ (output)}{Watts\ (input)} \times\ 100$$

$$Efficiency, \% = \frac{Watts\ (input) - Watts\ (losses)}{Watts\ (input)}$$

Other factors that influence motor efficiency include (UNEP, 2006):

- Motor age. New are more efficient
- Capacity. For most equipment, motor efficiency increases with the rated capacity, as shown in Figure 42. For example, the full-load efficiency of a 1kW three-phase induction motor is 75%, whereas this for 30kW at same conditions will be 90%. The single-phase motors are about 5-10 less efficient (CIBSE Guide F, 2012)
- Speed. Higher speed motors are usually more efficient, as shown in Figure 42
- Type. For example, squirrel cage motors are normally more efficient than slip-ring motors
- Temperature. Totally-enclosed fan-cooled (TEFC) motors are more efficient than screen-protected drip-proof (SPDP) motors
- Rewinding of motors can result in reduced efficiency
- Load

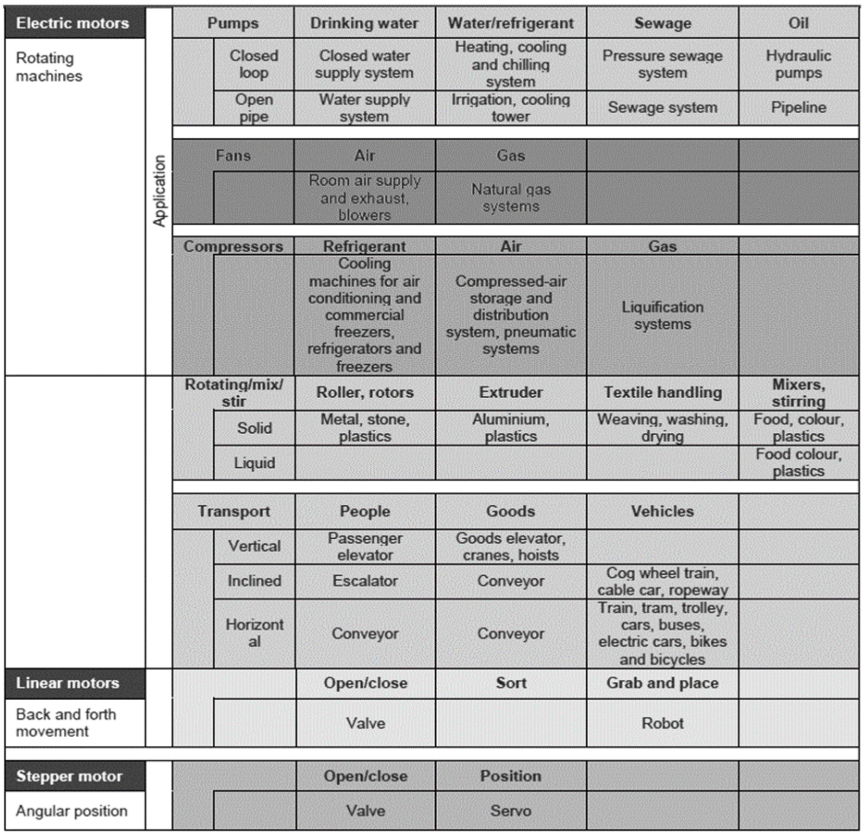
3.1.4.1 Motors and motor systems applications

Motors are the largest users of electricity, 43%–46% globally and are responsible for up to (6,040Mt) of CO_2 (Waide and Brunner, 2011), their varied use is shown in

Table 17. These are responsible for two-thirds of industrial electricity use (European Commission, 2014). The size of the motors varies from less than a few watts to up to 1MW. However, medium-sized motors are frequently used in most industrial systems. The four major such motor applications dominating the motor-related electricity use are: compressors (32%), mechanical movement (30%), pumps (19%) and fans (19%) (Waide and Brunner, 2011).

Motors below 0.75kW (small-size) are mostly used in residential and commercial sectors and contribute 9% towards motor power consumption. Between 0.75–375kW (medium-size), mostly consisting of asynchronous AC induction motors, consume the most motor-related electricity (4,700 TWh). These are mostly part of industrial EMDS, commercial applications, and infrastructure systems, and sometimes may be sold as standalone as indicated in Table 17. Therefore, their efficiency improvement matters. Most OECD and some non-OECD economies have imposed minimum energy performance standards (MEPS) on such motors when sold as a separate unit however little concerns are shown when sold as an integral part of a packaged system. This indicates the higher possibility for the EMDS system efficiency.

Table 17 - EMDS applications, (Waide and Brunner, 2011)



Electric motors	Application	**Pumps**	**Drinking water**	**Water/refrigerant**	**Sewage**	**Oil**
Rotating machines		Closed loop	Closed water supply system	Heating, cooling and chilling system	Pressure sewage system	Hydraulic pumps
		Open pipe	Water supply system	Irrigation, cooling tower	Sewage system	Pipeline
		Fans	Air	Gas		
			Room air supply and exhaust, blowers	Natural gas systems		
		Compressors	**Refrigerant**	**Air**	**Gas**	
			Cooling machines for air conditioning and commercial freezers, refrigerators and freezers	Compressed-air storage and distribution system, pneumatic systems	Liquification systems	
		Rotating/mix/stir	**Roller, rotors**	**Extruder**	**Textile handling**	**Mixers, stirring**
		Solid	Metal, stone, plastics	Aluminium, plastics	Weaving, washing, drying	Food, colour, plastics
		Liquid				Food colour, plastics
		Transport	**People**	**Goods**	**Vehicles**	
		Vertical	Passenger elevator	Goods elevator, cranes, hoists		
		Inclined	Escalator	Conveyor	Cog wheel train, cable car, ropeway	
		Horizontal	Conveyor	Conveyor	Train, tram, trolley, cars, buses, electric cars, bikes and bicycles	
Linear motors			**Open/close**	**Sort**	**Grab and place**	
Back and forth movement			Valve		Robot	
Stepper motor			**Open/close**	**Position**		
Angular position			Valve	Servo		

In 2001, the USA’s motor efficiency requirements (NEMA (National Electrical Manufacturing Association) MG1-1993) were upgraded to NEMA Premium™

(equivalent to EU's IE2). This was also recognised by the Consortium for Energy Efficiency (CEE) for motors up to 200hp.

In 1999, a voluntary agreement supported by CEMEP *(*European Committee of Manufacturers of Electrical Machines and Power Electronics) defined a three-level EFF3, EFF2, and EFF1 motor efficiency classification scheme. This became the basis for the EU's own motor efficiency scheme (European Commission, 2014). In 2007, the International Electrotechnical Commission (IEC) developed an internationally applicable electric motors' testing standard (600034-2-1) and classification scheme (IEC 60034-30-1) with four levels of efficiency codes ("IE-code"). These from IE1─IE4 represent standard, high, premium, and super premium energy efficiency respectively. In 2009, the EU set motor MEPS in directive 640/2009 at IE3 levels or IE2 in a combination with a variable frequency drive (VFD).

3.1.4.2 Motor efficiency opportunities

Internationally standardised motors can typically save 4%–5% of total motor power demand. The potential can be significantly increased by taking advantage of the 15%–25% saving potential (roughly 10% globally) linked to electromechanical solutions (Waide and Brunner, 2011). Even a 2% efficiency gain, from 92%–94%, can result in a 25% reduction in losses. Small motors are less efficient than medium-size based on a number of factors, as in Figure 42. The electromechanical solutions consist of, for example, use of adjustable/variable speed drives ASDs/VSDs to match the motor speed and torque according to the system requirements (Abdelaziz, Saidur and Mekhilef, 2011). Ozdemir (Ozdemir, 2004) investigates using VFD in a water tube boiler to control excess air during lower loads to reduce electric demand and increase boiler efficiency by 2.5%.

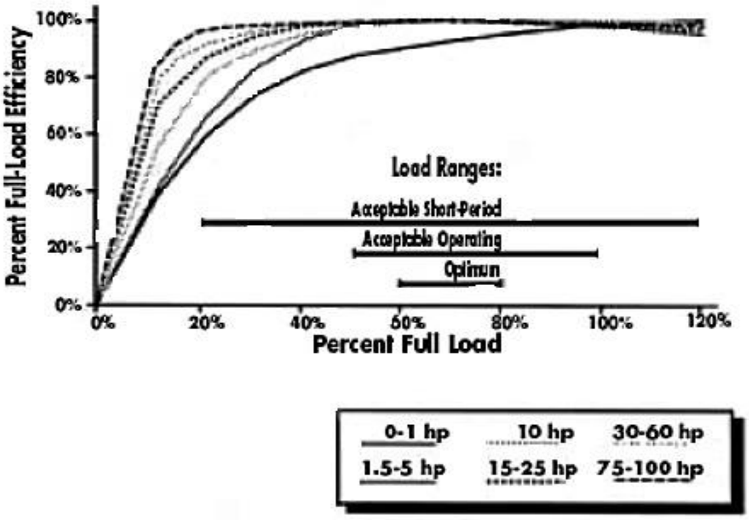


Figure 42 – Various motors efficiency at different loads, (UNEP, 2006)

The motor sizing based electromechanical solutions, efficient throttling devices, drives, gears, can be explored for enhanced savings. Motors are often designed to give the highest efficiency at 75% load, as indicated in Figure 42. To cope with higher demand-side, installing 15% higher rated power than the designed capacity motors had been a common practice in the past. However, the elevated loads do not occur that often (UNEP, 2006). Discounting this overcapacity, where permissible, for new installing/replacing motors can be helpful. The exact capacity will reduce demand as well as will allow it to run at higher (maximum efficiency) loads. Some relevant strategies are highlighted below;

- A motor audit can be carried out to gather capacity information, running hours, types and suitability for improving efficiency (such candidates for efficient motors/VSDs, and recording age, etc.)
- The audit helps to make decisions for a complete installation or component replacement is needed, with payback estimation
- O&M plan
- System optimisation e.g. correct sizing of pipes and ducts and measures that promote minimum flow resistance
- The use and the wrong selection of couplings, mechanical drives and gears, and belts can reduce the whole system's efficiency. The audit can help to avoid or replace such inefficient versions.

3.2 Utilities energy efficiency

3.2.1 Steam distribution system and end-use

Ensuring an efficient steam distribution system, schematically indicated in Figure 43 (U.S. DoE EERE, 2005), promotes an energy-efficient boiler operation. It is fundamental to (Einstein, Worrell and Khrushch, 2001) understand baseline metrics such as cost of steam generation and distribution before moving on to steam-related energy-saving measures. Industry-focused organisations such as The Carbon Trust have produced guides to understand and estimate costs for a steam generation (Action Energy, 2003) and steam distribution (Action Energy, 2004c). Having steam meters can provide more accurate information towards these, as suggested elsewhere (The Carbon Trust, 2005d; b; Spirax Sarco, 2011). The efficiency of a steam system can be determined mathematically, as given in Equation 9 below (Siddhartha Bhatt, 2000).

Equation 9

$$\eta_o = \frac{\eta_b \eta_l \eta_u}{\eta_r}$$

Where η_b is the boiler efficiency, η_l is the efficiency of the steam line, η_u is the useful task efficiency and η_r is the factor of un-recovered condensate

Designing a steam system audit method for energy saving researchers suggest and calculate heat recovery from flash steam and condensate (Gajjar, Ghodke and Kumar, 2012). The steam distribution system offers numerous areas for efficiency improvement such as, prevention of steam leaks, insulate distribution system (U.S. DoE, 2012i; The Carbon Trust, 2005b), use of appropriate steam traps, regular maintenance (U.S. DoE, 2012g), condensate recovery, eliminating redundant steam distribution pipes (The Carbon Trust, 2012d), and decentralising and rationalising steam supply where possible. Guidelines such as US DoE’s Best Practice Manual on issues on reducing steam pressure in a distribution system (U.S. DoE EERE, 2005) have been out, for example points of heat losses indicated in Figure 43.

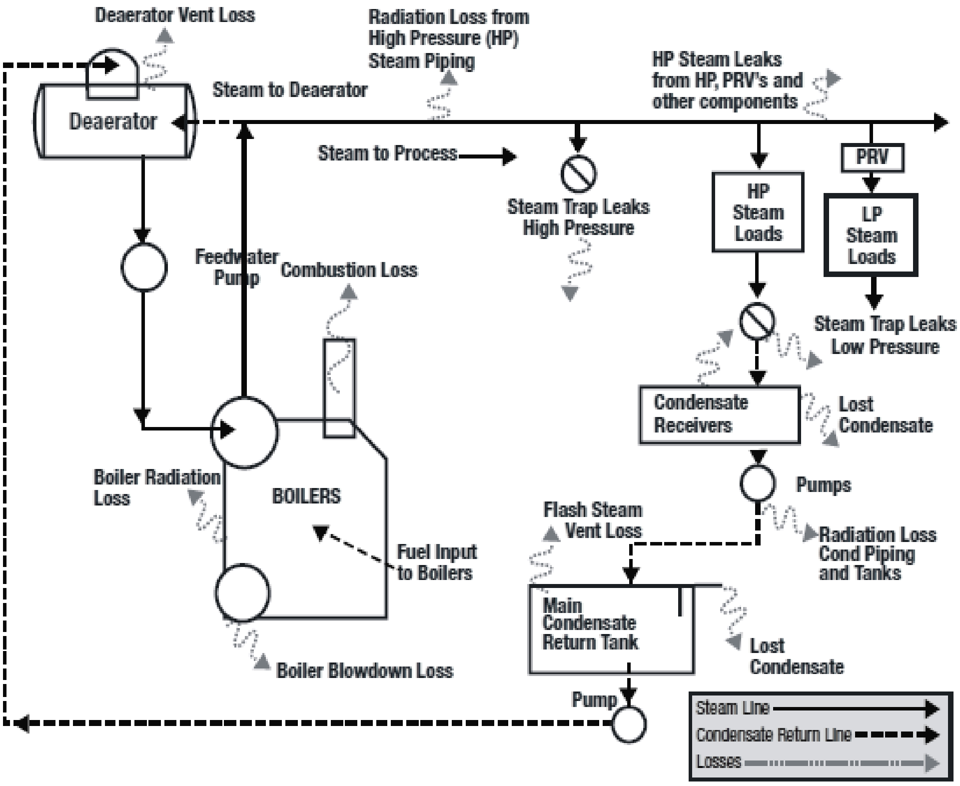


Figure 43 - Steam distribution system losses, (U.S. DoE EERE, 2005)

Alongside the efficient steam distribution system, efficient end-use is equally important. HE systems are the key thermal energy transformers at the end-use. Normally, the potential for further performance efficiency improvement exists (U.S. DoE EERE, 2004). Other ways of improving it also exist for example, direct use of super-heated steam for paper and textile drying is more energy efficient (van Deventer, 1997). This can be further improved by recovering energy from the wasted steam. Using heat pumps for recovery at the end-use, as discussed in Section 3.1.3.2, have also been advised (U.S. DoE, 2003c). Major end-uses of steam in textile buildings and the associated energy efficiency measures are discussed in Sections 3.1.2, 3.1.3, and 3.2.3. Generally, the steam is supplied through coils, therefore, condensate can be recovered, as discussed in Section 3.1.3.1 and shown in Figure 44.

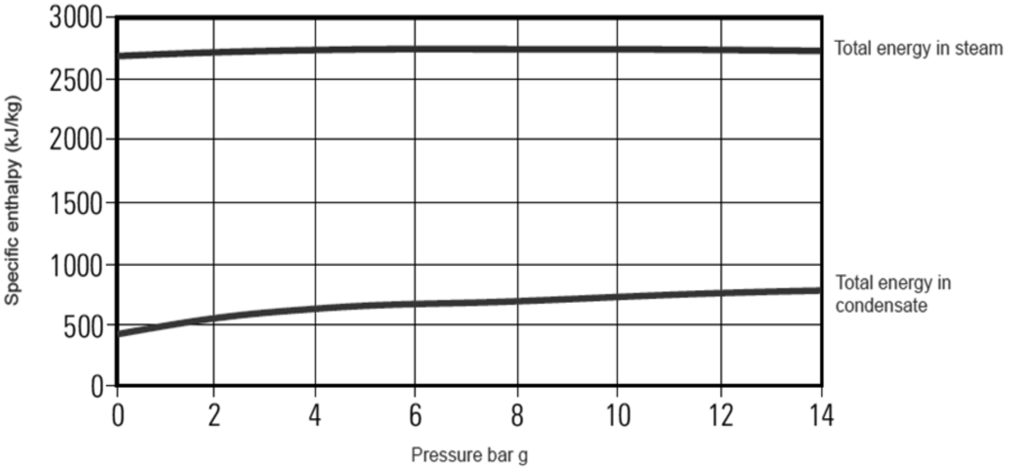


Figure 44 - Condensate energy recovery potential at various pressures, (Spirax Sarco, n.d.)

For a steam system, when shifting from components such as pipes, traps, and flash vessels to a whole system (analysing supply and demand), there will be a different picture of saving measures. It also suggests that focusing on individual components can sometimes distract from the major/broader issues that can only be identified/rectified when addressed through a system approach (U.S. DoE EERE, 2004), some of which are discussed in Section 3.1.1. Performance improvement of the steam systems has also been addressed strategically, for example in ISO-50001 energy management system. Online guides and training, such as the USA Advanced Manufacturing Office (AMO) Energy Resource Centre’s website comprehensive steam system assessment tool, are also available.

3.2.2 Compressed air system

The CA is referred to as the fourth industrial utility due to its versatility and usefulness. It is expensive to produce as only 10% of the total energy is converted into useful CA (Burgess, 2013). A five-year analysis of a new CA system indicates that electricity contributes 80% of the total life cycle costs (Liebenberg, Velleman and Booysen, 2012). CA is responsible for 10% of industrial electricity use in the EU and 10% of the total industrial energy use in the USA. The UK’s annual CA energy usage is 10TWh (Saidur, Rahim and Hasanuzzaman, 2010). In the textile industry its various uses include clamping, agitating liquids conveying, controls and actuators, automated equipment, spinning, loom jet weaving, and texturizing.

CA systems have a number of components including compressors, air receiver/pressure vessel, air dryer, filters, and condensate traps (for water, oil, and solid particles removal), a fixed pipe- net-work for CA delivery, and possible flexible hoses.

Simple conservation measures can save considerable CA energy and cost (Saidur, Rahim and Hasanuzzaman, 2010).

The end-use and the pressure in a CA system vary all the time, therefore adequate system type and design are required. Two dominant factors, the size and the control type of the compressor determine the cost of the CA. Oversized compressors and working at inefficient control modes increase operating costs (Saidur, Rahim and Hasanuzzaman, 2010). Improved control and system maintenance can significantly reduce the operating cost (Building Research Establishment, 1998). Mainly two types—displacement- and turbo-compressors are used in the systems (Peltomaa, 2010).

Discussing efficiency improvement (Abels and Kissock, 2011) highlight points like fundamental storage relation, the effect of cycle time and volume on storage, sizing storage vessels for effective volume band, and minimising cycling time. End-use savings and a thorough investigation about pneumatic actuators are comprehensively studied by (Harris, Nolan and O'Donnell, 2014). Countrywide impact of CA best practice programme is reviewed by (Neale and Kamp, 2009) with a literature review on energy-saving opportunities and payback calculations elsewhere (Saidur, Rahim and Hasanuzzaman, 2010). According to the Carbon Trust (2005a) up to 30% energy savings can be made by reducing the avoidable waste and without the need for capital investment in new technologies. Small- to medium-sized industries can save up to 15% CA cost with saving investments having less than two-year payback (E. Source, 2007).

Researchers enlist key data needed for the CA system's energy audit, shown in Table 18 (Saidur, Rahim and Hasanuzzaman, 2010). A system approach can be highly effective to improve and maintain peak CA system performance (U.S. DoE, 2003b) and (U.S. DoE, 2004b). Neale and Kemp divide CA system energy savings into two areas: demand-side savings having five key elements namely, air leaks, artificial demand or inappropriate use, peak demand management, pressure minimisation, and distribution inefficiencies, and supply-side savings having four key elements namely, compressor operation and control, environmental control (air intake and operational conditions), system ancillary equipment (driers, drains, etc.), and installation of new technology (Neale and Kamp, 2009).

Table 18 - Data required for a CA system energy audit

No.	Parameter
1	Load factor
2	Production figure
3	Power rating
4	Power factor
5	Efficiency at given LF
6	Efficiency adjusted to that at 75% of LF
7	Duty factor (hours of operation/year)
8	Motor load profile
9	Utility bill
10	Demand uses
11	Peak and off peak usage hours
12	Mass flow rate of air
13	Temperature
14	Pressure

Air leaks, which is the first demand-side management element, can be responsible for 20–30% of compressor output (U.S. DoE, 2004b) or 40%–50% or more for unmanaged systems (Neale and Kamp, 2009). Alkadi and Kissock noticed that the larger reduction in leakage during weekends resulted from shutting off branch-headers, and hence starving multiple leaks with a single action when production lines were not in use (Alkadi and Kissock, 2011). *Artificial demand* is the inappropriate use of CA for applications that can be cheaper to run on other forms of energy e.g. electricity. Several studies (The Carbon Trust, 2005a; U.S. DoE, 2003b, 2004e) provide a list of such inappropriate applications like pen blowing, sparging, and padding. *Peak demand management* gives an idea of matching the air supply with varying demand to maximise the compressor efficiency. Compressors when operating at full load are more efficient, and the off-load power demand can be 20%–70% of the on-load power (The Carbon Trust, 2005a). A properly managed supply-side will ensure stable with appropriate pressures, clean, and dry air delivery. Interesting CA peak demand management related savings studies have been carried out elsewhere (Liebenberg, Velleman and Booysen, 2012; U.S. DoE, 2004i, a; f). *Pressure minimisation* is optimally reducing the discharge pressure without affecting the end-use machines' efficiency. Despite most of the technologies requiring a pressure of 6.3bar or below, setting the CA system pressure at 7bar is a common practice (Building Research Establishment, 1998). This is due to a general 0.7bar (10%) pressure drop in the system (The Carbon Trust, 2005a). This demand management criterion for industries where the machinery use pressure below 6bar and the pressure drop is well below 0.7bar may therefore not be optimal. These sites can be good candidates for savings based on a rule of thumb that a reduction of 1bar can save 3% on energy cost (Neale and Kamp, 2009). Another study reveals that reducing the pressure by 0.5bar can reduce the cost by 3–4% (The Carbon Trust, 2012b). In addition to increasing the production cost and leaks, higher pressures cause greater volume expulsion. If pressure is regulated i.e. at 5.5bar, for conventional equipment requiring this level of pressure 14% can be saved on CA related energy consumption. This savings can become 24% if a further reduction of 0.5bar is achieved (Building Research Establishment, 1998). For some hand-held tools pressure-related health and safety restrictions exists for example, for air guns, the maximum allowed discharge nozzle pressure is 2.2bar (The Carbon Trust, 2012b; U.S. DoE, 2003b). Also, fitting a venture nozzle with these guns can save even more, up to 60% compared to a conventional air gun, with more quiet and safer operation (The Carbon Trust, 2012b; Saidur, Rahim and Hasanuzzaman, 2010).

A good example of *distribution-related inefficiencies* is related to storage tank resizing. The distribution related pressure drop should not exceed 10% of the compressor header pressure. Extra-long pipe work, inappropriate pipe size, sharp bends, inappropriate junctions should not be narrower than the diameter of the supply pipe, the wrong type of isolation vales e.g. butterfly type instead of ball type has an impact on the overall distribution efficiency. It is generally advised that these things should be carefully considered in the event of any future works on the distribution system.

For *compressor operations and controls* which is the first element of supply-side management various types of systems such as start/stop, load/unload, inlet air modulation via throttle valves/control vanes, and variable speed controls for centrifugal compressors, have been identified (Liebenberg, Velleman and Booysen, 2012). Schmidt and Kissock discuss similar controlling strategies for available displacement air compressors. In auto-dual control, a combination of modulation and load/unload control allows the compressor to operate in modulation control down to a specified pressure and switches to a load/unload control below this pressure to enhance and maximise the efficiency (Schmidt and Kissock, 2003). Detailed optimum controlling strategies are discussed in (U.S. DoE, 2004b) and speed controlling through VSDs in many cases is ideal (CASE, 2011).

The *environment* around the compressors and the intake air should be temperate and clean. As a general rule, every 4°C temperature rise in the intake air can decrease the compressor’s efficiency by 1% (Burgess, 2013; The Carbon Trust, 2005a). This effect is pronounced more for centrifugal air compressors and is less for rotary-screw air compressors (U.S. DoE, 2004d).

Different types of *dryers*, typically desiccants, deliquescent, and refrigerated types are used in CA systems. A refrigeration dryer uses only 3% of the energy which a compressor needs for CA production (The Carbon Trust, 2012b). A CA receiver is a kind of treating device which removes condensate with minimal air loss (U.S. DoE, 2004h). Zero-loss electronic condensate drain valves are more efficient than manual valves. The dryer inlet air temperature should not exceed 35°C otherwise it will reduce the capacity of the drier, for example at 40°C there will be a 20% capacity reduction. It is advisable that on the event of the rise in the temperature of the inlet air the flow of the cooling air should be increased.

The improper or ineffective function of traps can result in them being left open and can allow pressure drops or condensate back into the system. Therefore, their periodic inspection and cleaning is essential. Filters in the distribution system are another area for such inspection. Good quality air regulators can improve the delivery as well as better air control that reduce air waste due to poor control (Saidur, Rahim and Hasanuzzaman, 2010). Storage enables better control of pressure and air fluctuations during peak-demand periods. Additional pressure/flow controls at end-use can help to improve the receiver's and systems' efficiency (U.S. DoE, 2003b). *New advanced and efficient compressor* types are available with more tailored air production capacity and multiple control options.

Waste heat recovery is already discussed in Section 3.1.3. A significant part of this waste heat, from 50 to 90%, can be used for water or air heating purposes (U.S. DoE, 2003b; Saidur, Rahim and Hasanuzzaman, 2010; The Carbon Trust, 2005a, 2012b). From this air and air/water heat recovery system can produce up to 80°C of hot water. Whereas for air/air recovery system an up to 95°C hot air can be obtained (EEBPP, 1998). £5,000 for gas or £21,000 on electricity savings can be made through heat recovery on a compressor with a 55kW motor (gas rate at £0.045 and electricity rate at £0.08) (EEBPP, 1998).

3.2.3 Heating, ventilation, and air conditioning

HVAC systems mainly consist of HE, motors, and compressors. The efficiency opportunities for these are discussed in Sections 3.1.1, 3.1.3, and 3.2.1. However, some strategies, listed below, can help to enhance the savings further.

- Controlling the HVAC system through BMS

- Changing the thermostat setting to save energy
- Reducing the cooling load by improving lighting efficiency
- Ensuring buildings draft proofing and allowing infiltration not more than prescribed air change rates

3.2.4 Lighting

Low-level (under five-metre) (The Carbon Trust, 2006a) artificial lighting is mostly used in non-domestic and manufacturing buildings. To identify efficiency opportunities, the fluorescent tube lights and light emitting diodes (LED) are discussed.

Currently, over 33 billion lamps demanding over 2,650TWh/annum (19% of global) are operating (IEA, 2010) of which industrial buildings can be responsible for 5%–25% demand (Myer, Paget and Lingard, 2009; Yacout, El-Kawi and Hassouna, 2014). In the UK, artificial lighting demands 20% of the total electricity (The Carbon Trust, n.d.) with many industrial facilities having inefficient lighting (Lee, 2000). When compared with newer efficient lighting technologies 75% of the UK installations are out-of-date (The Carbon Trust, 2011) which indicates saving potential. Up to 82% of lighting related energy use can be saved by using efficient technology (NSW Government Australia, 2014). Many industry focussed organisations have established building lighting/energy best practice exercises/benchmarks.

Though relatively straightforward, lighting retrofitting calculations are often misguided by diversity factors and running hours resulting in less-accurate energy consumption/saving estimations. To reduce such uncertainty measuring based lighting monitoring has been adopted elsewhere (Lee, 2000; Menezes et al., 2014). A 50% reduction in lighting energy through efficient lighting installation and daylight harvesting has been demonstrated through simulation (Energy Saving Trust, 2006).

For a basic understanding, defining lighting terminology is helpful. Light output is given in lumens or lumens/m^2 (lux). A fixture's utilisation factor, UF, determines the actual quantity of the produced light reaching the horizontal work plain. Illuminance equates to luminous flux/unit area. The lamp efficacy refers its quantitative ability to produce lumens/unit (lm/W). The maintenance factor of a fixture/tube (MF) refers to efficacy/performance reduction over time. Luminaires/fixture (or lighting systems (U.S. EPA, 1997) are the apparatus/fixture generally used for lamp holding, heat sinking, and light reflection and can contain control gear/driver/ballast, a reflector, and a diffuser for light uniformity, and sensors/controls.

3.2.4.1 Components of a lighting system

Various types of lamps have forms, usage, and efficiencies, some common types are shown in Table 19. Three fundamental characteristics—performance, appearance, and control are considered, as guided in (SLL, 2012b) for a better selection of the lamps.

Table 19 - Common lamps types and uses, (SLL, 2012b)

Lamp type	Usage	Average life (hours)	Colour rendering (Ra)	Efficacy lm/W
Tungsten filament lamps (GLS)	Bedrooms, bathrooms, kitchens	1,000	100	8—14
Tungsten halogen	For display and security	2,000-4,000	100	15—25
Fluorescent tubes	For office, manufacturing sheds	5,000—15,000	82—95	20—93
LEDs	For low-level lighting as well as for low- and high-bays	15,000—60,000	40—85	30—100

The control gear is a component of most lighting systems. Ballasts, which are the control gears for lamps are used to harmonise voltage and power flow to ignite the arc in a lamp. These have two main types: electromagnetic (older, higher parasitic energy) and electronic/high-frequency. Electromagnetic ballasts can add up to 0.2% of the lamp's rated power to the circuit watt (BSI, 2007). These, delivering lower lamp efficacy, can cause more flicker and a humming sound. Electronic ballasts use less energy (2W approx.), deliver better lamp efficacy, less noticeable flicker and noise, and can last for up to 50,000 hours (NSW Government Australia, 2014). Electronic ballasts can be dimmable and operate at a near perfect power (=~1) factor. Ballast factor determines the relative light output of a combined lamp-ballast system when compared to the manufacturer's rated light output for the specified lamp (Taylor, 1993). Using the right lamp-ballast combination intelligently can help to reduce the number of luminaires (Action Energy, 2004b). Better heat sinking performance enhances the lamp's and control gear's life. LED systems are normally manufactured as a complete luminaire. Luminaires produced by A-class manufacturers may be expensive but are mostly backed up with better research, design, and materials.

Control systems can mean switches/sensors and auxiliary systems to turn the light on/off and reduce operating times. Such manual/automatic controls can save 30–50% energy cost (The Carbon Trust, n.d.) as given elsewhere (Haq et al., 2014). Better control in most cases can increase the system's life expectancy but inappropriate use, i.e. too many on/offs (impractical for luminaires with longer strike times), can deteriorate the lamps. Zone lighting, occupancy scheduling, and nighttime load shedding are some controls triggered saving strategies. Daylight harnessing (i.e. sky panels and fenestration, and lighting level linking to it) is widely used where appropriate. Time delay switches and BMS are also used for such controlling. A large number of factors dictate controlling strategies such as lighting levels, activity, individual personal requirements, and temperature (NSW Government Australia, 2014).

3.2.4.2 Key low-level lighting technologies

A large variety and forms of fluorescent lamps is widely used for low-level lighting. The latest such example is multi-layered phosphor (tri-phosphor) offering longevity and more and brighter light. Replacing phased out T12 (38mm diameter) with T8 (25mm diameter) tubes can save in the region of 10% of energy consumption. T5 (16mm diameter) linear tri-phosphor tubes, which normally come in 5ft., giving up to 104lm/W can last up to 30,000hours and can reduce up to 40% energy use as compared to T12 (Dubois and Blomsterberg, 2011). The bulk replacement for these tubes is 24,000-hour as compared to 13,000-hour for T8. T5 are slightly dearer, do not fit in the existing fittings of 5ftT8, and only use electronic ballasts. Therefore, needing replacement of the whole fitting for most retrofits can significantly increase the project cost. However, the efficacy and longevity often prove them attractive energy-efficient option.

LEDs are popular for high efficacy and longevity (up to 100,000hours) (SLL, 2012b). Their efficacy is consistently improving (200lm/W at present) (El-Zein, 2014) Their increasing reliability and a choice of variety and forms make them a viable alternative to fluorescent tubes. However, making a reliable LED luminaire is based on technology, research, and development. These steps help to reduce overheating, and improved light and colour rendition (El-Zein, 2014). A large number of LED manufacturers have been embroiled in extensive litigation (Sanderson and Simons, 2014) for sub-standard products. Such threats have already been addressed through improved product standards such as IESNA LM-95 and manufacturer and consumer awareness raising guides for the technology (LLLG, 2012).

Many a times LEDs can be ideal for new buildings but are generally not recommended even for the florescent tube retrofitting due to design complexities. For example, most of the LED tube lights are directional hence would not be a true like-for-like representative replacement (El-Zein, 2014). The higher efficiency of individual fixture components results in a higher efficiency of the luminaire. For example, LED chips with 100lm/W efficacy when implanted in a fixture that has 90%, 80%–92%, 85% optical, driver, and thermal efficiency respectively, will end-up with 76lm/W efficacy

(El-Zein, 2014). Researchers elsewhere (Duff, Kelly and Whitty, 2014) suggest that the growth of LED products is based on three reasons, namely: 1) immense capital investment in product development resulting in a rapid development; 2) exceeding regulators' interest seeing them as the ultimate efficient lighting solution; and 3) fashion. Since the technology is continuously evolving, many substandard products are still being sold. Unlike the fluorescent tubes, there is a lack of standardisation/specification for this market. Most of the products confirm conformities like RoHS (restriction on hazardous substances), CE (European conformity), ISO9001 and 14001, and IP. These are more about manufacturing management, product safety, and environmental stewardship but have little evidence of MF, endurance, and delivery of service over a lifetime. IESNA (Illumination society of North America) created IESNA LM-95 to address this problem. Recent years has seen further developments, for example, IESNA has developed advanced methods such as IESNA-LM-79-80 and IESNA LM-80-80 (for MF and projected lifetime). To facilitate a better LED procurement decision (Duff, Kelly and Whitty, 2014) indicate a set of questions, ensuring product quality.

As mentioned in Section 3.2.4.1, both fluorescent tube and LEDs can be used for similar applications, but authors like (El-Zein, 2014) show concerns about the effectiveness of the LED system. Arguing about LED retrofit projects elsewhere (NSW Government Australia, 2014), the authors strongly negate replacing the fluorescent lamps with LED lamps due to design and other complexities. Some LED manufacturers argue or imply that due to design and directionality (El-Zein, 2014), LED products can achieve equal or better overall lumens compared to fluorescent products (Myer, Paget and Lingard, 2009). This in certain cases can help to reduce the number of fluorescent tubes specifically the ones without reflectors. Another potential lighting energy saving measure is T5 lamp adapters for T8s. In countries like Australia, New Zealand and in some European countries these adapters have been found to be non-compliant to essential safety requirements such as protection against electric shock (ERAC, 2011)[1]. Therefore, care must be taken before installing.

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[1] "Recent enforcement actions on LED Tubes or T8/T5 fluorescent lamp adaptor replacement tubes by Safety Regulators in Australia, New Zealand, and countries in Europe have shown instances where these products do not comply with essential safety requirements, such as protection against electric shock. In Australia and New Zealand these safety principles are specified in AS/NZS 3820 (*Essential Safety Requirements for Low Voltage Electrical Equipment"*. This Information Notice was superseded by AS/NZS60598.2.1:2014, Including Amendment 1:2016.

3.2.4.3 Lighting efficiency opportunities

Due to lighting systems/components advancements, even small changes to existing systems can help to uplift the overall (Myer, Paget and Lingard, 2009; Yacout, El-Kawi and Hassouna, 2014). For such investigations and retrofitting lighting audits and surveys have been designed and advised (Fact Sheet, 2003; SLL, 2012a). More efficient/cost-effective lamp/technology e.g. T5 and LEDs are available. Improving control and controlling strategies, which can vary from site-to-site, is another efficiency improvement supporting area. Whereas, general strategies such as last to leave the switch off, and individually controlling task lighting can effectively and universally be utilised, as discussed elsewhere (The Carbon Trust, 2005c). The lighting energy in office buildings, based on 2000h/year ranges between 20–27kWh/m^2/year, the difference indicates the saving potential through controlling strategies and efficient lighting installation (Dubois and Blomsterberg, 2011).

Achieving energy efficiency without compromising the lighting levels is possible through various approaches. For example, in many cases, it is seen that the building lighting levels are much higher than the required amount (e.g. lux/m^2 in SLL guide). This situation may be due to multiple factors like evolutionary lighting installation, office setup change/machinery relocation, or more lighting in response to low-visibility complaints. This can be handled through different measures, e.g. behavioural change by accepting acceptable levels, scheduled maintenance and cleaning, and relocating lighting along with office/machinery. Studies have shown that lighting levels even below CIBSE’s (SLL) benchmarks can be sufficient (Dubois and Blomsterberg, 2011). Use LPD (lighting power density) indicators e.g. LENI (Lighting Energy Numeric Indicators) (Dubois and Blomsterberg, 2011) as defined elsewhere (EEBPP, 2002; SLL, 2012b) or target to reduce your own LPD against the baseline. Absence of lighting maintenance can reduce levels by 30% from the second to the third year of installation. In addition to maintaining a better environment, a basic lighting maintenance programme can reduce costs by up to 15% (The Carbon Trust, 2010b). However, such savings is generally possible for buildings where lighting shares a major part of the demand for example office, hospital, and academic buildings. For manufacturing, specifically where the highest demand is process energy, achieving such a high percentage might not be possible. However, savings in relation to the share of the lighting energy can still be significant. A lighting refurbishment programme should always be followed by a regular maintenance schedule. This includes cleaning of wall surfaces, windows, and skylights as well as reflectors and panel diffusers to optimise lighting performance. For a high maintenance degree, bulk fluorescent tube replacement have been recommended after every 10,000hours for T8s (Dubois and Blomsterberg, 2011) or after 80% of the lifetime of T5s (NSW Government Australia, 2014).

In addition to daylight harnessing and skylights, modern techniques to capture and transfer daylight into the desired location are used (The Carbon Trust, 2012c). Dimmers to increase/decrease the light in response to rise/fall in the daylight can be used for persistent lux levels. Dimmers and compatible drivers and lamps can be utilised to fulfil the lighting needs (Dubois and Blomsterberg, 2011). Studies using such daylight harnessing techniques have shown a significant reduction in lighting energy demand (Krarti, Erickson and Hillman, 2005). As minimum energy is lost in producing heat in energy efficient lighting so these can help to reduce building cooling cost.

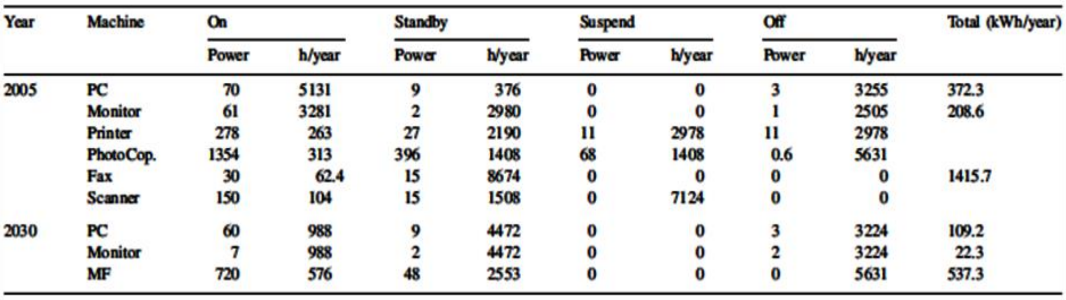
3.2.5 Information technology

Electronic equipment (collectively called IT or business equipment) play a key part in information processing, communication, and data storage in all types of non-domestic buildings. The business equipment relevant load is known as the plug, non-hard wired, and “unregulated” as shown in Table 20 (California Energy Commission Public Interest Energy Research Program in a presentation elsewhere (Higgins, Mercier and Calwell, 2012)). However, this study will refer to general IT equipment (as mentioned in Table 21). Business equipment demands 15% energy in office buildings and by 2020 it is expected to rise to 30% (The Carbon Trust, 2006b). This has led researchers, and policy- and equipment-makers to encourage energy-saving and labelling projects. For example, assessing the IT-related heating/cooling load in buildings, (Jenkins, Liu and Peacock, 2008) emphasise the necessity of energy efficient IT equipment. Based on current ratings at different operating modes, as shown in Table 21, they try to relate future IT energy use in buildings with heating/cooling loads.

Table 20 - Business equipment in general

Office equipment	White goods and other
Computers and monitors	Vending machines
Small power supplies	Large coffee machines
Speakers	Other appliances
Copiers and multi-function devices (MFDs)	Space heaters
I-items	Task lighting
	Servers

Table 21 - Prevailing and projected IT equipment efficiency ratings



Year	Machine	On		Standby		Suspend		Off		Total (kWh/year)
		Power	h/year	Power	h/year	Power	h/year	Power	h/year	
2005	PC	70	5131	9	376	0	0	3	3255	372.3
	Monitor	61	3281	2	2980	0	0	1	2505	208.6
	Printer	278	263	27	2190	11	2978	11	2978	
	PhotoCop.	1354	313	396	1408	68	1408	0.6	5631	
	Fax	30	62.4	15	8674	0	0	0	0	1415.7
	Scanner	150	104	15	1508	0	7124	0	0	
2030	PC	60	988	9	4472	0	0	3	3224	109.2
	Monitor	7	988	2	4472	0	0	2	3224	22.3
	MF	720	576	48	2553	0	0	0	5631	537.3

The different IT equipment running modes (power management), in Table 21, have been defined by (Roth, Larocque and Kleinman, 2002), as shown in Table 22, where "active" is equivalent to "on" in Table 21. Different IT equipment may have variable energy demand at the same mode, for example with the "on" mode. This can be based on various reasons such as technological advancements (based on year of manufacturing (YOM)) like hardware involved as indicated in Figure 45. Another example is the LED-based more advanced monitors as compared to the generation before. It can also be based on the software and the job it undertakes. For example, a PC (personal computer), when processing information (reading/writing data) through an inbuilt CD/DVD player, may have slightly higher energy consumption than when being operated for word processing, as suggested by (Stefanek, Harder and Bradely, 2012).

Table 22 - Office equipment operational modes, (Roth, Larocque and Kleinman, 2002)

Mode type	Description	Example
Active	Device carrying out intended operation	•Monitor displays image •Copier printing
Stand-by	Device ready to, but not, carrying out intended operation	• Monitor displays screen saver • Copier ready to print
Suspend	Device not ready to carry out intended operation, but on	• Monitor powered down but on • Copier powered down but on
Off	Device not turned on but plugged in	• Monitor off, plugged in • Copier off, plugged in

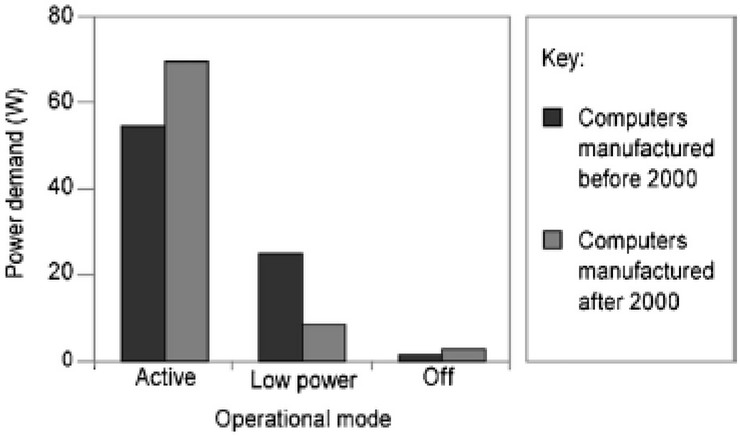
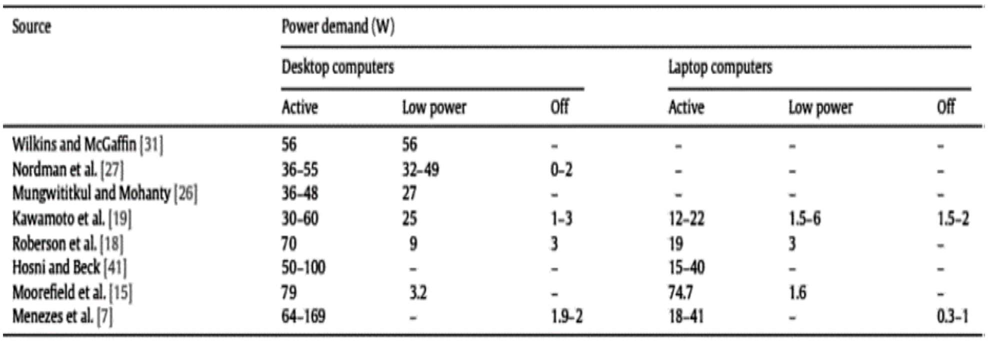


Figure 45 - YOM based change in rated power, (Menezes et al., 2014)

The complexity of these running modes is an interesting area for load estimation studies. It can be assumed that operating on such variable modes modern IT equipment can become (overall) more energy efficient. This IT-related load demand variation can be significantly high/low for office/other buildings. However, for manufacturing buildings, such load variation differences are likely to be less noticed, unless measured, when compared with larger quantity/loads of the process machines. Such differences can be noticed through measured versus rated power. Even these types will show different outcomes when assuming steady-state and transient conditions. For non-measuring based assumptions, generalising identical technologies as having the same demand (rated-power estimations) will have its own implications.

Studies based on measured data have been carried out such as (Hosni and Beck, 2011). Since office work-patterns are quite consistent, so are the running of IT and services related equipment. Therefore, different load calculations methods, demand segregation of different equipment, and identifying efficiency opportunities have been designed elsewhere such as (Menezes et al., 2013). The researchers use smart meters through the Zigbee wireless protocol to identify the small power equipment loads. They utilise existing sub-meters for HVAC and other building facilities' loads segregation and recommend saving measures. Monitoring computers, printers, and fridges demands in a university building (Stefanek, Harder and Bradely, 2012) use SmartPlug meters from a company—AlertMe. They find out that it is possible to accurately measure a desktop's CPU (central processing unit) through monitoring. Menezes et al., propose an innovative method for buildings' small power-related load estimation. They suggest some new IT equipment demand figures at different operating modes (Menezes et al., 2014). Researchers (Wang and Ding, 2015) determine occupancy-based IT equipment load by designing an occupant based energy consumption model. However, the estimated power demand for PCs and laptops in different studies vary significantly, as mentioned by (Menezes et al., 2014) (shown in Table 23). This can be either due to the differences in the method or the data sources.

Table 23 - Laptops and PCs demands at different modes



Source	Power demand (W)					
	Desktop computers			Laptop computers		
	Active	Low power	Off	Active	Low power	Off
Wilkins and McGaffin [31]	56	56	-	-	-	-
Nordman et al. [27]	36–55	32–49	0–2	-	-	-
Mungwititkul and Mohanty [26]	36–48	27	-	-	-	-
Kawamoto et al. [19]	30–60	25	1–3	12–22	1.5–6	1.5–2
Roberson et al. [18]	70	9	3	19	3	-
Hosni and Beck [41]	50–100	-	-	15–40	-	-
Moorefield et al. [15]	79	3.2	-	74.7	1.6	-
Menezes et al. [7]	64–169	-	1.9–2	18–41	-	0.3–1

Figure 46 shows the proportion of total IT demand in a small office. PCs and monitors are the largest energy consumers (relatively typical). However, the Figure does not show operating conditions or the number and the type of equipment. Compared to a complex industrial site, it is relatively less complicated to distinguish between different (IT equipment) streams in these buildings. The increase in IT equipment and associated energy use can be realised from the estimated increase in worldwide computers as shown in Table 24. The power related to networking and internet service providing is estimated to be 52.4TWh (Lambert et al., 2012).

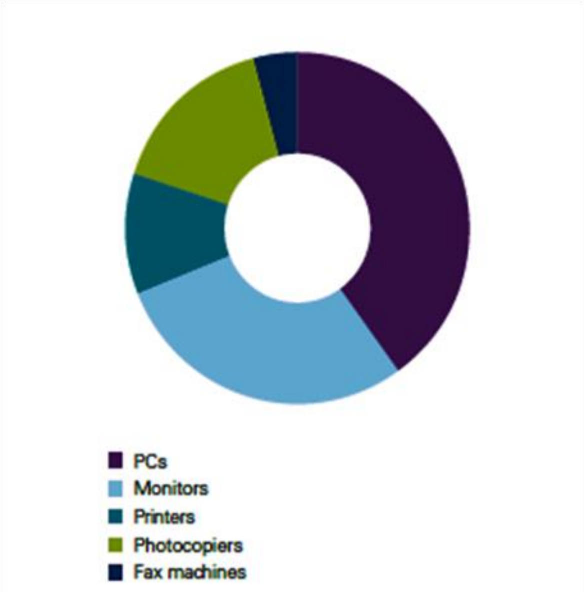
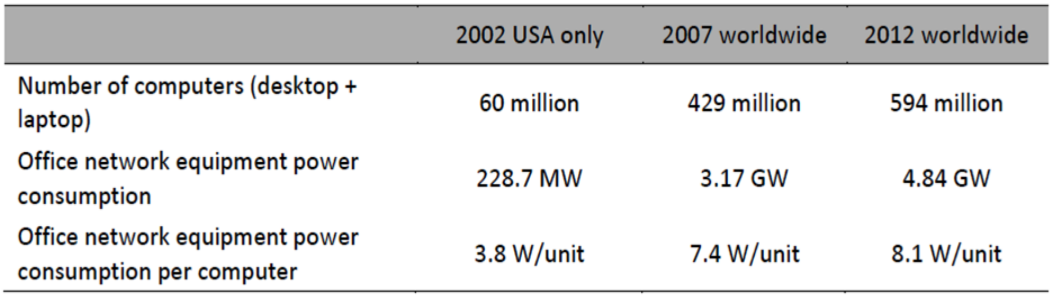


Figure 46 - IT equipment energy demand share in a small office, (The Carbon Trust, 2010b)

Table 24 - Worldwide computers and their power demand (Lambert et al., 2012)



	2002 USA only	2007 worldwide	2012 worldwide
Number of computers (desktop + laptop)	60 million	429 million	594 million
Office network equipment power consumption	228.7 MW	3.17 GW	4.84 GW
Office network equipment power consumption per computer	3.8 W/unit	7.4 W/unit	8.1 W/unit

Table 25 shows the average nameplate demands of individual sets of the observed equipment (Hosni and Beck, 2011). The figures are quite reasonable apart from the nameplate average ratings for desktop computers and flat panel monitors. These seem to be higher than the existing technology nameplate ratings. In another study (Wilkins and Hosni, 2000) the nameplate power consumption for all monitors ranged from 168W–565W and that for the computers was recorded to be from 165W–759W. The study carried out in 2000 may be representing a stock of older and newer generation computers (Energystar® and earlier types). This can be a valid estimation criterion, even post 2000, for many existing organisations, specifically manufacturing sites where more investment may be carried out on the manufacturing machinery, than IT equipment. According to Menezes et al,. (2014) as shown in Figure 45 the newer generation computers use more power, in active mode, as compared to the older generation. This can be assumed from these studies that due to variation in technology characteristics higher/lower nameplate rating may have little to do with actual demand. This can be seen in the Table 25 and Figure 45. The higher average values for flat-panel monitors may be due to the inclusion of large size (up to 30”) monitors. Due to the scope of the enquiry and simplicity of the calculations IT operating characteristics have been generalised, based on the Table 25. This is based on the assumption that everything is running on a permanent basis during working hours.

Table 25 - Averaged IT equipment power demand, (Hosni and Beck, 2011)

Equipment	Nameplate average demand (W)	Actual demand (W)
Desktop computer	708	68
Laptop computer	87	25
Flat panel monitor	312	52
Laser printer	719	106
Multifunction (copy, scan, print)	447	60

To design IT equipment related energy policy, strategy, and investment proposals guides on office equipment energy efficiency measures and strategy (The Carbon Trust, 2006b, 2010b; EEBPp, 1996) and benchmarking (EEBPp, 2000) have been formed. These can be utilised for various purposes like a no-cost IT energy strategy based on switching-off after use awareness-raising, and special attention on the IT equipment procurement process, as discussed in Chapter 2. Promoting considering the running cost instead of just capital cost. Centralising IT printing/scanning services, for example, a copier when active generally uses between 1.4kW–1.6kW and 0.04–0.07kW when on standby (The Carbon Trust, 2006b). Also, various features of the IT equipment can be adjusted/optimised to encourage energy saving, such as double-sided printing.

Laser printers are known to use more energy than inkjet equivalents. The energy efficiency can be further enhanced by choosing Energystar® or other types of energy efficiency labeled brands. Most of the power used by printers and copiers is to melt the ink, therefore inks that melt at low temperatures can be selected. As most of the heat from these machines is dissipated into the immediate environment, that can increase cooling load too. Looking at less prominent equipment, vending machines that often have a 24hrX7days operation can be switched off during non-office hours. Many of them have a separate light button, which can be switched off after working hours.

3.3 Renewable energy technologies

Onsite energy generated specifically from renewable sources is helpful to reduce the load on the national grid, process carbon emissions, and overall energy cost. RE energy technologies are used for both micro- and macro-power power generation (Manish, Pillai and Banerjee, 2006). Some low-carbon energy technologies, such as heat pumps, as discussed in Section 3.1.3.2, and cogeneration/combined heat and power (CHP) are also useful to achieve similar goals. A variety of technologies and methods, each having specific characteristics and applications, are available to be tailored for a specific purpose. The topic is out of the scope of the thesis however a brief review will be helpful to understand the RE technologies' importance for similar projects. Unlike fossil-fuel based electricity generation, that has a lower risk of a flow interruption, energy from most of the RE technologies is periodic (e.g. PV based on daylight) or unpredictable (wind turbines). In addition to that, RE electricity management may demand numerous technical requirements. For example, power storage, along with reactive power and voltage control is required for large numbers of turbines and PV sources. Only key RE technologies that can generally be used in industrial sites are briefly discussed below. With regards to the scope of the study, no installation suggestions for such technologies have been made.

3.3.1 Biomass

Biomass is an attractive source of RE as during its lifecycle the carbon or CO2e produced gases are recycled back into biomass, as shown in Figure 47 (Srirangan et al., 2012). According to Srirangan et al, (2012) it can be classed into three types/generations as shown in Table 26. With typical examples of sugarcane, wheat, and oilseeds the first-generation feedstock comes from edible materials i.e. agricultural crops. The second-generation feedstock is non-edible agricultural and forestry waste and residues. The third-generation feedstock is photosynthetic and fermentative bacteria and algae. These can be produced in bioreactors without needing a large-scale cropland. Research is being carried out to seek out better species with more mass and energy output.

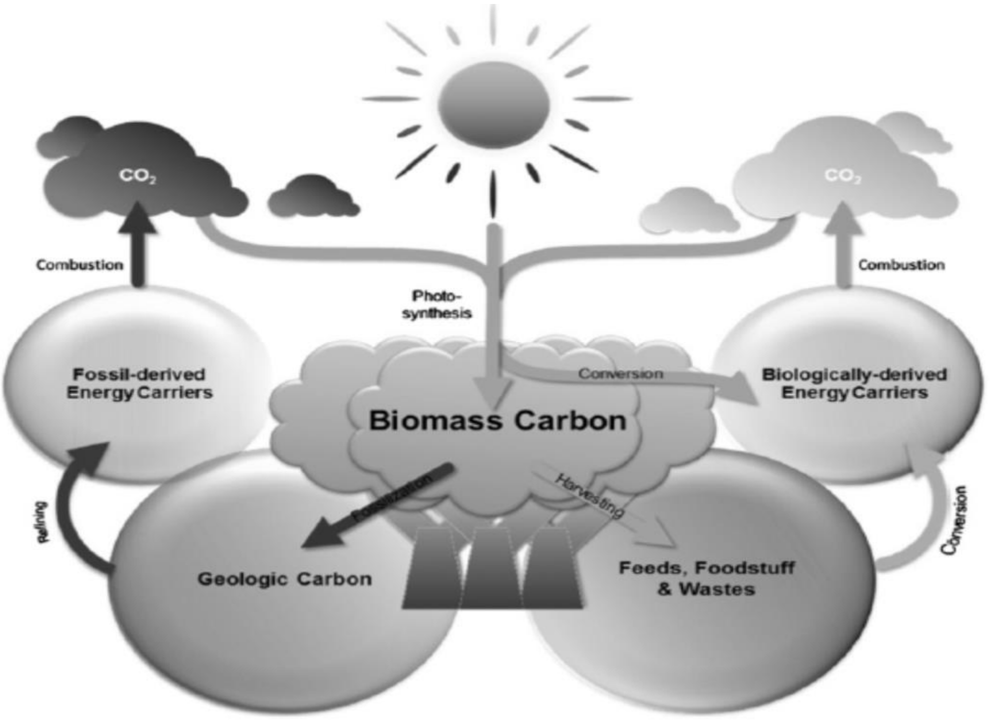


Figure 47 - Carbon cycle model, (Srirangan et al., 2012)

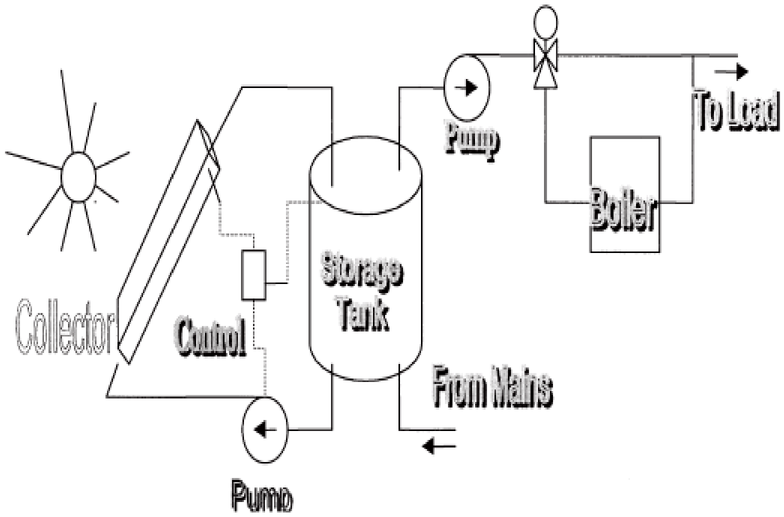
Table 26 - Types of globally available biomass feedstock, (Srirangan et al., 2012)

Feedstock	Advantage	Development of associated technology	Limitation	Share of total renewable energy in the world (%)	Share of total energy in the world (%)
First-generation (e.g.: food crops)	Excellent energy content	Relatively mature (e.g.: bioethanol refineries)	Requires tropical arable land	~9	~1
Second-generation (e.g.: energy crops)	Devoid of competition with food industries	Relatively immature	Laborious and costly treatment technologies	~87	~10
Third-generation (e.g.: microalgae)	Devoid of farming and land inputs	Immature	Low yield of energy carriers	~0	~0
Other (e.g.: municipal solid wastes)	No cost associated with feedstock	Mature (e.g.: anaerobic digestion)	Size of feedstock inconsistent	~4	~0.5

However, the availability and use of many of these resources is based on geographical, technical, and socio-economic factors. Pillai and Banerjee (2009) evaluate the biomass resources for Bangladesh and categorise them. The key resources, the researchers identify, include agriculture residues, wood and wood waste, animal dung, and municipal solid waste. They also indicate the improvement opportunities in the technologies associated with their use. The study indicates and suggests improvement in biogas plants, cooking stoves, biomass briquetting, and gasification and pyrolysis of organic waste. Similarly, in an industrial cluster of fabric producing factories in India the major fuel (over 90%) for thermal energy is derived from firewood, as discussed above. Other technical details and energy efficiency opportunities in boilers are discussed in Section 3.1.1. In another example, biomass is used to produce steam, chemicals, and polymers by (Saygin et al., 2014). Findings reveal several factors that may affect the success of this type of application, such as biomass availability/supply and relative cost of fossil fuel.

3.3.2 Solar thermal collectors

Solar thermal collectors are of a wide variety and can produce low- to high-thermal energy with many end-uses, as shown in Figure 48 (Pillai and Banerjee, 2009). Although medium-temperature collectors, in Figure 48, have industrial use too however, they are not being discussed for brevity. The discussion therefore briefly focuses on low-temperature collectors (below 98˚C) which are more relevant to key textile thermal processes. Low-temperature thermal collectors collect heat from the sun transfer it to a liquid such as water/glycol which then delivers this heat directly to the end-use. In some cases, it is delivered to the point where the quality of energy can be further enhanced (Abdel-Dayem and Mohamad, 2001). A general schematic of a low-temperature solar thermal collector is shown in Figure 49. The use is equally beneficial for both domestic and non-domestic buildings. For industrial applications these have multiple uses, for example “domestic” water heating, connections to heat-pumps (as in 3.1.3.2) where higher temperatures are required, or utilised for feed water in boilers. The efficiency of these thermal collectors can be calculated by using Equation 10.



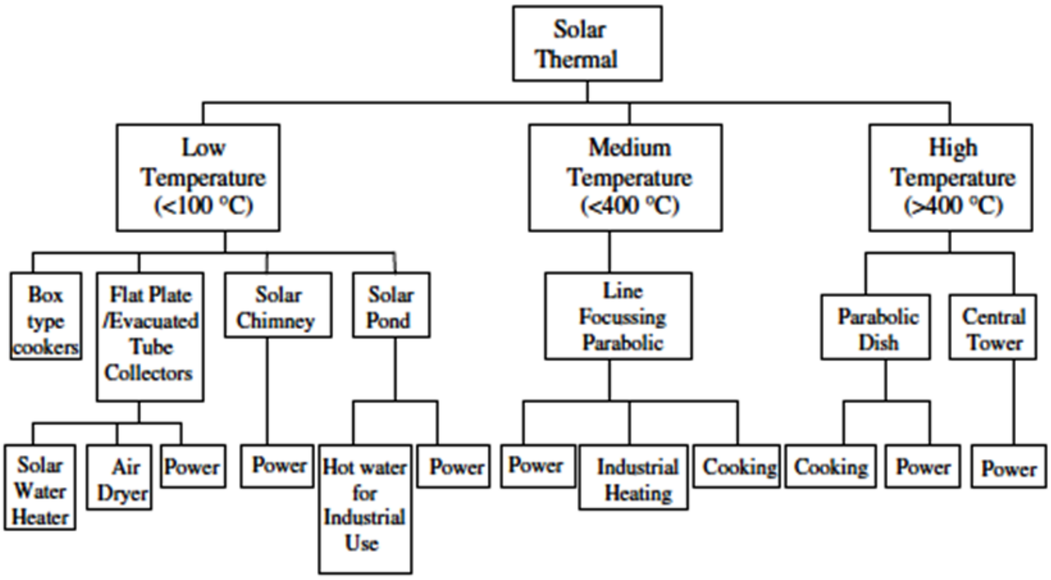


Figure 48 - Solar thermal power technologies and end-uses, (Pillai and Banerjee, 2009)

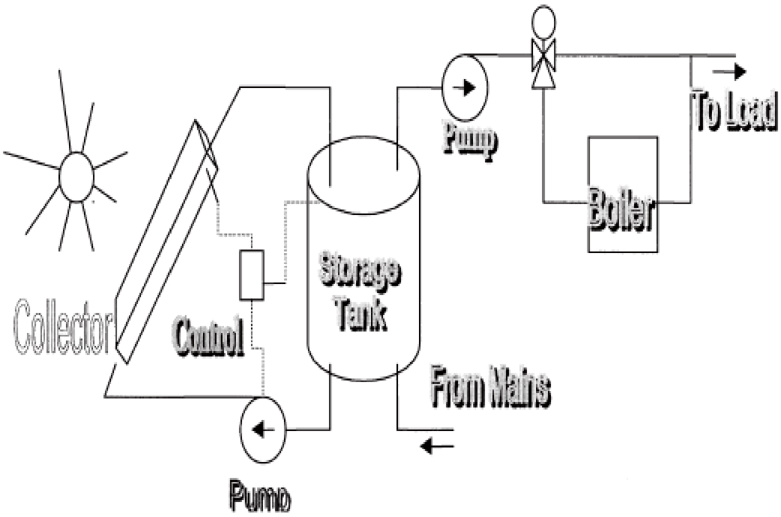


Figure 49 – A schematic of solar thermal collectors, (Abdel-Dayem and Mohamad, 2001)

Equation 10

$$System\ efficiency = \frac{System\ output\ energy}{Input\ solar\ energy}$$

3.3.3 Photovoltaics

PV systems directly convert light energy into electric energy. These are safe, easy to install, no moving parts involved, and have less maintenance cost and can be installed at both micro- and macro-levels. However, the higher associated costs of the technology have been one of the major discouraging factors over the last many years.

In 2016 the total UK PV energy was less than produced by other RE resources such as wind power generation, and biomass and waste (DECC, 2016). However, a gradual decrease in cost is significantly improving rate of the technology deployment (Marks, Summers and Betz, 2012). Encouraging studies on cost reduction and effectiveness are being carried out (Bazilian et al., 2013).

For installation feasibility many factors are considered for example irradiance, the amount of kWh/m2/annum on a specific site, for Scotland is between 722–850kWh/m2/annum (MCS, 2012). In addition, other factors such as building orientation, the pitch of the roof, and shading must be considered. The increase in shading and temperature can have detrimental effects on the performance output of the PVs. Details of calculating these is given elsewhere (MCS, 2012). Estimating the electricity generation on a particular site is an important aspect when determining a site's installation potential. A reasonable method has been suggested in the UK's Microgeneration Certification Scheme (MCS) organisation's guide. The standard method is discussed below in Equation 11 (MCS, 2012).

Equation 11

$$Annual\ AC\ ouput\ (kWh) = kW_p \times k_k \times SF$$

$$Where\ kW_p\ is\ kilowatt\ peak\ of\ array\ and\ k_k is\ the\ orientation\ which\ is\ = \frac{kWh}{kW_p}$$

Tables for $k_k\ and\ calculation\ method\ to\ determine\ shading\ factor\ (SF) is\ in\ the\ guide$

To calculate the output, you need to have the following information available at hand;
the postcode region
the array pitch
the array orientation
the shading factor of the array (SF) according to any objects blocking the horizon - kWh/kWp (Kk) using the appropriate location-specific table
and one more thing, establish the electrical rating of the PV array in kilowatts peak (kWp)

Since PV systems convert light energy into electricity directly, therefore these are easily integrated into any industrial applications. The technology's own performance improvement has also been a main concern to widen use, applications, and cost-effectiveness. PV/T (thermal) systems, are more attractive useful to industries needing power and hot water, have been in long use in industry (Kalogirou and Tripanagnostopoulos, 2007). Innovative research such as increasing wider coverage in terms of process specificity, system performance improvement, system design, is also being taking place. A recent study investigates PV/T for water distillation (Al-Nimr and Al-Ammari, 2016). Assuming steady-state conditions and utilising mathematical modelling the study assesses and compare the performance of such systems for application suitability. Padmanathan et al., (2018) undertake surveys for detailed modelling and designing for industrial and commercial electricity generation applications. There is a well-established understanding of PV systems' reliance for future electricity however, different angles such as water electrolysis through these is also being investigated (Boudries et al., 2014). This is to produce industrial hydrogen renewably and also to produce fuel or store energy into hydrogen as fuel.

A detailed report on modelling the use of RE systems (PV only) for water desalination has been carried out by a consortium of research institutes (Infield et al., 2006). Assessment of PV systems suitability for different case study site conditions with desalinating potential has been carried out (George and Banerjee, 2011). These researchers carry out a study to assess the impact of renewably produced electricity on the national grid in terms of load sharing (due to unpredictable and inconsistent energy generation of most RE sources). They focused on capacity savings through RE resources in Tamil Nadu state in India. The analysis performed pinpointed the importance of considering such factors when planning energy generation technologies integration for both present and future purposes. Issues relating to the rated and real efficiency of certain RE technologies exist.

3.3.4 Wind turbines

A turbine is simply a mechanism of coils that generates electric energy when rotated, often described as the reverse of an electric motor. Like some technical requirements for solar PV installation, harnessing wind energy through wind turbines also questions similar investigations. An information portal-Renewable UK (RenewableUK, 2019) contains comprehensive information on different aspects such as wind speeds in different areas, and initial and socio-technical requirements for such projects. For example, to start with, a suitable site is suggested to have a minimum of 5m/s wind speed (wind power choosing a site and getting planning permissions (Scotland) (Energy Saving Trust, 2018). The speed should be persistent at the point of installation/generation and should not be interrupted by vegetation, buildings or other structures. In addition to that windmills may have direct noise and visual impacts on human life, and wildlife such as birds. For example, in Scotland, there is a curtilage of 100m for a building-mounted wind turbine (Energy Saving Trust, 2018).

Wind farms are becoming more popular and in 2016 the UK's total energy generation through this technology was estimated to be 3,737GWh (DECC, 2016). The installation of medium-scale turbines (between 50–500kW) has been reported to be rising (Renewable UK, 2013). Best practice guides on how to install and commission a small scale wind turbine have been published by (Energy Saving Trust, 2004).

Even with the existence of, for example, the Renewable UK website tool, it is recommended that real-time studies be carried out on the specific site. This is to investigate if there are any local factors such as buildings or trees affecting the speed. The installation of the turbine at a higher point can potentially increase the generation output (Energy Saving Trust, 2018). This is due to the power carried out by the wind is directly proportional to the cube of the wind speed, as shown in Equation 12.

Equation 12

$$P\ (w) \propto S(w)^3$$

Where p is power, s is speed and w is wind

In reality, however, the case is different as the actual power output delivered by the wind turbine is more complex. The “cut-in” wind speed is the minimum speed required to enable the turbine to start generating power. From the cut-in speed onwards the power output increases until it reaches the maximum— that is, the rated wind speed, as shown in Figure 50. A frequently used term for wind power calculations is the CF. The CF is defined “as the ratio of average delivered power to theoretical maximum power” (Boccard, 2009). It is seen in many cases that CF is overcome by design measures, such as large rotor and a small generator. Boccard suggests using the mean realised CF, for example 21CF for the EU, instead of a globally assumed 35CF.

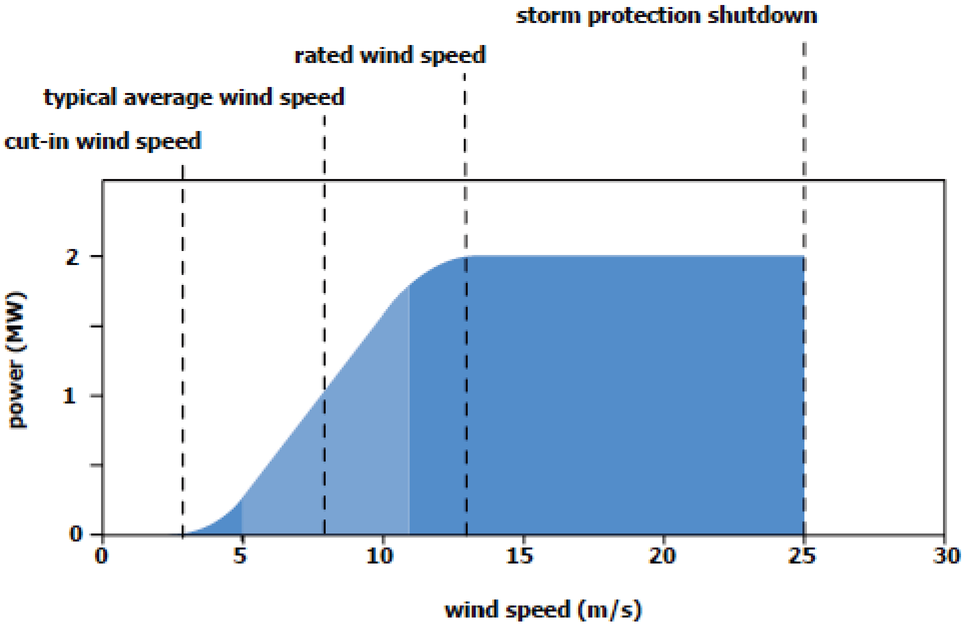


Figure 50 - Typical wind turbine power curve, (BWEA, 2005)

3.4 Conclusion

The chapter reviewed the applications and the key associated energy efficiency measures for various cross-cutting and textile-specific technologies and utilities. The discussion reveals a considerable number of no- to low-cost measures exist for these varied systems. Depending on the energy culture and site-specificity, most of the measures are generally easy to implement. However, some measures such as components/systems within the system retrofitting can be medium- to high-cost. Costs for the measures, where possible, are indicated in Chapter 6.

Key equipment for the case study consisted of both electric and gas user technologies. Boilers and stenter in the textile industry, depending upon the fuel used for HVAC, can be responsible for the major part of gas demand. Boilers discussed above, indicated a variety of saving measures that is adaptable to most of the industrial sites. These consisted of from electronic automation of various systems within the machine to installing/replacing components for fuel-saving and energy recovery. Similarly, stenter showed a few electric and gas energy efficiency opportunities through VSD drives and heat recovery options. In addition to that energy efficiency in other technologies such as dyeing, drying, and washing technologies was also briefly reviewed. An extended discussion on heat recovery, heat pumps, and electric motors was generally undertaken. Some of the identified opportunities were found suitable for the case study site. Discussing the utilities, the steam distribution system and the HVAC and the saving opportunities associated with it were reviewed. The energy efficiency measures associated with the compressed air system were also discussed.

A brief review of RE and LC technologies is also taken to supplement the overarching theme of carbon reduction. However, their application to the case-study was not documented in Chapter 6 due to brevity. Similarly, dyeing, drying, and washing technologies were also briefly discussed to broadly cover the wet finishing area. However, due to data shortage and brevity the application of such electric technologies could not be carried out in analysis section. The Chapter along with Chapter 2 determines the theoretical and technical challenges of the energy auditing subject to this study.

Chapter 4 − CASE STUDY SITE

Describing the case-study site, manufacturing, and production management processes, this chapter delineates the PhD project's physical boundaries. It also highlights energy efficiency improvements areas as well as briefly discusses the organisation's general sustainability initiatives.

Textile industry although belongs to SMEs but sometimes exceptions like size, energy use, and composite factory exist such as the case study. Understanding the case study in detail will help to establish the significance of the study on such terms. For example, the vertically integrated group employs over 800 people (over 500 on Elgin site), has more than £52million turnover with a 21GWh demand.

4.1 Textile supply chain

As learnt in Section 2.3.2.4 textile supply chain involves multiple suppliers and manufacturing stages. Manufacturing/processing firm/units/plants, as explained below, may be standalone, or composite, or in the form of clusters: carrying out textile specific processes; e.g. dyeing and finishing processes cluster in Pali in South India (BEE, 2010). The supply chain can easily go across borders depending on multiple factors like better skills/technology, cost-effectiveness, or buyers' supplier selection. Each process or sub-processes (a process within the process) may have particular supply chain characteristics as indicated in Figure 51.

The process-specific units will have specific energy requirements, for example, more electricity for weaving and more gas for steam-based dyeing. This directly affects energy cost and carbon emissions. Energy demand and carbon emissions for a specific process vary from country to country. For example, process-specific/whole supply-chain energy demand in countries having more technology use, i.e. the USA and the UK is likely to be higher. More labour-rich economies like China, India, and Vietnam are likely to have reduced energy use throughout the supply chain, though the process itself might be different. However, there may be other factors that increase/decrease overall energy demands, like batch sizes, production management methods, old and less energy-efficient technology, and climatic conditions.

The efficiency improvement process in textile manufacturing depends on multiple contributing factors. Some more, in addition to the ones above, are process management, energy culture, materials, and methods used to optimise processes. These challenges can be significantly different for vertically-integrated and or composite textile manufacturing units like the case study that carries out all the processes within the same industrial facility as compared to standalone units. Improving energy efficiency in such a production facility can be a challenging task. For large-size companies hiring energy specialist/s may become necessary. Whereas, for smaller standalone units things may be different and existing staff might be responsible for such matters as well. However, to control organisational energy culture these individuals may lack the required skills. Improvement in production management, such as on-time material supply to reduce lead- and idling-time, technology, and the facilities can increase energy efficiency. This, for a composite textile factory, is easier to control as compared to distant processing units for the same manufacturer (as there is minimal dependence involved on external suppliers, no transport-related delays, and less likelihood of miscommunication issues). On the other hand, a standalone independent unit will have reduced intensity of such issues intrinsically. A significant number of energy efficiency studies on individual processes and standalone units have been carried out. Vertical integration in the textile industry is common around the world however there is hardly any, except for the case-study site, in the UK. Similarly, composite textile manufacturing sites, as discussed above, may be acceptable where geographical and other factors allow. This in the UK can be seen more in technical/innovative textile (for example fireproof, anti-bacterial activity textiles) manufacturing compared to general textile manufacturing, like the case-study site. Therefore, energy studies on such instances will not only help to improve efficiency but will accentuate their energy situation within the sector e.g. energy demand in individual processes as compared to similar standalone units. This will help owners to decide about energy use implications when expanding their businesses.

4.2 Textile manufacturing process

The textile manufacturing involves several stages as illustrated below in Figure 51. Each process stage contributes towards the finished product. Different stages or building-blocks of the supply chain are shown, in grey, on the left side of Figure 51. The manufacturing process can be divided in to three main stages. Yarn manufacturing and weaving processes are largely based on motive power hence are electric intensive. Whereas, wet processes are thermal in nature hence use gas, solid, and liquid fuels.

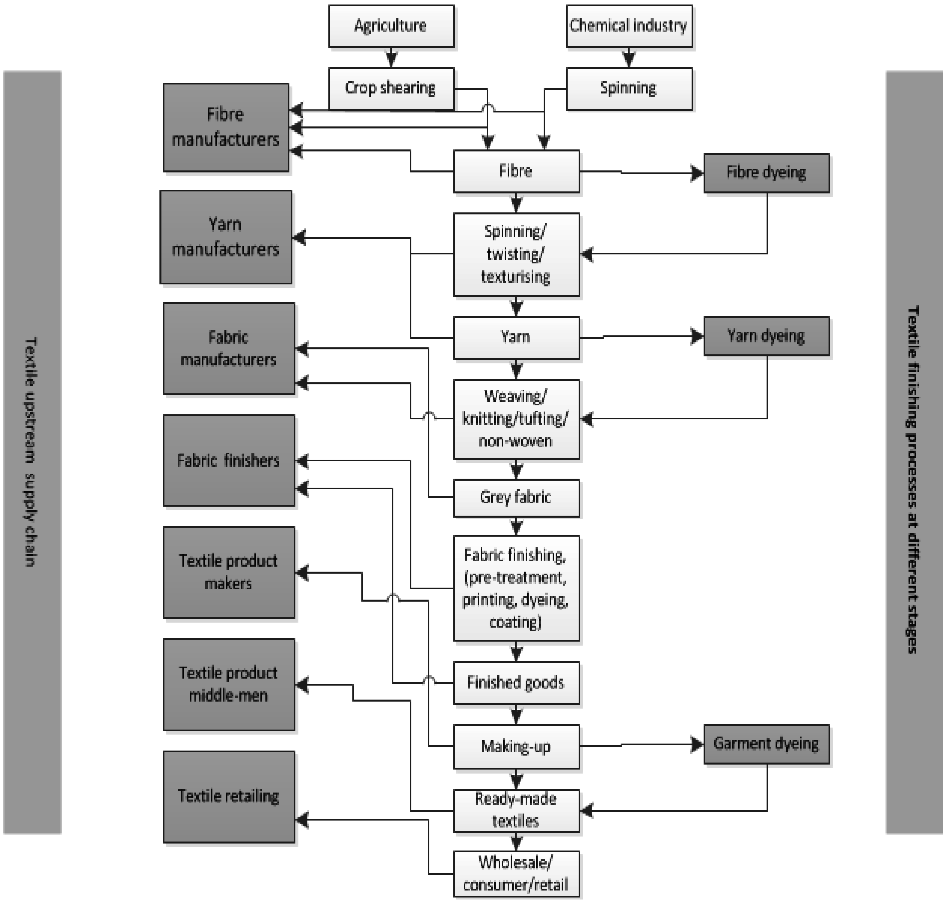


Figure 51 - General textile manufacturing processes, (Hasanbeigi, Hasanabadi and Abdorrazaghi, 2012)

4.2.1 Yarn manufacturing

Involving several sub-stages, the process turns raw fibre in to yarn. For example, specific combed ring yarn making involves blowing, carding, combing, and yarn finishing treatments (Koç and Kaplan, 2007). For synthetic yarns (more energy-intensive (out of scope)) sophisticated technology for fibre/thread making and then spinning is used. Whereas natural (animal/plant fibres) yarn making will have a series of stages. Teasing/blowing is breaking, blowing and softening of fibre. This fibre is then turned into continuous un-spun long strands by carding machines. These strands, when spun by the spinning (ring spinning in this case) machines, are transferred to winding machines which wind them on to cones. This thread, referred to as yarn, is sometimes combined (two or more) to make a thicker yarn on twisting machine. This adds more energy to yarn manufacturing (texture/form/blend enhancement) in one way but can reduce the picks of weaving (per unit of fabric production) on the other. However, it is most likely to increase the weight per unit length. All these processes use quite specifically engineered pieces of equipment, which are not always well represented in academic literature or industry guides (further discussed in Section 4.3). Yet, if aiming to reduce energy consumption significantly in the textile industry, these quite bespoke examples of energy use will need to be assessed and managed appropriately.

4.2.2 Weaving

Weaving transforms yarn into fabric. Setting up the quantities and design pattern arrangements, straight threads (warp) are wound up onto the big spools by warping machines. Weaving machines using these spools carry out the next process stage—threads are run across (weft) the warp, to make the woven cloth. Weaving machines can be electric or pneumatic (CA operated) or using both. With specific design and patterns, each type has a specific number of thread-picking (per unit time) and will have specific energy/utility demand. The selection of weaving machines is mainly made on the quality and quantity of the textile product.

4.2.3 Wet processing

Wet processing is classed into two major processes—Dyeing and Finishing. Dyeing is the application of colour (hot liquid) to raw materials (different for synthetic materials) using large containers. Having a variety of processes, Finishing involves washing, resizing/trimming, ironing and raising the quality of cloth. These mainly use thermal (mainly steam) energy. Drying is one of the most frequently used Finishing process. A considerable amount of electricity, for example, motorised parts of the equipment, as well as for other drying processes as discussed in Chapter 3 is also used.

4.3 Description of case-study

The case-study site, James Johnstons and Co. of Elgin Ltd. is a "vertically integrated" and composite textile manufacturing company. In complicated textile manufacturing occurrence of such industry (vertically-integrated and composite manufacturing) is a rarely occurring phenomenon. This is due to even the vertical integration tends to have scattered individual processing units. This makes the case-study site a unique and thus suitable candidate for such energy studies. The company, manufacturing-wise, has two independent production factories: one is located in Elgin and the other in Hawick in the Scottish borders. The former produces finest cashmere and wool (collectively wool) fabric and related articles (non-stitched) and the latter produces knitwear items like socks, gloves, and allied products. The company imports wool, cashmere, and other raw materials majorly from China, and semi-finished raw materials e.g. yarn locally and from the EU. However, small quantities of wool are also bought from India, Iran, and Mongolia, which may depend on many factors such as economy of scale, quality, trade rate or currency fluctuation. The company always stocks large quantities of raw materials and consistently monitors the world market to buy in advance. Due to China being one of the main markets for such goods, it can be assumed that wool sold by Chinese suppliers is a mixture of sources from different countries including Australia and New Zealand as discussed in Chapter 2 further explained in Chapter 5. In that the company has no true control over upstream goods however, the company has some retail outlets across the UK and around the world (in Germany, Japan, China, and the USA). In these outlets, in addition to some products manufactured elsewhere, the company's own branded items (some produced and stitched externally) are sold. This adds to its vertical integration status.

All the financial and operational affairs of the other manufacturing site and retail outlets/offices are controlled from the case study site. The company's main buyers are high-end retailers like Burberry (the largest), Chanel, Hermes, Hugo-Boss, etc. The largest quantity of a product, the factory produces, is a scarf for one of the major buyers (hence opted for product-specific CO_2 accounting). This seasonal article has some consistent characteristics over many years however some change in terms of colour combination is introduced when desired. However, this study does not consider these trivial changes affecting the product's manufacturing energy (onsite embodied energy). This slight variation introduces the change in article number for internal classification. The number for this article, at present, is WA000608. This is further discussed in Chapter 5. This thesis only covers Elgin factory which, according to the groups initial ESOS external assessment in 2014, is responsible for about 85% of the total energy use in the UK.

Located in Elgin in the North-East of Scotland, UK, the factory has an approximate 22,800m^2 treated area with over 45 buildings, some of which are over 200 years old (as shown in Appendix 1 (a)). Along with production, there are some accommodation buildings for visitors and on-site directors as well as a factory outlet and accessory shop. The factory can only produce yarn between 50–160TEX (refers to grams/unit length (1,000 metres)) of yarn. To cope with the increasing demands of changing fashion trends, the company has been producing lighter fabrics more (below 50TEX) in recent years. In certain cases, it is cost-effective for the company to have one or more of the four manufacturing stages (discussed below), partly or fully, undertaken by external organisations (outsourcing). This will clearly have an impact on metered onsite energy consumption. In response to the latest (in 2006) energy audit

(The Carbon Trust, 2008a), some aspects discussed in Chapter 5, sparse efforts for energy efficiency (mainly lighting) have been seen around the factory.

4.3.1 Key technology inventory at the case-study site

Gas and electricity are the only energy sources and the main electric meter is H-H data enabled with no provisions of sub-metering around. Three utility boilers, shown in Table 27, produce steam for production and building heating (mostly), two of them have gas sub-meters. The other major gas user is the stenter frame—as discussed in 3.1.2.2, as shown in Table 28. In addition to that, there are five hot-water boilers (around 70kW each) for building services and two large gas-fired heaters (redundant). Some technology used can be over 50-year old. There is also some cooking-related gas-use in the factory coffee shop (with an estimated demand of 140m^3/day in April 2014, when the other boilers were shut); with certain buildings using electric heating. There is an old non-operational wastewater treatment (external services used) in the factory still being used for water storage and retention. The major steam and gas user technology is shown in Table 28. An overview of technology exceeding 15kW rated power, except for the weaving machines, is given in Table 29. Of note, there is 30kW (collectively) estimated load of air conditioning systems around the factory in summer. Some motor-driven systems have VSDs. Two main utility boilers are sufficient to meet production demand in summer but all the three are needed in winter (for building heating).

Table 27 - Utility plants at the factory

Technology/quantity	Primary energy/fuel	Other energy	Process support (each)
Boiler/ 3	Gas	7.5 kW each	3000kg/h ±Steam (approx.)
Compressed air units/2	40± kW (each)	NIL	Compressed air @ 7bar
Small boilers/5	Gas	1.5 kW each	Hot water for heating and tap

Table 28 - Steam/gas based technology

Technology/ Quantity	Department	Primary energy	Use/tech type	Other energy
Dye pots 7	Dye house	Steam	Raw wool dyeing/similar	Electric & air
Hank dyers 7	Dye house	Steam	Yarn dyeing/similar	Electric & air
Washing/de-sizing machines 5	Finishing	Steam	Cloth washing & de-sizing/various	Electric & air
Stenter 1	Finishing	Gas	Cloth drying & size setting	Electric & air
Vaporama Pinwheel 1	Finishing	Steam	Cloth drying & size setting	Electric
Rotary press (James Bailey)	Finishing	Steam	Drying and pressing	Electric
Autoclave TMT Italy 1	Finishing	Steam	Drying and pressing	Electric
Decatiser 1	Finishing	Steam	Drying and pressing	Electric

Table 29 - Main technology at the factory

Technology/ Quantity	Department	Rated power (kW)	Use/tech type	Other energy
Teasers /2	Yarn production	21.5 (each)	Wool teasing and mixing/identical	Air
Bailer 2	Yarn production	15 (each)	Yarn bailing	None
Fettling units 3	Yarn production	120 altogether	To remove stuck fibre from the machines	None
Carders 8	Yarn production	24 (each) ±	Carding/identical	Air
Hemel pre- twister /1	Yarn production	15.8	Yarn twisting	None
Hemel cone winder/ 1	Yarn production	52	Yarn winding	None
Schlafrhost/ 2	Yarn production	19 (each)	Thread winding/identical	Air
Savio cone winder/ 1	Yarn production	20.75	Cone winding	Air
Corgi cone winder/1	Yarn production	20.75±	Cone winding	None
Spinning 4	Yarn production	55 ±(each)	Thread spinning/identical	None
Jaquard looms 18	Weaving	12± (each)	Cloth making/identical	Air
Dorneir looms 6	Weaving	8± (each)	Cloth making/identical	Air
Hydro-extractor 4	Various	21 (each)	Water extraction/identical	None
Zonco 2	Wet finishing	59 & 108±	Washing/identical	Air & steam
Serracant 2	Wet finishing	45	Washing/identical	Air & steam
Mozer 3	Wet finishing	55±	Raising & finishing/identical	Air
Decatizer 1	Dry finishing	29±	Raising and drying	Air & steam
TMT Autoclave 1	Dry finishing	40	Raising and drying	Air & steam
Stenter	Dry finishing	80	Drying and sizing	Air & gas
Rotary press	Dry finishing	16	Raising and finishing	Steam
Tumble dryer 2	Wet finishing	18.9 (each)	Drying	None
Microwave dryers 2	Dye house	55± (each)	Drying	None
Radio frequency dryer 1	Dye house	35	Drying	None

4.4 Factory operation

Activities at the factory can be divided in to two—Production and Operations (administration). Table 30 shows the factory's operating hours which is further explained in Figure 52. Of note, from January 2014 there has been a change in weekly operations (in general Finishing and Yarn production departments would work like Weaving and Dying departments (117hours Monday–Friday) instead of 78/week in the past) as indicated in Table 30. The Production has four departments, discussed below, and has six week-long four-holiday segments in a year. This is, between December–January (two-week), Easter (one-week), summer between July–August (two-week), and in the second week of October (one-week) as indicated in Table 31. The factory, therefore, operates 46weeks/annum. Many of the Operations departments/sections work throughout the year, with the holidays adjusted accordingly. Depending on the amount of work, the production departments can be completely or partially closed during holidays. Such a complicated production and the variation in energy use is more difficult to relate and predict which is further discussed in Chapter 6.

Table 30 - Departmental/sectional operating hours

Area	Department/section	2011		2014	
		Weekly hours	Annual hours	Weekly hours	Annual hours
Production	Dyeing house	103	4,738	117	5,382
	Yarn production	78	3,588	117	5,382
	Weaving	117	5,382	117	5,382
	Finishing	78	3,588	117	5,382
	Warehouse	78	3,588	117	5,382
Operation	Customer Service	39	1,794	39	1,794
	Design	39	1,794	39	1,794
	Finance	39	1,794	39	1,794
	Maintenance (operate throughout the year)	103	5,356	103	5,356
	Main Office	39	1,794	39	1,794
	Planning	39	1,794	39	1,794
	Retail shops (operate throughout the year)	70	3,640	70	3,640

The 24-hour Production and Operation shift patterns are quite complex as shown in Figure 52. The modified figure is used in Chapters 5 and 6 for simplicity. All production departments—Yarn production, Finishing (manufacturing “A”), Dye house, and Weaving (manufacturing “B”), and the Operations departments are generalised (pre-2014) in Figure 52. The weather-based seasonality (slightly intense) and production matrices are indicated in Table 31. For convenience, the peak-production season is termed as “on-production” or “on-season” and the off-peak production seasons as “off-production” or “off-season” where needed. The factory is sales-orientated and can undertake any orders round the year. Therefore, identifying borderlines between the production seasons is difficult and thus the production variation overview is based on what is generally experienced. Interestingly, the number of peak-production and winter season months is the same. Such information will be relevant to later analysis and findings chapters.

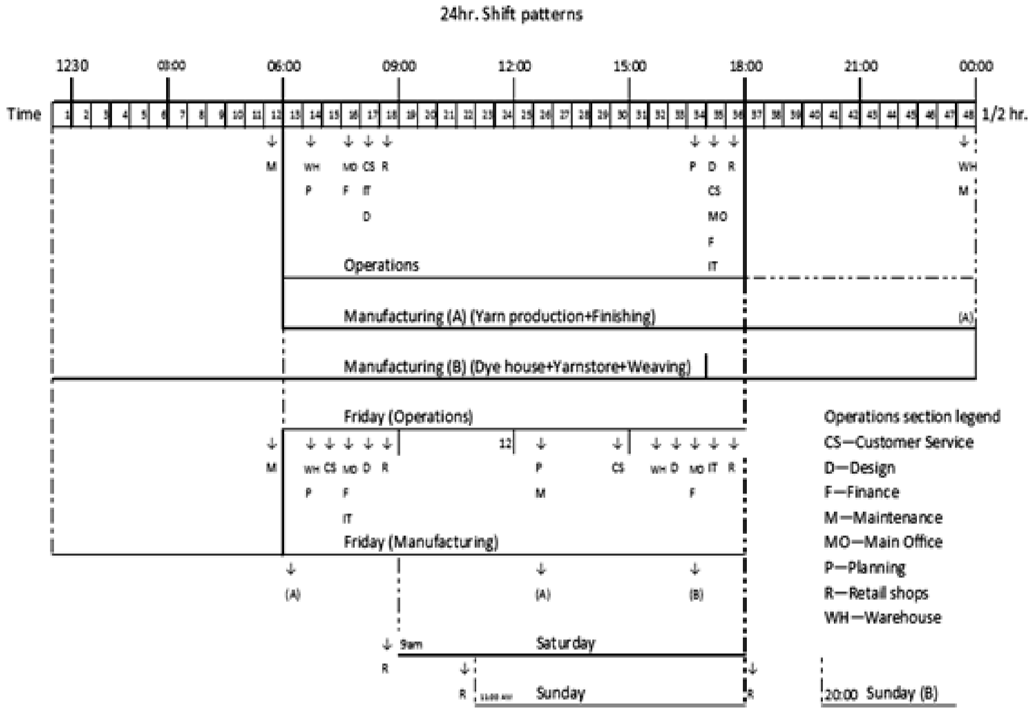


Figure 52 - 24-hour shift patterns

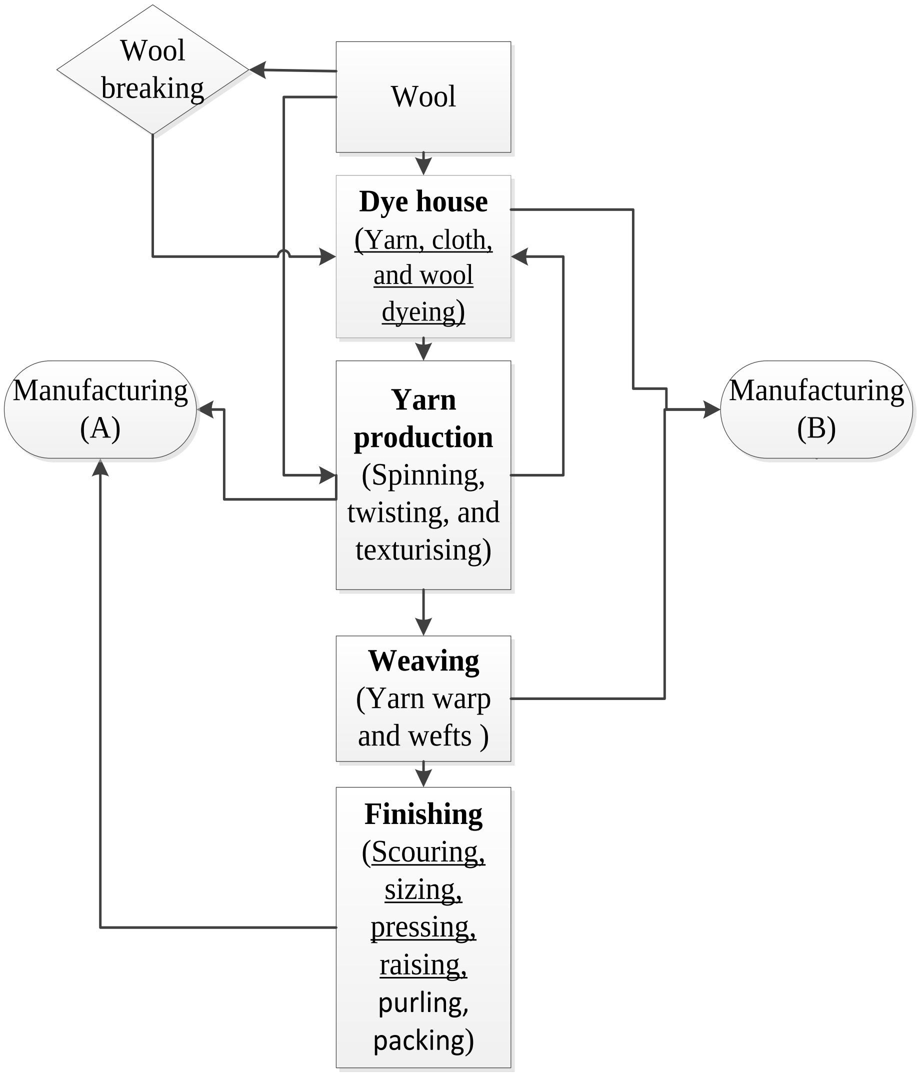
- *Bold and lines represent shift continuation of the relevant section/department and termination or start/stop of shift, respectively*
- *Downward arrows after mid-day, except for Sunday, indicate shutting time of the section/department*

Table 31 - Activity- and weather-based seasons

Seasons		Months			Weeks of holiday
		Start	End	Duration	
Production-wise	Peak	March	September	7	3
	Off-peak	October	February	5	3
Weather-wise	Winter	Mid-October	Mid-May	7	3
	Summer	Mid-May	Mid-October	5	3

4.4.1 Departmental operations and energy flow

As a composite textile manufacturing site the process are thermal energy intensive. Electricity is mainly required for motive power. Key processes and the associated energy is indicated in Figure 53 below.



In brackets, the underlined text is predominantly gas based thermal (steam) energy and the rest is electric

Figure 53 - Onsite manufacturing processes and energy flow

As the factory is the hub, therefore some of the carbon/energy, as indicated in Figure 54 below, may be attributed to the group's other sites. Knowledge of the onsite production processes will allow us to understand the energy flows:

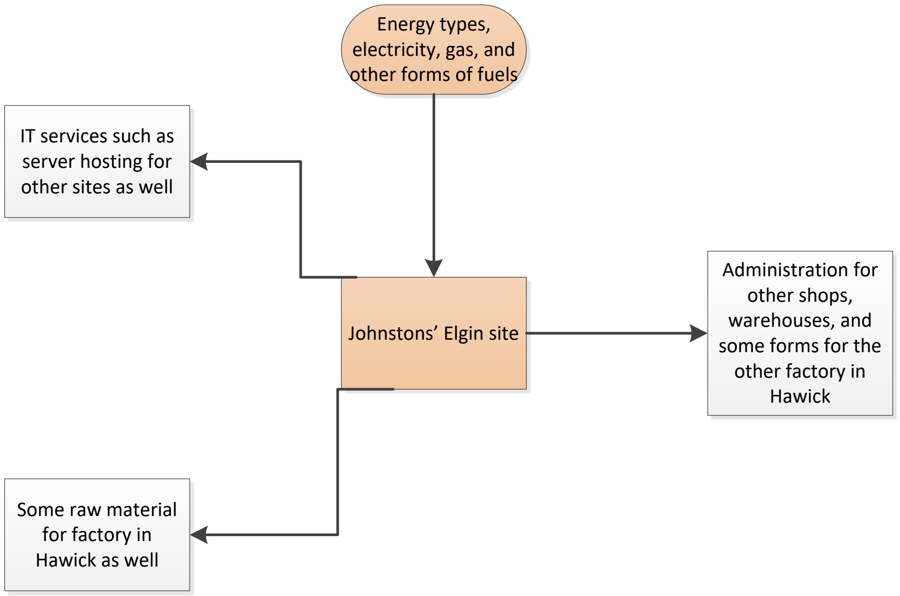


Figure 54 - Factory's activities for the whole group

a) In the *Dyeing house* raw wool, yarn, cloth, and garments are dyed using steam. Big dyeing pots with optimised temperature, water supply and agitation, and dye mixture control are used. Materials' drying is carried out by using electric spinning (centrifugal) drums (hydro-extractors) for water extraction, and variable frequency (Micro- and radio-waves) heating machines for bone drying. In addition to the internal dyeing, the company also outsource dyeing in different ways such as when already dyed yarn, wool, or fabric is bought in. Sometimes the company buys-in un-dyed yarn, wool, or fabric for specific items. Since it is a company's usual practice, it is therefore difficult to assume that all the fabric the factory produces is dyed on-site.

b) The *Yarn production* department processes wool into yarn involving different stages such as wool breaking and mixing (dyed/un-dyed), often using higher quantities of the electricity. In general, the factory's yarn production capacity is lower than how much the factory can weave therefore different types of yarn production processes are outsourced as shown in Figure 55 below. In 2014, the management decided to run the Yarn production non-stop from Monday–Friday as to maximise in-house production. However, buying-in for lighter fabrics (using yarn below 50TEX) was unavoidable.

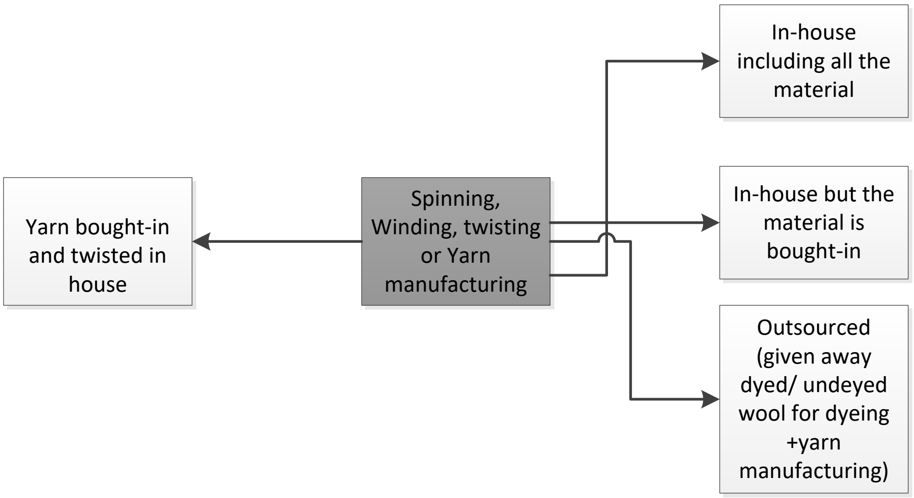


Figure 55 - Supply chain for Yarn production

c) *Weaving* undertakes weaving and caters for the yarn storing. Although the department has a reasonably good production capacity, weaving during exceeding workloads is still outsourced. Different types of weaving outsourcing in relation to a combination of yarn outsourcing is shown in Figure 56. In 2013, the company decided to upgrade its weaving monitoring and production scheduling and installed a Belgian Monitoring System formerly BarcoVision monitoring software. The company opted for two types of licenses ─ real-time monitoring and production scheduling.

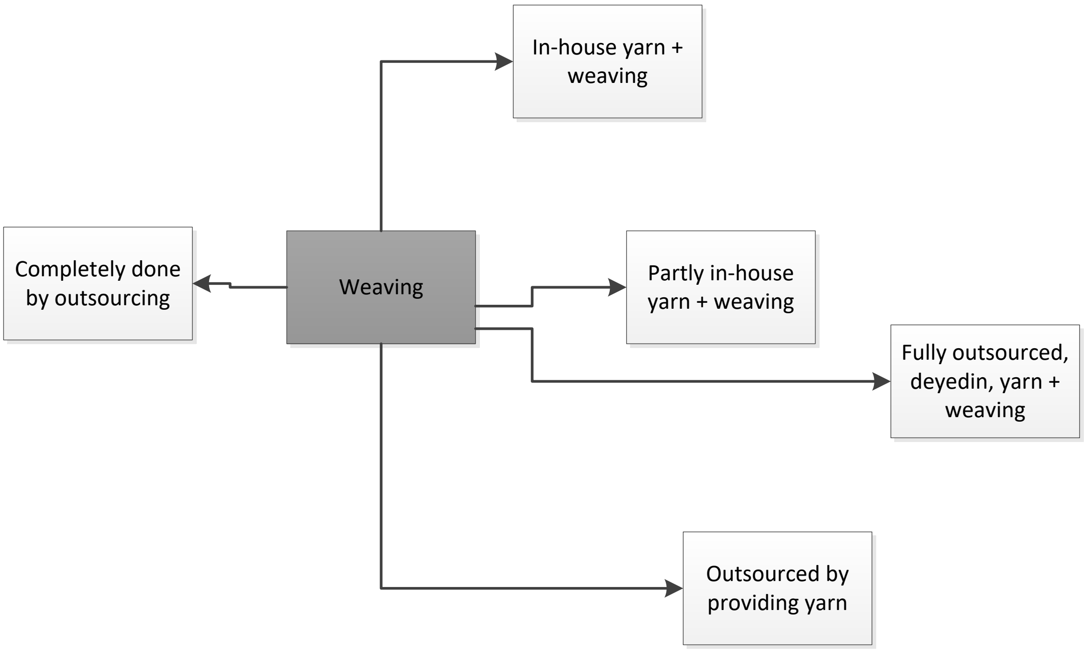


Figure 56 - Weaving supply chain

d) *Finishing* undertakes washing, resizing, cloth enhancing and repairing (each representing individual section) processes prior to being dispatched to customers. Although the company has a complete range of such finishing sections but sometimes requires carrying out all, one or more of these externally as, in relation to weaving, shown in Figure 57.

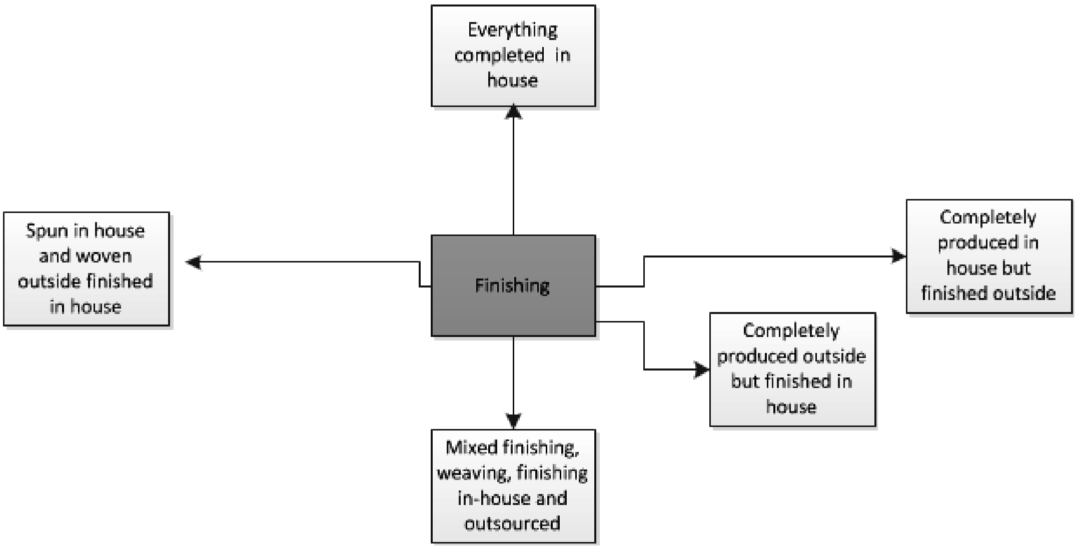


Figure 57 - Finishing supply chain

The Operations section, as shown in Figure 52 consists of IT office, human resources, design, finance, maintenance, planning, administration offices, customer services, factory retail and coffee shops, factory warehouse and stock room. These sections control main operations for the whole group. Factory retail and coffee shops are also located within the premises. Another part of the Operations is the controlling of logistics (such as raw material, and finished and semi-finished goods transportation among the sub-manufacturers for the company, etc).

4.4.2 Sustainability initiatives

The thesis's focus is not on making recommendations for production management at the factory. However, to clarify the processes involved with production management in the factory, and how it can impact on energy demand, this will be briefly discussed. Until 2007, the factory had been using an old-style system known as T-card system to schedule, manage, and monitor production. In 2008, the factory replaced the existing system with a production management software—Jomar system (Jomar, 2018). The system offers multiple management solutions, from production scheduling, design and quality control to technology maintenance. However, the company utilises the system only for production scheduling and some other related functions. It is felt by the production management experts in the factory that the system has helped, to a greater extent, to cope with problems that had occurred with the previous system. Any shortcomings that arise due to the Jomar system are mainly attributed to limitations to the training, skills, and expertise required dealing with the software. The emergence of unexpected orders, that occur frequently, is also one of the major contributing factors for if any, troubled production management. The company's CSR (corporate social responsibility) framework is being strengthened over time. In addition to energy efficiency initiative (i.e. the PhD project), the company in 2015 applied for management accreditations like ISO-14001 and ISO-9001. Waste reduction and recycling programmes have been strengthening. The company has a defined energy policy published on its website and has been seriously working towards it.

4.5 Summary of energy uses within the textile industry

Depending on the nature of process/s a particular factory/unit can have more thermal or electrical energy demand. A more detailed account of individual technology for a certain process is helpful to understand the variety of processes and specific technology involved. This, in many cases, can be the use of different technologies to carry out similar processes. Although, electric and thermal EI process, in terms of the number of departments—two each, are equal but the kWh ratio is 1:4 respectively, as indicated in the following chapters.

Chapter 5 – METHODOLOGY

Based on energy audits (as discussed in Chapter 2), key textile-related (fabric) manufacturing technology/systems (Chapter 3) and the generic manufacturing and production management process (Chapter 4) have been reviewed. The discussion helps to understand the key relevant topics in depth so that the thesis scope and the objectives can be contextualised. This research project also developed a robust energy measuring and monitoring method. In addition to meeting the wider research goal, it also enables to address key (10) points below (as to diagnose and identify energy and carbon saving opportunities). The chosen approaches primarily consisted of estimating the total and departmental-level energy demands, and relating it to production, activity, and weather-related variations (mainly H-H energy profiling). The energy and carbon performance is designed into SEC and cradle-to-factory gate carbon footprint.

5.1 Key investigations

As indicated in the previous Chapters, this is a performance-based energy assessment which utilises and monitors (where applicable) data from various variables, energy and cost (whole-system and individual technology/system). Methods used for energy auditing and carbon accounting has been reviewed in the Chapter 2 with a brief discussion on key (general and industry-specific) technology and its applications in Chapter 3. Chapter 4 introduces the case study site, with a summary of individual production processes, key technology inventory, and sustainability (energy and carbon) aspirations of the industry.

Considering both top-down and bottom-up routes, the energy and utility demand and savings estimations mainly rely on two assessment approaches. One of those is theory based (such as rated power, estimate utility invoices, rule of thumb, and engineering principles) and the other one is based on metering and measuring (generic meters, sub-meters, BMS, and intrusive/non-intrusive measurements). Qualitative techniques for certain measures such as observations of the onsite engineers and the researcher are also used where needed, as discussed further below. The background and a review to the approaches along with some data processing techniques, such as calculating the rated power demand per annum, has been covered in the literature review . For the “theory-based” data and its analysis, this study utilises the already established methods as discussed in Chapter 2 particularly in Section 2.2.3.2 and demonstrated in Sections 6.1.1, 6.1.2, and 6.2.1.1. For the “metering and measuring based” approach new analyses (such as visualisation techniques using time series (H-H demand) data against activity (shift-patterns), and designing an activity matrix for departmental demand disaggregation based on such data) for both gas and electricity have been suggested. Such analyses in this thesis are based on similar types of analyses and objectives, as discussed in Section 2.2.4.1 on energy in buildings previously. However, their usage for such a complicated manufacturing process using activity table to enhance clarity of assessment and the inferences for saving strategies, as in Section 6.3, is unique to this study. Data collection and analyses on individual technologies such as boilers and air compressors are mainly based on sub-meters and monitoring values. A scheme of discrete areas and steps, with an indication (tick mark) of existing, adapted, and brand new methods used along with the objectives of the study addressed, to accomplish the methodology of the audit is indicated in Table 32 below. The proposed methodology is also a portable process with improved investigation and analytical techniques that can work within existing processes of analysing energy and identifying saving recommendations.

Table 32 - Steps taken to accomplish the detailed energy audit for the study

Top-down approach. Macro-audit (Walk-through/O&M and utility cost analysis leading to detailed energy audit							
Audit approach	No.	Energy/consumption measurement	Fuel/material	Method development process based on			Targeted objective/s
				Existing	Existing but ammended/ adapted	New/Orginally designed	
Total energy	1	Monthly utility invoices	Gas and Electric	✓			I
	2	Main meter readings		✓			I
Demand disaggregation	3	Nameplate based	Electric mainly	✓			I
	4	H-H metered load based on peak- and off-peak times energy profiles	Gas and Electric	✓	✓		II
	5	H-H metred load based disaggregation in response to activities			✓	✓	II
	6	Observation based		✓	✓		I,II,III, and IV
Total energy for SEC and CO_2 accounting	7	Monthly utility invoices based annual consumption		✓			I and III
	8	Annual fuel consumption data	Diesel and LPG	✓			I and III
	9	Annual raw materials consumption and metre production data	Wool and Cashmere	✓			I and III
	10	Secondary production, consumption, waste, and other data sources and emission factors	Animal fibre produced	✓	✓		I and III
Audit outcome	11	Housekeeping (maintenance department)	Gas and Electric	✓	✓		I and IV
	12	Housekeeping (production departments involvement)		✓			I and IV
	13	Organisational initiatives		✓	✓		I and IV
	14	CO_2 reduction evaluation through renewable resources		✓	✓		I and IV
Bottom-up approach. Micro-audit (standard- and detailed-energy audit using macro-audit as foundational							
Measurement based	15	Compressed air	Electric mainly	✓	✓		I
	16	Yarn production tech		✓	✓		I
	17	Weaving technology		✓	✓		I

Meter based	18	Boilers	Gas mainly	✓	✓		I
	19	Indirect metering for boilers with no meters		✓	✓		I
Engineering principles and rule of thumb based	20	Thermodynamic principles for heat loss/gain/phase change. Rule of thumb based leaks/losses	Gas and waste heat mainly, and electric	✓	✓		I and III
Nameplate based	21	Stenter gas	Gas mainly	✓	✓		I and III
	22	Motors on stenter and boilers	Electric mainly	✓			I and III
	23	Lighting	Electric	✓	✓		I and III
	24	IT		✓	✓		I and III
Audit outcome	25	Organisational initiatives	Gas and Electric	✓	✓		I and IV
	26	Individual technology		✓	✓		I and IV
	27	Others		✓	✓		I and IV

Various streams of results such as whole site and individual system/technology demands from high- to low-resolution were derived which then were drawn and analysed against different variables to understand the response in Chapter 6. In addition to that, similar nodes of results such as demands at departmental and individual technology levels, were also compared to understand the difference, applicability, benefits, and limitations of each method. The methods based on measuring and monitoring based approach along with the proposed analytical method indicated better representation of real-time energy consumption. As a result, the identified saving measures and the associated savings are likely to be more accurate as compared to "theory based" approaches. One of the reasons for such in-depth energy modelling of industrial buildings is to pinpoint suitable energy efficiency investments. Many of these potential saving recommendations can be risky due to higher capital costs involved and as such are deemed unsuitable. Thus the assessment process, is at the least, helpful to increase certainty and justify the investment related to site-specificity. Therefore many companies including the case-study may not be interested in investing in those projects.

Unfortunately, due to limitations associated with the available funding for the proposed retrofitting a large number of them could not be implemented and hence validated. Due to various limitations, i.e. varied production and consumption processes and absence of sub-metering or monitoring equipment, validating the ones that were implemented such as certain good housekeeping measures, thermostat temperature revision in some buildings, and total dissolved solid (TDS) blowdown control system and a heat recovery system on it could not be validated. The exercise however can inform those objectives being a form of non-numerical but a conceptual validation instead. This can be seen through general savings and can be felt on a bigger picture. This is obvious from a consistent (over 1GWh) gas savings in 2013 and 2014 , as indicated in Section 6.1. The methodology designing approach widens the role of various auditing types' contextualising (i.e. as in (Krarti, 2012) and the applicability. In order to comprehensively define and accomplish the research objectives (I–IV in Chapter 1), stepwise actions (1–8) as described below and related in Table 33, have been followed. Defining their tier of use, it helped to identify stages and the levels of analyses, as well as the project scope and limitations. The defining of these stepwise detailed actions also helped to clearly indicate the tasks targeted to achieve under the individual topics of the methodology design, as in Section 5.3, as well as the scope and the limitations of the project.

1) Evaluate and estimate utility and production data collection and billing for baseline energy, materials, and cost. Understand the site including activity, processes, and management operations and identifying low-hanging fruits
2) Carry out energy mapping to identify key demand contributing technologies/systems, individual departments, and activity/processes. This is for energy auditing based on both indicative (nameplate rating and engineering principles) and, where possible, real-time demand data at sub-levels (measured by clamp-on meters, and direct- and indirect-metering) measuring
3) Assess changes/retrofitting required for energy efficiency with payback indications
4) Evaluate the impact of key variables such as production and climate on energy consumption and carbon emissions. Calculate performance against indicators such as SEC, CO_2, building-specific lighting levels and HVAC
5) Design a high-resolution energy data analysis method to characterise activity-based demand variations for both short- and long-periods for a manufacturing environment. The method, in addition to identifying energy trends and patterns and saving opportunities, can help to estimate demand against activity
6) Provide an approach for highlighting the magnitude of savings across energy demand profiles of an entire site and setting up saving targets
7) Compare energy consumption with historical energy use to further develop the method and place longer-term energy changes in context
8) Calculate the factory's current organisational and specific-product carbon footprint

Table 33 - A list of objectives indicating the level of analytical complexity for each task

Point no.	Main objective/s	Macro-audit		Micro-audit	
		Condition survey	Utility cost analysis	Standard energy audit	Detailed energy audit
1	I	D	M	Contributing to	Contributing to
2	I, III	D		D	B
3	I	D	B	D	M
4	II and (III)	D		M	M
5	II			D	D
6	II and III		B	D	M
7	I, III, and IV			M	M
8	III			D	M

B (Basic), M (Medium), and D (Detailed)

5.2 Challenges to existing industrial energy auditing process—some examples

Before proposing a new methodology, it is worth overviewing existing energy approaches at the case-study site. These, audits/surveys if lacked the required time and effort, can technically suffer from underperformance as identified elsewhere (ASHRAE, 2002). One of the several associated reasons is the audit of technology based on reduced details. The case examples, in which the main gas user technology and stenters are omitted, are discussed in Sections 5.2.1 and 5.2.2. Section 5.2.1 recommends low-hanging fruits and a more detailed energy audit. In addition to that, signposts are provided to avoid mistakes. These intentionally chosen examples have been personally observed by the researcher during his stay on site. These also help to define the business' historical energy picture and sustainability initiatives.

5.2.1 Energy auditor's approach

Quite often, quick-fix energy audits and surveys, become a source of misrepresentative energy demand/saving measures, like the survey and cost analysis at the case-study (CPP, 2006). Backed up by the Carbon Trust, this Government funded project was implemented by an engineering consultancy. The audit also gives an insight into the factory's past energy performance, as shown in Table 34. In light of findings, the audit extends into a more comprehensive building heating system (kind of micro-audit) audit (CPP, 2008). Suggesting empirical gas end-uses, mainly based on qualitative observations, the audit ignores one of the key gas user technologies—the stenter (as shown in Table 35). The report approximates that equal amounts of the steam are used for heating and the process, as shown in Table 35. The approximation matched with the generally established rule-of-thumb by the onsite engineers. The flawed estimate monthly gas invoices used, which is discussed in Chapter 6 as well, happened to be another exacerbating factor for the miscalculation intrinsically. Additionally, the probabilistic future energy costs in the report were quite high e.g. reaching almost double the energy cost a year after. Upon researcher's further investigations a different thermal energy balance view of the onsite engineers was discovered, as shown in Table 35. The thermal demand, estimated through more robust engineering principles by the researcher, appeared to be quite different than previously identified. The calculations are based on one of the key establishments of the thesis, which relates to the importance of empirical observations and energy data with sound engineering principles (such as nameplate based demand calculations, total water consumed for steam production representing how much kWh were consumed), wherever possible, to compute energy demands, which is further discussed in Chapter 6. It could be argued that these figures are produced more for the requirements of a standardised report rather than for reliable energy-saving analysis.

Table 34 - Energy use in 2005, (CPP, 2006)

Utility	Energy consumption		Cost		Specific energy consumption
	kWh/year	%	£/year	%	
Elelectric (2005)	4,343,860	20.4%	229,048	47.9	1.74
Gas (2004)	16,994,512	79.6%	249,287	52.1	6.68
Total energy	21,337,372		478,335		8.42

Table 35 - Thermal energy demand disaggregation by various experts

Measure	Carbon trust's consultant report		Onsite engineers' estimation		Reseracher estimation*		
	kWh	%age of total gas consumption	kWh	%age of total gas consumption	kWh	%age of total gas consumption	Cost @0.03£/kWh
Annual heating consumption	7,749,122	45%	-	40	4,957,800	32	148,734
Annual process steam consumption	9,379,272	55%	-	40	7,987,200	52	239,616
Stenter	missed	missed	-	20	2,013,000	13	60,390
Others**	-	-	-	-	497,000	3	14,910

- *Based on monitored data an account of seasonal demand variation is also taken, unlike as a straight assumption made in Section 6.2.2.3. This is done on purpose as to indicate the variance related to different methods and approaches to calculate the same demand. Cost per kWh was assumed £0.03 as discussed in Section 5.3.1.2*
- ** Assuming that boilers number 3 and 4 operate non-stop throughout the year and boiler number 2 operates only in winter*
- *** includes gas demand from the coffee shop, hydroponic boilers, and gas heaters*

The building heating system micro-audit (CPP, 2008) was to identify the enhanced savings potential of the existing equipment. These assumptions, based on quick-fix audits, led to results less compatible with the reality. However the report, considering the reported qualitative data based on site complexity, also recommended sub-metering to minimise the error. It also emphasised the importance of revising the calculation through a thorough and robust process of extensive EM process. The scope of such hasty audits, if loosely designed, faces threats like this and often repeated. It can be assumed that such funded programmes are designed in response to the government's initiatives towards energy policy and strategy. It could be argued that either the policy/strategy or the Carbon Trust's approach towards implementation needs to be more robust and tailored. However, this issue is out of the scope of this thesis. Nevertheless, one of the findings of the audit was suggested to have more focused energy serves as the basis of this PhD project.

The audit report used a selection of straightforward and repeatable rules-of-thumb and engineering principles that result in good approximations. It is arguable that although quick-fix condition surveys and utility cost analyses are less accurate, they can potentially save energy. These audits are mostly designed to identify saving opportunities instead of accurate appraisal of empirical energy consumption and they satisfy the purpose. The savings made can be due to energy efficiency improvement in general. These may consist of identified low-hanging fruits and improved O&M measures such as organisational behavioural change. These measures, if identified or implemented thorough a structured audit process, can encourage a constructive energy efficiency initiation to the starter organisations.

5.2.2 Energy-efficient technology installer's approach

The factory management decided to upgrade the existing building energy management system (BEMS) for energy efficiency (may be inspired by the energy audit in 5.2.1). The existing BEMS system with limited features, as indicated in Appendix 1 (a), was being used for buildings' temperature setting, control, and scheduling. The new system installer's survey report did not take the stenter into account, repeating the assumptions like in Section 5.2.1. It further suggested that the upgraded BEMS would save a large amount of steam. As the new system will improve control, temperature settings, and scheduling along with better user comfort, some improvement in savings would have been likely. The savings were estimated to be around £39,000/annum. This, when compared with the researcher's total building heating cost estimation (as in Table 35), was found to be 26%. This was calculated by dividing 100 by 148,734 (as in Table 35) and then multiplying the answer by 39,000. The figure sounded highly optimistic upon realising that only less than half of the factory's buildings are controlled through the BEMS (as indicated in Appendix 1 (a)). In common practice, such large savings are only possible through highly advanced and innovative system installations. Yet for this particular instance, the BEMS was only a like-for-like replacement with some additional features. Although this was a type of micro-audit on the BEMS, the energy use and savings estimation methods applied were either poorly designed or insufficiently understood. Another reason for the suspected flawed estimation can be due to the condition survey lacking attention to detail, such as ignoring the gas used by the stenter. The assessment of this error portrays the level of uncertainty in energy efficiency projects. This commercial energy efficiency appraisal is another type of audit that was carried out without a guided procedure lacking comprehensive research and onsite observations. It is only when these energy end-uses are thoroughly known, miscalculations of such overestimated quick-fix processes/projects can be understood, challenged, and avoided.

Another such type of appraisal is observed when the factory decided to install a Reverse Osmosis (RO) plant for boiler water conditioning. The feasibility survey and report was carried out by the technology provider. According to the firm's estimation, the RO plant's purified water could potentially save £200,000/annum (some of which may be attributed savings of salt). However, according to sub-metering based estimations, the boilers' annual total gas cost was £325,000 (as calculated in Chapter 6). Thus in the light of this report, the RO plant can save up to 63% of the boilers' total energy cost. The non-representative savings again indicated the shortcomings of the observations and the assumptions in the feasibility report. These may be based on different factors such as the calculation method, lack of research/expertise in the area, generalisation of estimates and exaggeration of savings figures to sell the technology. These types of miscalculations, which lead to misrepresentative saving figures, are of particular importance to this thesis. The examples above raise the importance of utility sub-metering, at least, at key technology/department level.

To summarise, procedures of many energy efficiency projects may consist of commonly practiced quick-fix audit processes with misrepresentative results, as observed from the above. Consequently the market for energy and carbon savings achievements, based on such types of projects, can be misinformed too. Therefore, the need for vigorous and precise energy assessment methods is evident.

It is clear that both macro- and micro-audits that generate key information for EM process/es and the associated decision-making are prone to misrepresentation. Expanding the scope of the level of detail and physical extent of the subject buildings/technology, in addition to a robust methodology and calculative methods, will help to improve the quality of results. Yet, even these methods are not without errors or misrepresentations, so care should always be taken when initiating an audit procedure. The list, to minimise such perceived risks, however, is extensive. Some of the things that can be particularly helpful include improving communication, more precise and accurate site observations, and accurately measured site-wide and end-use energy data. To summarise the findings of the previous audits of the case-study, and to help formulate an improved approach to industrial energy assessment, the following key points should be considered for a more robust detailed condition survey and audit (that may also lead to any higher-level energy audit):

- Use accurately metered energy data whenever and wherever possible
- Use energy data sources other than estimate utility invoices, such as daily/weekly recorded meter readings
- Carry out site/technology inspection, including no- to low-cost saving opportunities, containing accurate information that thoroughly informs standard or detailed energy audit
- Sufficient time should be spent observing practice on-site, and improve engagement between the surveyor and onsite engineering staff
- Detailed technology mapping is required to identify key energy-intensive technologies
- Disaggregate end-use energy demand (based on any or many of these types such as fuel, process, and department) for comparison and to identify precise saving opportunities and cost savings associated with them
- Minimise the reliance on predictions of energy/cost, if possible, through the use of historical energy data
- Maximise the use of robust and repeatable scientific methods to identify energy/technology efficiency opportunities across a range of industries (that are not currently well-served by existing methods)
- Double check the accuracy of the findings/results using some secondary methods

5.3 Methodology design

Keeping in view the discussion above and the practical constraints/limitations (such as brevity, resources, and data), a detailed energy audit methodology has been designed by using different methods as explained below. Divided in to five key areas the first Section 5.3.1 indicates the sources of numerical and physical data and portrays the whole site. Utilising lower-resolution energy and other data the section establishes the general performance. This exercise, generally part of the standard- or macro-audits, puts the light on whole site activities, the processes involved, and their management. This led to identifying and establishing baseline parametric figures (such as utility demands, production/consumption of raw, semi-finished, and finished materials, and activity in individual sections/departments). The section also discusses how the learning and the calculated data (as discussed in Section 5.4) helped to design various types of analyses.

Section 5.3.2 discusses more robust techniques (i.e. measuring and monitoring) used for enhanced performance evaluations. Micro-level technical review of some key technologies and systems the scope is broadened from standard to detailed energy audit. In addition to helping disaggregating demands/supplies of some key technologies/systems, it lays foundations for systems' performance evaluation at building/site levels. Section 5.3.3 evaluates energy signature (i.e. demand segregation and saving opportunities) and trends and patterns using high-resolution consumption and activity data. Analytical methods such as line plots for weekday energy profiling, and line profiles drawn against activity schedules, have been used. Some analyses, depending on the scope, are generally used in standard or macro- and micro-type audits so were chosen for this method. The high-resolution data is utilised to calculate average daily demands during peak- and off-peak activity periods. Section 5.3.4 discusses textile specific key performance benchmarks/indicators. Performance assessment comparison methods, based on observed and recorded data from Sections 5.3.1–3, are also discussed in this section. The last Section (5.3.5) takes a snapshot of designing organisational and specific-product level carbon accounting procedures and methods for the textile industry. An indication of how these sections help to address the detailed research objectives is given in Table 36 below.

Table 36 - Methodology sections covering detailed objectives

Section	Detailed points addressed
5.3.1	1,2,3,4
5.3.2	2,3
5.3.3	4,5,6,7
5.3.4	3,4
5.3.5	3,8

5.3.1 Performance assessment based on generic data

5.3.1.1 Premises and technology condition, operation, and management assessment

The project started off from a condition survey to understand the technology, and operational and functional aspects. Individual buildings, as in Appendix 1(a) along with the basic information (such as fabric, area, energy supply and activity) were recognised.

The technology/system database was collected on an excel spreadsheet, a sample data collection sheet is shown in Appendix 1 (Table 105). For motors and motor systems having no common nameplate, each individual contributing load was accounted for. In the absence of nameplate, load estimations were taken from the experienced onsite engineers. The technology rating modelling was applied to each type and category of machinery on site (for example from key technologies to the number of fridges, and IT equipment as in Section 5.3.2.4). Relevant utilisation factors, generally from 78hours–117hours, pertinent to individual technologies (where possible) were used. For seasonal i.e. in summer/winter technology, 18 and 28 operating weeks were considered respectively. A generalised load factor and rated efficiency of 0.8 was assumed for all types of motors and other equipment (where possible)_ for consistency. The whole exercise generated a database that was helpful to identify key technologies/systems demands, disaggregate departmental load, and calculate end-use specific categories contribution towards the total demand. This helped to identify and estimate main contributors, saving opportunities, and focus on energy efficiency investment areas.

A review of departmental and technology operation and production management was also taken. Most of the technology ran in tandem to departmental activity hours (as discussed in Section 5.4.2.2), with some exceptions such as stenter as discussed in Section (5.3.2.1). The technologies that ran under the management of maintenance department were mainly utilities (like boilers, air compressors, and heating systems) as discussed in Section 5.3.2. This initial exercise helped to design and target key technologies to focus on for micro-auditing and investigate any saving opportunities.

5.3.1.2 Establishing cost and baseline energy demand

A consistent representative energy (unit) cost was established. This was necessary in many aspects such as for a steady past, present, and future cost/saving comparisons/measures, prediction for future energy cost based on historical values, and other analyses such as energy efficiency related investment, and cost-benefit. Based on three-year (2011–2013) figures the rates for gas and electricity were established as £0.025/kWh and £0.10/kWh, respectively. Gas cost for steam calculations was rounded up to £0.03/kWh. This was to indicate the element of the true cost of steam generation as discussed in (U.S. DoE, 2003a).

Calculating the true cost of steam generation (that includes a number of cost components like boiler feedwater treatment, raw water supply, electric supply, etc. here collectively referred to as maintenance cost) was not possible for the case study site. This cost is assumed (where mentioned) in Section 6.2.2.3. Combining a walkthrough and a utility cost analysis, in addition to complementing each other, can identify low-hanging fruit (significant energy-saving opportunities). For example, using utility information, higher winter demand for one year as compared to another, without any significant change in weather, occupancy patterns, or technology retrofit, could indicate energy wastage. This may be due to air infiltration through windows/doors, steam leaks, inappropriate thermostat settings, or disabled/breakdown controls—all of which could be highlighted from a walkthrough.

Utility demand and cost analyses were carried out using energy invoices. For gas, where estimate billing was a general practice, consumptions based on real-time and estimate billing were compared, as discussed in Chapter 6. 2011 was set to be the base year for the study.

5.3.1.3 Departmental and end-use categories demand evaluation

Using the nameplate rating and operational data, one can calculate organisational energy and cost in numerous ways. Three types of such evaluations were chosen for this thesis. The first one is establishing individual technology load and cost (discussed in Sections 5.3.1.1 and 5.3.2). By multiplying the individual technology's utilisation- and load-factors with the total/aggregate load, the total demand/cost was obtained. The second is estimating departmental contribution towards the total load as discussed in Section 5.3.1.1, and the third one is based on the end-use load categories. Main contributing technologies belonging to individual departments were considered for this.

For a comprehensive classification of end-use categories energy and cost disaggregation, the technologies and systems are divided in to six main categories—gas users, steam users, radiation-based (e.g. microwave dryers), motor-based, small power and IT (computer/printer, lighting), and others (electric heaters, kitchen appliances, immersion heaters, domestic-type microwaves which were ignored due to lower demand). This logical categorisation was helpful to pinpoint possible potential for saving and capturing the devices with negligible demand and hence generally ignored in audits. The inherent magnitude of error persisted due to uncertainty in inputted utilisation- and load-factor. Therefore, alternative analysis methods offering the use of real-time energy data (as in Section 5.3.3) are considered for a crosscheck. The sub-sections in Section 5.3.3, in addition to directly addressing points 1–3 (in Section 5.1), create databases and make grounds for a detailed energy audit. This also provides an opportunity to compare these techniques. However, depending on the scope and method of the audit points 3─10 are more or less included in all enhanced standard and detailed energy audits. The points 3─4 and 7─10 are mostly considered in the detailed energy audit packages.

5.3.2 Performance evaluation of some end-use technology and key systems

Few key end-use technologies and systems were micro-audited by using various data sources (billing, manual collection (main gas and boilers sub-meters), clamp-on and invasive meters (as in Section 5.4 and the data generated from Section 5.3.1)) where necessary. Some evaluations were based on engineering principles (i.e. steam system) and indirect metering (boilers). The main purpose of measured/monitored data analysis was to have an in-depth understanding of the energy behaviour and efficiency opportunities. However, the method was also used to check, where possible, the theoretical and practical difference between nameplate and measurement-based assessments (like CA systems). Both long- and short-term monitoring with varying resolution was carried out, which is discussed subsequently. For the lighting nameplate rating method, a specific building—yarn production department was chosen for demonstration. The assessment mainly investigated lighting load, improvement opportunities, and (if) possible best practice lighting levels.

5.3.2.1. Gas using technology

Two key technologies, main boilers and the stenter were assessed. To identify boilers' various types of site-specific energy efficiency measures, as discussed in Chapter 3, monitoring along with technical assessment (such as, optimisation, and heat recovery) were designed. Monitoring included regular meter reads logging, as discussed in Section 5.4.1.2, the operation, maintenance, and controlling strategies, as discussed in Sections 5.4.1.2 and 5.4.1.4.

Gas demand for stenter was assumed from the product manual. Electric (motor) consumption was estimated through the aggregate demand of individual blowers. Short-term operation monitoring and scheduling were undertaken to identify the possible saving opportunities. These, for example, consisted of machine operating behaviour change, flue gas energy recovery, exhaust-air water vapour load optimisation, and hot gases dwell-time optimisation, as discussed in Chapter 6.

5.3.2.2 Steam using technology

Designing steam load measuring methods is difficult due to the complexity of steam consumption in technologies. This is due to several reasons such as complicated steady-state demand, unknown condensate return quantities, and no consumption rating information available on the nameplate. Only few will have inbuilt measuring devices and the rest requiring costly metering as arresting limitations for measuring and monitoring. Looking at steam distribution (such as insulation, leaking, and traps/valves repair), system improvement and affluent heat recovery can be effective. The evaluation in alliance with steam generating systems (boilers) can offer reasonable thermal energy efficiency opportunities.

Energy recovery from Dyehouse and Wet Finishing with site-specific limitations like sub-metering calibration were considered as discussed in Sections 5.4.1.2 and 5.4.1.5. Other limitations included the inability to install portable metering escalating reliance on theoretical consumption estimations. Water consumption in the dyeing house has been estimated through two estimations. According to one opinion (the departmental managers' observation as discussed in Section 5.4.1.5), roughly 35% of the department's total demand is used for thermal processes ($350m^3 \times 0.35=122m^3$). Another estimation, based on dyeing process data, suggests 80 batches/week (or 16 batches/day) of the dye pots only. These dye pots range between $1{,}000m^3$ to $2{,}000m^3$ and are thought to be responsible for 70% of the total thermal demand. This estimation is more reliable as it bypasses existing (non-calibrated) water metering and general human observation and is based on real-time production data. However, it poses issues like generalising the water quantity for various pot sizes (which is roughly assumed to be $1{,}500m^3$ for all) excluding the hank dyers. Hank dyers are being ignored due to two reasons: (i) connecting these machines to the heat recovery system facility can be a significantly costly job (as discussed in Section 6.4.3.2), and (ii) these machines do not generate a large quantity of hot water.

According to the department manager's estimation (as discussed in Section 5.4.1.5), wet finishing has a $350m^3$ water demand (or 80,500 m^3/annum), 35% ($122m^3$/day or $28{,}175m^3$/annum) of which is used for thermal treatment. To minimise the possibility of error these figures were crosschecked with the fresh water supply meters around the factory. Engineering principles based on straightforward mathematical heat recovery formulas (thermodynamic equations), as discussed in the relevant section of Chapter 6 were used for calculations.

5.3.2.3 Motor based technology

Three systems and technologies from two departments, Weaving and Yarn production (as discussed in Section 5.4.3.3) along with (in-depth) CA systems, were selected for a motor based micro- or detailed energy- audit. The use of clamp-on and invasive meters was designed for a more robust assessment to understand the difference between the two methods.

Due to the project scope, studying Weaving and Yarn-production machines in-depth (one-off invasive/non-invasive measurements were taken) was not possible. However, various efficiency opportunities were generally covered through motors Section 3.1.4. There were two types of weaving—Jacquard looms and Dornier looms. The three tested Jacquard looms indicated similar demand leading to an assumption that others were similar. The few tested Dorniers, similarly, indicated identical demands leading to assume the same for the rest. Due to technical challenges and operational restrictions, the use of clamp-on meters was not possible in the Yarn production department, hence invasive (electrical meter) method was used. Since, most technologies in these sub-sections were identical or at least were built in the same era one measurement on each type was assumed to represent the individual lot (machines carrying out same particular jobs). Assuming steady-state and measured data of the machines, the transience in the load-factor was ignored.

Out of two identical air compressors (CompAir®), only one runs (24×7hours) and the other is on backup alternately. Technical energy efficiency measures at generation point, distribution system including pressure dropping, and end-use were assessed. A clamp-on meter was used for hourly short-term (nine-hours/day for one month) monitoring. Some weekend readings (Saturday/Sunday) along with time gaps between two (on/off modulations) were also taken. This helped to assess the idling load that is attributable to leaks. The measured demand was the average of all the individual three-phase readings. The information helped to understand demand variation in response to activity, system leaks, and other parasitic loads (steam pumps) and identified saving opportunities as a result. Leaks and supply isolation/control systems throughout the distribution system were identified and a better leak control and supply management plan was devised (as discussed in Chapter 6).

5.3.2.4 Small power and IT

Due to the limitations discussed above and a large number of buildings, a case study building (Yarn manufacturing) was selected for a non-invasive (nameplate based) detailed lighting investigation, as discussed above in Section 5.3.1.3. Catering three manufacturing processes/sections (carding (1,512m^2), spinning (442m^2), and winding (494m^2)), the Yarn manufacturing building is a reasonably large-size shed (2,448m^2). Due to various sectional relocations within the building, over time, the lighting systems (T12 tubes with magnetic ballasts) and the arrangement offers (technical, operational, and behavioural) saving potential. The building is a typical example of old UK textile sheds.

Acquiring and using proprietary lighting simulation software was logical but was impractical due to budgetary constraints. Nonetheless, for certain knowledge and understating two lighting installation companies were contacted. Evaluating through software and product quotes only one company “B” completely undertook it. The other company, “A” was an LED specialist so they only proposed LEDs that would fit in the existing linear luminaires. The company, “B”, along with the simulation assessment presented various options (fluorescent T5 and T8, and LED tube lights). However, both the quotes indicated inaccuracy in their building assessment. Company “B” miscalculated the total building area leading to a misrepresentative number of installations, cost, and savings whilst “A” miscounted existing fluorescent tube lights. This was another example, as discussed in Section 5.2, of the risks involved with quick-fix surveys and the resultant efficiency. Although these types of misrepresentations could be adjusted if scrutinised by the receiver organisation, this would create more uncertainty about the project cost, illuminance levels, and the savings in this case.

Based on existing lumen levels and lighting energy demand, the researcher evaluated the fluorescent tubes and LED efficiency improvement potential without simulation. A light meter was used in the building to estimate incident light at different spots, as discussed in Section 5.3.4.2.

IT equipment in industrial sites can be of different types, with varied operational and energy requirements. In manufacturing, these might not be in as constant use as in office buildings, therefore assuming steady-state conditions may be unfair. Designing and applying some algorithm for a more appropriate methodology was out of scope for this thesis. It was also difficult to take account of individual IT equipment’s demand due to variation in technology, total number, brands, and age of the appliance. The problem was therefore simplified by assuming consistent demands for individual types of IT equipment (such as monitors, desktop CPUs, and other types). These demands were averaged from an ASHRAE’s nameplate rating based study (Hosni and Beck, 2011) as discussed in Section 3.2.5. The reason for selecting this study was as it indicated more than one nameplate rating for individual technologies. This was the case of calculation at the case study site as discussed in Section 5.3.1.4. For others (fridge, fan heater, and immersion heater) recorded nameplate ratings using relevant weekly hours and seasonality months were utilised.

5.3.3 Energy profiling and efficiency assessment based on high-resolution data

A review of high-resolution energy data is already taken in Section 2.2.4.1 and its use for complex manufacturing systems' energy analysis can be limited for both macro- and micro-audit types. Although it allows live data, biases like noise (parasitic demands) of technologies and equipment running elsewhere exist. Having departmental sub-metering installed at section/department level can reduce it as, discussed in Chapter 2, but have limitations. The proposed MS excel based whole analysis for the study is an EM technique having various enquiries and solutions, as discussed below.

The using of generally understood MS excel platform was to avoid the proprietary software. This allows energy managers/responsible for EM in the SMEs to easily use (or get trained on) this method. This multi-facet purpose-based technique can be tailor-made cost-effectively.

Yearlong sets of H-H energy data are calculated against the activity (mainly for electricity and gas unless mentioned). For electricity data (four-year-long) analyses have been carried out mainly, with some exceptions, for 2011 and 2014 for comparison of changes in the activity. The consumption and activity for 2012 and 2013 were very similar to that of 2011 (confirmed by producing daily demand profiles for these years), hence these years were removed for brevity. The analyses included understanding and establishing energy baseline load, averages, and variations for daily and weekdays, demand reduction during holidays, and the impact of weather and production on consumption. How data was organised to minimise misrepresentation, such as clock change, holiday periods, peak- and off-peak times and on- and off-production seasons are discussed in data collection Section 5.4.

Due to the unavailability of similar analyses for gas were not possible. The available data is used to understand consumption patterns and suggest saving opportunities. This method highlighted the importance of in-depth gas consumption analysis (for such manufacturing process). The whole exercise demonstrated that the method could be applied to high-resolution gas data to understand and identify key efficiency opportunities.

5.3.3.1 Baseline load and average demand

There are different ways to utilise H-H data to understand baseline load and average demand. This includes drawing daily consumption against kWh with/without any data arrangements (such as weekdays, and holiday removal), arranging and assessing weekdays individually, and taking and comparing averages (i.e. yearlong) of individual days. Having its own implications and level of details each one of these has something significant to offer for a particular analytical purpose. Some of these methods have been utilised in this thesis.

Various approaches were used to establish, understand, and compare (where desired) the baseline and average demands on site. A method of daily peak- and off-peak demand estimation using H-H data was designed after a thorough observation of the factory operations. Peak- and off-peak times in a day were identified for weekdays (Monday–Thursday, and Friday) and weekends. This was to segregate and estimate real-time average figures for each of these timeslots. This method was also used to estimate daily end-user demand (at departmental level). Further details about the different aspects and outcomes of the method are given in Sections 5.3.3.4 and 5.4.2.2. Daily total electricity demand was established by adding up all the 48 data points of the daily data. H-H data (kWh) was also used to calculate, segregate, and compare individual weekday total demand profiles over a year with the other year. To understand daily total demand variation of individual days in the whole year H-H data (kWh) was put together in a graph. For enhanced clarity, a summary of four years' demand was also added.

Statistical methods such as percentile for demand categorisation were also used. Values were taken for a weekday (Monday) to review the change in energy demand throughout the year. The whole procedure is further discussed in the next sub-section. To compensate for non-existent H-H historical data, another form of statistical analysis (box-and-whisker plots) was chosen for gas to establish weekday highs/lows and demand variation for the baseline year. The analysis was based on manually recorded daily gas demand.

5.3.3.2 Line plots for energy demand profiling and diagnosis

Demands (kWh) against daily consumption graphs have been produced to understand the whole year's energy picture and waste periods. This was based on H-H electricity data arrangements, such as defined above and below in Section 5.4, and then understanding the baseline energy use in 24-hour line graphs. The created profiles were also used to investigate baseline consumption and trends and patterns. To avoid misrepresentation holiday periods, as discussed in Chapter 4, were removed.

The H-H (kWh) data was transformed into kW to calculate the power demand. This was achieved by dividing kWh by 0.5 for all the 365 daily demand values. The comprehensive (4-yearlong electric) data was reasonably consistent (no gaps (except for gas), other than the clock change-related misreads) and was segregated and categorised, and individual weekdays noted. Using the weekday formula on the MS excel the data was separated into (51−53) individual weekdays. Two sets of data (2011 and 2014) were created to visualise and compare various seasonality-related (peak- and off-peak production and weather seasons) impacts on energy including waste/saving periods.

In addition to that, the H-H data was further organised in to five types of averages of each day as shown below;

- Total average
- On-production (March–October)
- Off-production (November–February)
- Summer-season (May–mid of October)
- Winter-seasons (mid of October–April)

These sets were then used to calculate different forms of values (i.e. average, highest, and lowest demands for analyses). This was to understand and interpret, in general, different demand aspects specific to the year and activity as discussed in Section 5.3.3.3. The individual day, average, analyses for individual years (2011 and 2014 electric) were carried out.

One year-long complete set of 2015 H-H gas data in kWh format was made available, analysed and segregated in a similar fashion to electricity. Unfortunately, the data represented the factory's changed operating times only (from January 2014 onwards) and no past data was available for comparison. After the rectification, as discussed in Section 5.4.1.2, this data was segregated into numerous average data sets as discussed in the above paragraph and treated the same way.

Percentile analysis is useful to understand and predict various demand scenarios against different conditions. These may be established by using historical energy, production, and climate data and empirical observations. Percentile values were taken for a weekday (electric Monday) to review the change in energy demand frequency throughout the year.

5.3.3.3 Demand profiling against activity for enhanced analysis

A novel approach of utilising empirical energy use to calculate demand profiles against the activity is carried out. The suggested approach/relationship can be used to realise energy-saving opportunities/waste (diagnose), understand energy efficiency against numerous variables such as production rates/activity, weather, and appropriate energy efficiency optimisation approaches. Different forms of average line plots, as discussed in Section 5.3.3.2 have been utilised against the activity table, as indicated in Section 5.4.2.2. The table is based on the factory's generalised daily operations as discussed in Chapter 4.

By observing the 24-hour shift patterns as identified in Section 5.4.2.2, time periods representing major activity changes were pinpointed and the corresponding average demands over those periods obtained. Using this combination of empirical energy data and known practices within the factory can provide quite a complete picture of energy use throughout the week and help highlight what is causing the features seen in the data. For example, the Dye house and Weaving (manufacturing (B)) are the only two departments that work through midnight (00:00–06:00). Therefore, the average load during these hours must represent the load incurred by them and, other than relatively low standby loads from elsewhere, nothing else. However, the same time period for Saturday and Sunday represents the assumed base load. The method however has some limitations such as inability to indicate the average number of staff, number of process technology in use, production units, and utilisation factor. Having details available of such metrics and analysing each of the metrics individually can make the analyses more robust.

The analyses carried out through high-resolution data developed a weighty relationship with both electric and gas data calculations based on macro- and micro-audits (Sections 5.3.1, 5.3.2, and 5.3.4). It was only possible through this analysis that change in activity within a day (24-hour) can be visualised in a more meaningful way. Thus, this can further be translated into causes (change in activity during the day) and their causal effects (i.e. the effect on energy demand). Hence, the start/stop activity of major causes (i.e. departments) and their impact on demand can be attributed, in an in-depth and more revealing way. The understanding and the figures computed through these analyses were used to compare and validate (if possible) the figures obtained through different standard energy and detailed audit calculations. For example, for electric these consisted of nameplate demand data based department demand, departmental demand figures calculated by using H-H empirical (numerical) data, and baseline energy use. The calculations through this method were also comparable with demand assessment made through Section 5.3.3.4. Despite, the shortage of H-H data for gas this was still used in different types of data interpretations such as validation for the boiler (sub-meter based), as well as the stenter's (nameplate based) demands. The data obtained was also used to compare demands assessed on the basis of observations such as consumptions for coffee-shop and hydroponic boilers. The data was also used to compare the past gas consumption data the accuracy of which had been put in to a question.

5.3.3.4 Assessing the energy use and efficiency of key end-uses

The H-H data is also used to calculate numerical energy demand values, which are then compared with energy profiles. These values are then visually compared with real-time energy data, and departmental energy demand figures based on nameplate value calculations. The method not only helped to produce realistic demand figures and highlight saving opportunities but also featured the strengths and weaknesses of individual approaches. To estimate the varying energy demand in a day, different periods corresponding to specific activities were identified, as discussed in Sections 5.3.3.1 and 5.4.2.2. By utilising half-hourly electricity data, estimates representing the average load over these time periods were obtained. Averages for Monday through to Thursday were taken together due to similar working hours (except for 1hour early finishing on Thursday) and Friday was estimated separately as it helped to determine the base load; this was further improved by adding on the average demand for Saturday and Sunday base loads. Due to complex working hours and variable start and finishing times of the Operations sections throughout the year, it was not possible to segregate the load for individual sections directly. However, based on the method, the average end-use consumption for the production departments (manufacturing (A) Yarn production and Finishing and Manufacturing (B) Dye house and Weaving), baseload, and for Operations were identified.

5.3.4 Textile manufacturing-specific energy performance assessment

5.3.4.1 SEC and building energy benchmarking

Monthly and annual data was used for SEC and the carbon emissions calculations for the whole factory, as discussed in Section 5.4.2.1. This data consisted of materials/processes produced/carried out, in all the four departments, both internally and externally. Ideally, the SEC for the individual companies' individual processes should be known to disaggregate energy use/carbon emissions taking place internal/external to the factory (as, it allows in-depth understanding and analysis). Unfortunately, this was practically not possible due to the availability/accessibility for the energy/SEC data for the supplier companies. This again shows the need of the energy evaluation of individual textile units that will act as building blocks towards the larger sectoral/industrial energy picture. Such data/knowledge obtained could be utilised in different angles i.e. for the researchers, for the carbon-conscious textile products retailers, and for the green consumers. Although tailored to an individual case-study, the essential structure is designed to be transferable to other textile firms wishing to carry out such studies. Some sub/process energy use assumptions, specifically based on subcontracting, are generalised as most of these factories are EU based. This is based on the assumption that the technology, environment, and labour conditions are almost the same in the region.

The simple equation for the SEC calculation, as mentioned in Section 2.3.1, is being used for such evaluation in the thesis. SEC for the finished product is possible either for units invoiced or meters produced. Due to complications in the unit of items produced, as discussed in data collection Section 5.4.1 e.g. variation in sizes, it would create misrepresentation. Although metres produced is a consistent product unit but even this will have issues like the variation in weight (and the resultant energy use) per meter for different varieties. This could invite some further investigations (out of the scope of this thesis). Therefore, metre was the most suitable product unit for SEC calculations (in that it is technically average SEC (SEC_{AV}) as discussed in Section 2.3.1, but is being termed as normal SEC). Another benefit of using this product unit was the opportunity to compare the present SEC with the past SEC as calculated in the energy survey report in 2005 (CPP, 2006) as shown in Table 34. SECs for all the four years were calculated (with and without upstream energy as discussed in the next section) and compared.

Building energy performance assessment (kW.h m^{-2}) was also carried out to compare with benchmarks indicated by (CIBSE Guide F, 2012). There were various things such as the population, shift-patterns, and format of the textile units that were not clear about the data. Based on these factors benchmark comparison for a complicated manufacturing like composite textile might not be a greater choice. However, the benchmark had some advantages too, such as being UK specific and relatively recent. Therefore, a comparison was thought to be a reasonable choice to indicate performance in terms of building energy use per floor area.

5.3.4.2 Lighting levels in textile manufacturing

Guidelines for lighting levels/energy performance in different industrial buildings have been suggested in industrial performance exemplars such as (SLL, 2012b). These indications play a key role in lighting performance studies/implementation projects. These indicators have been designed on a different technical basis e.g. watts/unit area/annum for energy, lumens/unit area for visibility experience, or incident lighting levels on the imaginary floor/surface area. In the absence of these one could compare and improve against the existing conditions.

Watts/m^2 is generally used for non-domestic buildings. However, for manufacturing sites lighting within the same building/premises/shed may be subject to different tasks and intensities (another reason for energy specificity in manufacturing requiring site-specific energy investigation). Therefore, lighting assessments in industrial buildings may require similar approach designed in a different manner. As inappropriate lighting levels can affect the workers' performance too, therefore, the use of higher lux levels is very much likely to happen. Therefore, generalising energy use per unit area may not be something that is exactly desired.

Due to the complex nature of processes and distinction among the boundaries of some buildings/sheds imaginary boundaries were delineated. Evaluating these buildings on watts/unit area/annum against the existing performance was a good thing to start with. One may compare this with existing energy benchmarks, which was not only difficult to find but also slightly less justified criterion as mentioned above. The other way was to benchmark these buildings against the existing energy demand and then targeting for reducing that. This approach was found to be suitable therefore a pilot project on one of the buildings—Yarn Production was carried out.

Since the factory's main lighting source was fluorescent tubes therefore the case-study building, as discussed in 5.3.2.4, was evaluated against different lighting technologies. Different buildings have different lighting benchmarks, working conditions, lighting setups, and activity times, therefore will have different lighting requirements. However, the assessment procedure used for the case-study shed is suggested to be adaptable to any type of buildings in the factory. SLL's (SLL, 2012b) textile lighting levels benchmarks may be a good option to follow.

5.3.4.3 Building heating and cooling and production related energy assessments

HVAC can make-up a large portion of industrial energy and the system's control, without an EM initiative in place rely on the users or the maintenance engineers. Either way the system's underperformance, in terms of both energy efficiency and user comfort, is likely. Therefore, temperature settings guidelines for factory buildings have been published by industry focused research institutes such as CIBSE Guide B (2005). This in addition to enhancing energy efficiency and the user experience can become a strong basis for the decision-making. Examples of lower/higher thermostat settings compared to the guidelines have also been observed.

The temperature settings around the factory, specifically controlled through the BEMS system, were reviewed against the CIBSE's indicators. In some buildings the heating was found to be 1˚C–2˚C higher than the CIBSE's hence were suggested to be revised accordingly. However, it is difficult to measure and realise the total and individual savings as it can escalate new investigations. These can include investigating from quantifying building-heating related thermal demand, building fabric, draught-proofing, to and process heat will be needed. Many buildings have independent automated and manual heating systems and the existing features of the BEMS need upgrading. Through this project the building heating related thermal demand has been estimated through basic principles, as indicated in Table 35 along with a simple regression analysis, as discussed below. Due to brevity and the reasons, discussed above, it was not possible to undertake a thorough HVAC investigation for energy analyses and tailoring savings measures. However, the equipment has been minimally covered through behavior management as mentioned above, motor systems, and general steam system improvement. It is, however, believed that a thorough investigation can yield beneficial results and could be investigated in future.

Simple linear regression between the variables such as energy and production and weather was chosen for analyses in Section 6.1.4.1. Monthly energy data from the invoices, H-H, and or manually recorded (aggregated kWh) was used to regress against production and weather data. This was to establish the strength of the correlation as well as the impact of their variation on energy use.

5.3.5 Carbon accounting

It requires a systematic calculation approach to estimate and reduce CO_2 emissions. A textile retailer, for example, will require emissions calculations from its operations, production processes, and the supply chain. Comprehensive information on such topics is generally not available due to several reasons as discussed in Chapter 2. This requires organisations to use factors/values pre-set by relevant professional institutes.

One way of designing such an assessment method for the factory is calculating upstream CO_2 footprint i.e. wool and other raw materials produced through to the after manufacturing and disposal phase (downstream flow). However for brevity, the scope boundary was confined to upstream (cradle-to-factory gate flow) which also had data availability limitations. Port-to-port and land distances (due to complicated sea and land (or both raw materials and unfinished goods) movement) related problems with complicated supply chain, and data availability were hindering factors. Unfortunately, due to the unavailability of transportation data, emissions could not be estimated. Another accounting step skipped due to data unavailability was the amount of factory's wastewater generation in 2014.

Based on LCA approach the accounting methodology utilises instructions and approaches suggested by major CO_2 accounting methods/specifications (such as Defra/DECC, PAS-2050, and PAS-2395) and Defra's emission factors, as discussed in 2.3.2. Two types of CO_2 assessments, organisational (limited upstream processes) and a selected factory article (WA 000608) were undertaken.

5.3.5.1 Organisational GHG

Four years' organisational GHG emissions were evaluated, with 2014 being the best described. The emissions covered from some of the high-impact activities, as indicated in Table 9, with a wider range from raw material (wool/cashmere only) sourcing to processing on site (as discussed in Chapter 4). This is indicated and clarified in schematic Figure 58 below and scope Table 37. Scopes 1 and 2 emissions were mainly focused (including well-to-wheel, and tank-to-wheel for fuels, assumed to be included in the emission factors) as compared to Scope 3 due to prevailing limitations as suggested elsewhere (BSI, 2011b). This included unavailability of 2014 wastewater generated onsite (treated off-site) data. Due to complex raw materials and unfinished goods' supply chain (across the world, mainly from China to the UK and then from UK warehouse/s to the factory) transport-related data could not be retrieved. The limitation, also being related to low-intensity materials/processes, led to an easy exclusion from the calculation, as suggested elsewhere (PAS-2050/2011) and discussed in 2.3.2.2, and indicated in Figure 58. The PAS-2050/2011 also suggests that the employees commuting could be ignored (further elaborated in 5.4). Despite all, it is assumed that 95% of the anticipated CO_2 is being covered (as recommended for scoping by the PAS-2050/2011). Some of the part/s of each process is fully or partly processed offsite by some sub-contractor (from Chapter 4). Going back to individual sub-contractors and learning about their individual site's energy efficiency is not practical. However, most of the sub-contractors processing units are the UK and the EU (mainly in Italy) based, hence considered alike. Although the energy/CO_2 used by these sub-contractors is likely to be missed out. In some ways, it is helpful to minimise some energy/carbon uncertainty, for example, the yarn used in the factory was produced elsewhere, as in Section 4.4. The emission calculations, depending on the data availability, were based on primary and secondary data as indicated in Table 38.

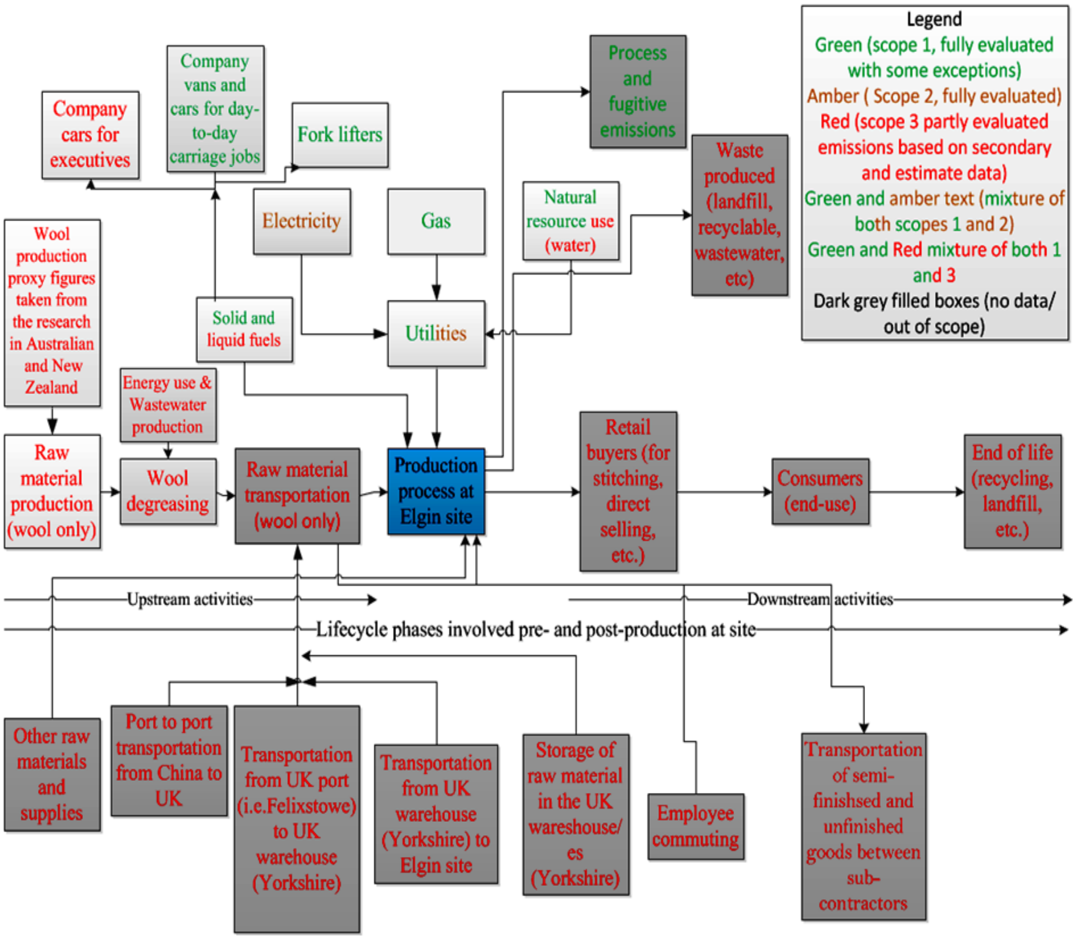


Figure 58 - Schematic of scopes covered for CO_2 accounting

The colour in the legend refers to an individual text. Mixed colour text in the boxes indicates the scope and the type of evaluation.

Table 37 - Scopes and the relevant forms of data subjects

Scope 1	Scope 2	Scope 3
Gas (kWh)	Electricity	Company cars for executives (kilometres)
Solid and liquid fuels (litres, kg)		Raw materials (wool only, kg/tonne)
Company cars and loader vans (kilometres)		Water used and wastewater produced for raw material production (kg/tonne)

Table 38 - Data gaps and assumptions made for analysis

Assumptions	Primary data sources	Secondary data sources
All the raw material (wool/cashmere in this case) is imported from China	Amount of wool and cashmere used per year	GHG/CO_2 emission factors for: fossil fuels, power, power supply and distribution losses, well to tank and tank to wheel
	Total electricity, gas, liquefied petroleum gas, diesel used on site	Kg of CO_2e for per kg of wool production
	Miles covered by leased company cars and fuel used by company owned loader vans and cars	Energy involved in greasy wool cleaning and water treatment from some UK study

The scope and limitations of the whole organisational GHG assessment (cradle-to-factory gate/business-to-business) are already defined above. For organisational GHG calculation (factory-to-factory) scope 1 and 2 emissions are mainly targeted.

For the primary and secondary carbon emissions Defra's emission (factors) were used. Whereas, going out of the organisation's boundaries (wool production) was tricky hence estimates that were produced by other researchers ((Singh, Carliell-Marquet and Kansal, 2012), (Eady, Carre and Grant, 2012), and (Murphy and Norton, 2008)), as discussed in 2.3.2 were used (this was the best available research-based possible approach). These mainly consisted of energy/carbon from; raw wool production, and degreasing, and the wastewater treatment resulting from it.

5.3.5.2 Specific product GHG

The specific cashmere article (WA000608) was selected for limited (at simplest levels) GHG evaluation as discussed in Sections 5.4.2.1 and 5.4.2.5.

Within the limitations and scope of the case-study site, one evaluation approach could be segregating emissions at two levels that is upstream and within the organisation. This approach could have been more robust if energy and supply chain data from the external suppliers were available. The method used for the current calculation was based on organisational (including some upstream emissions) footprint. The only difference that was made to it was subtracting the calculated emission (per unit of production) from the total emissions corresponding to the quantity of the WA000068 was produced.

5.4 Data collection and management

Better EM starts with better energy measuring and monitoring. Two forms of data, based on resolution, was recognised—high-resolution (available on a sub-daily basis) and low-resolution data (generally, greater than a day). In the absence of appropriate high-resolution data, conventional low-resolution data play a key role in energy assessments (demands/flows and saving measures). High-resolution data, if appropriately dealt with, can facilitate far better and revealing analyses. In the absence of both, observation-based estimations become key information contributor (as used in some cases). Four years (2011–2014) long data for both gas and electricity have been collected and organised with some exceptions such as 2015 H-H data for the gas. Other types of data such as production, weather, or monitoring have been selected from within these four years.

5.4.1 Utility data sources

Utility invoices (estimates) and meters are the two main demand data sources for initial condition surveys and cost analysis. Manual or automatically collected metered data (electricity and gas) can be useful.

Modern electric meters have an AMR system with an online portal. For gas, high-resolution data is not mandatory therefore such readings were uncommon until more recently, as discussed in Chapter 2. Therefore, separate units are becoming a common practice. Similarly, small quantities of such data were made available onsite.

Recorded in-situ demand data for individual technology represents a far more accurate consumption than anything else discussed in Sections 5.4.2.3 and 5.4.3.3 and steam in 5.4.1.4. For energy/steam evaluations, water-related data is useful in different forms as discussed in Section 5.4.1.5.

5.4.1.1 Electricity data

Various forms/formats (kWh/kVA) of electricity data such as invoices, distribution boards, primary-, built-in- (technology) or sub-meter for online data logging can be useful. The monthly invoices with peak- and off-peak demands (highest/lowest values) and cost summary are useful for various analyses.

In the absence of sub-metering, distribution boards to various channels can play a reliable demand indication/estimation role. However, in the case of old-style non-digital distribution boards higher levels of error and bigger scale on the dial is pertinent as observed onsite. Therefore these were not taken the advantage of. Energy monitoring devices, self-purchased/hired from companies such as ENMAT (ENMAT, 2018) and Optimal Monitoring (Optimal monitoring, 2018) could not be installed due to the associated costs.

Manual readings can be a common practice for many industries and can be extended to sub-meters, if installed, and can be useful along with other data sources. However the risks, human error, gaps, and differences (i.e. values/times) are likely to occur. These data are historically crucial for sites/systems EM. Despite daily meters' readings taking routine electricity has been ignored possibly due to no EM programme or H-H data logging.

Having electricity sub-meters around the site, for accurate end-use demand and consumption understanding, was considered. Unfortunately, limitations like complicated supply systems and higher costs refrained it. To analyse the available H-H data, scientific methods, as discussed in Section 5.3.3, were designed.

The electric tariff plan for the site is day-time (7 am-midnight) higher and night-time lower. Thus the available H-H data for analysis is from the main meter which supplies the whole factory, excluding some buildings (highlighted red in the Appendix 1 (a)). The measured consumption (online portal) accuracy is cross-checked with another meter installed alongside, as shown in Figure 59.

Figure 59 - Primary electric and verifier meters

5.4.1.2 Gas/thermal energy data

Gas data, generally, consist of utility invoices, primary meters, sub-meters, and meters installed on the end-use technology. Gas supplies still largely rely upon analogue flow meters, as shown in Figure 60 (A) and correctors for larger sites, as shown in Figure 60 (B). In the absence of sub-meters, the primary meter along with the corrector can be a good source of demand evaluation. The factory had been recording both primary and the corrector meter readings since 2010. During the daily (Monday–Friday) gas database compilation, any human errors were rectified considering the past and future consumption (i.e. duplicating). The database obtained thus helped to overcome the estimate invoicing/cost issues. Energy invoices are generally used to establish cost, average (periodic) use, and can also be used for rough demand trends such as weather or production seasonality based demand. Although the monthly gas invoices were estimates, these were still helpful to understand the unit cost, calorific value, correction factor, and comparison of real-time consumption and the supplier's estimation.

A) Analogue gas meter on site

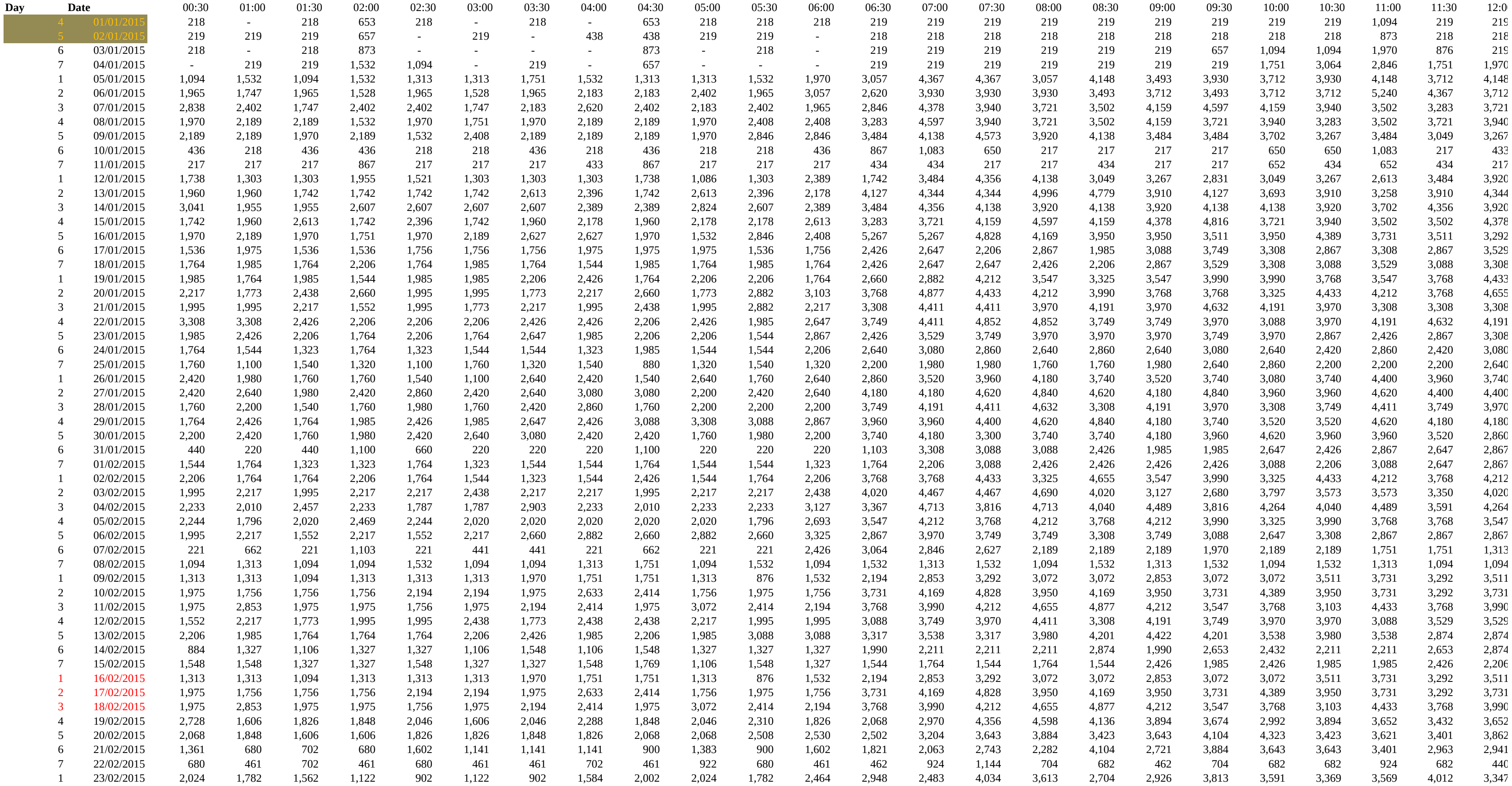
B) On site gas corrector meter

Figure 60 - Gas metering system

Sub-meters could have been a more accurate and reliable data option. Unfortunately, they only existed in the boiler house (only on boilers 3 and 4). As these had never been monitored, therefore taking daily manual readings was implemented. Due to these meters' life expectancy, only less than 1½ years (between 2012–2014) data was recorded. This played a pivotal role in various such as demand and categorisation estimation at end-use level, and total steam quantification as discussed in Section 5.3.2.2.

Installing AMR data loggers can be unpopular due to the reduced data usefulness, reduced availability of analyses tools, and higher equipment and installation cost. The increasing trend of H-H gas data availability requires novel analyses techniques for energy demand interpretation diagnosis. With the researcher's efforts, an AMR data logger was installed on the main gas meter in 2013. Unfortunately, a series of installation and optimisation issues halted the production of reliable, quality long-term data.

Only a limited quantity of whole-year H-H data (2015) was made available, though represented consumptions with varied operations as discussed above. Minor issues, such as double readings and missing data (red for February 16-18 in Figure 61) were corrected with the values (1,2, and 3 in column A) available previously (day, week, or weekends). Zero readings were left unattended indicating consumption below a certain minimum quantity (automatically added to the next value). Holiday data was separated and was dealt with separately. The production and electricity demand for 2015 is unknown. However, the total gas demand was 17,422,390kWh (which is 426MWh more than in 2011).



Day	**Date**	00:30	01:00	01:30	02:00	02:30	03:00	03:30	04:00	04:30	05:00	05:30	06:00	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:0
4	01/01/2015	218	-	218	653	218	-	218	-	653	218	218	218	219	219	219	219	219	219	219	219	219	1,094	219	219
5	02/01/2015	219	219	219	657	-	219	-	438	438	219	219	-	218	218	218	218	218	218	218	218	218	873	218	218
6	03/01/2015	218	-	218	873	-	-	-	-	873	-	218	-	219	219	219	219	219	219	657	1,094	1,094	1,970	876	219
7	04/01/2015	-	219	219	1,532	1,094	-	219	-	657	-	-	-	219	219	219	219	219	219	219	1,751	3,064	2,846	1,751	1,970
1	05/01/2015	1,094	1,532	1,094	1,532	1,313	1,313	1,751	1,532	1,313	1,313	1,532	1,970	3,057	4,367	4,367	3,057	4,148	3,493	3,930	3,712	3,930	4,148	3,712	4,148
2	06/01/2015	1,965	1,747	1,965	1,528	1,965	1,528	1,965	2,183	2,183	2,402	1,965	3,057	2,620	3,930	3,930	3,930	3,493	3,712	3,493	3,712	3,712	5,240	4,367	3,712
3	07/01/2015	2,838	2,402	1,747	2,402	2,402	1,747	2,183	2,620	2,402	2,183	2,402	1,965	2,846	4,378	3,940	3,721	3,502	4,159	4,597	4,159	3,940	3,502	3,283	3,721
4	08/01/2015	1,970	2,189	2,189	1,532	1,970	1,751	1,970	2,189	2,189	1,970	2,408	2,408	3,283	4,597	3,940	3,721	3,502	4,159	3,721	3,940	3,283	3,502	3,721	3,940
5	09/01/2015	2,189	2,189	1,970	2,189	1,532	2,408	2,189	2,189	2,189	1,970	2,846	2,846	3,484	4,138	4,573	3,920	4,138	3,484	3,484	3,702	3,267	3,484	3,049	3,267
6	10/01/2015	436	218	436	436	218	218	436	218	436	218	218	436	867	1,083	650	217	217	217	217	650	650	1,083	217	433
7	11/01/2015	217	217	217	867	217	217	217	433	867	217	217	217	434	434	217	217	434	217	217	652	434	652	434	217
1	12/01/2015	1,738	1,303	1,303	1,955	1,521	1,303	1,303	1,303	1,738	1,086	1,303	2,389	1,742	3,484	4,356	4,138	3,049	3,267	2,831	3,049	3,267	2,613	3,484	3,920
2	13/01/2015	1,960	1,960	1,742	1,742	1,742	1,742	2,613	2,396	1,742	2,613	2,396	2,178	4,127	4,344	4,344	4,996	4,779	3,910	4,127	3,693	3,910	3,258	3,910	4,344
3	14/01/2015	3,041	1,955	1,955	2,607	2,607	2,607	2,607	2,389	2,389	2,824	2,607	2,389	3,484	4,356	4,138	3,920	4,138	3,920	4,138	4,138	3,920	3,702	4,356	3,920
4	15/01/2015	1,742	1,960	2,613	1,742	2,396	1,742	1,960	2,178	1,960	2,178	2,178	2,613	3,283	3,721	4,159	4,597	4,159	4,378	4,816	3,721	3,940	3,502	3,502	4,378
5	16/01/2015	1,970	2,189	1,970	1,751	1,970	2,189	2,627	2,627	1,970	1,532	2,846	2,408	5,267	5,267	4,828	4,169	3,950	3,950	3,511	3,950	4,389	3,731	3,511	3,292
6	17/01/2015	1,536	1,975	1,536	1,536	1,756	1,756	1,756	1,975	1,975	1,975	1,536	1,756	2,426	2,647	2,206	2,867	1,985	3,088	3,749	3,308	2,867	3,308	2,867	3,529
7	18/01/2015	1,764	1,985	1,764	2,206	1,764	1,985	1,764	1,544	1,985	1,764	1,985	1,764	2,426	2,647	2,647	2,426	2,206	2,867	3,529	3,308	3,088	3,529	3,088	3,308
1	19/01/2015	1,985	1,764	1,985	1,544	1,985	1,985	2,206	2,426	1,764	2,206	2,206	1,764	2,660	2,882	4,212	3,547	3,325	3,547	3,990	3,990	3,768	3,547	3,768	4,433
2	20/01/2015	2,217	1,773	2,438	2,660	1,995	1,995	1,773	2,217	2,660	1,773	2,882	3,103	3,768	4,877	4,433	4,212	3,990	3,768	3,768	3,325	4,433	4,212	3,768	4,655
3	21/01/2015	1,995	1,995	2,217	1,552	1,995	1,773	2,217	1,995	2,438	1,995	2,882	2,217	3,308	4,411	4,411	3,970	4,191	3,970	4,632	4,191	3,970	3,308	3,308	3,308
4	22/01/2015	3,308	3,308	2,426	2,206	2,206	2,206	2,426	2,426	2,206	2,426	1,985	2,647	3,749	4,411	4,852	4,852	3,749	3,749	3,970	3,088	3,970	4,191	4,632	4,191
5	23/01/2015	1,985	2,426	2,206	1,764	2,206	1,764	2,647	1,985	2,206	2,206	1,544	2,867	2,426	3,529	3,749	3,970	3,970	3,970	3,749	3,970	2,867	2,426	2,867	3,308
6	24/01/2015	1,764	1,544	1,323	1,764	1,323	1,544	1,544	1,323	1,985	1,544	1,544	2,206	2,640	3,080	2,860	2,640	2,860	2,640	3,080	2,640	2,420	2,860	2,420	3,080
7	25/01/2015	1,760	1,100	1,540	1,320	1,100	1,760	1,320	1,540	880	1,320	1,540	1,320	2,200	1,980	1,980	1,760	1,760	1,980	2,640	2,860	2,200	2,200	2,200	2,640
1	26/01/2015	2,420	1,980	1,760	1,760	1,540	1,100	2,640	2,420	1,540	2,640	1,760	2,640	2,860	3,520	3,960	4,180	3,740	3,520	3,740	3,080	3,740	4,400	3,960	3,740
2	27/01/2015	2,420	2,640	1,980	2,420	2,860	2,420	2,640	3,080	3,080	2,200	2,420	2,640	4,180	4,180	4,620	4,840	4,620	4,180	4,840	3,960	3,960	4,620	4,400	4,400
3	28/01/2015	1,760	2,200	1,540	1,760	1,980	1,760	2,420	2,860	1,760	2,200	2,200	2,200	3,749	4,191	4,411	4,632	3,308	4,191	3,970	3,308	3,749	4,411	3,749	3,970
4	29/01/2015	1,764	2,426	1,764	1,985	2,426	1,985	2,647	2,426	3,088	3,308	3,088	2,867	3,960	3,960	4,400	4,620	4,840	4,180	3,740	3,520	3,520	4,620	4,180	4,180
5	30/01/2015	2,200	2,420	1,760	1,980	2,420	2,640	3,080	2,420	2,420	1,760	1,980	2,200	3,740	4,180	3,300	3,740	3,740	4,180	3,960	4,620	3,960	3,960	3,520	2,860
6	31/01/2015	440	220	440	1,100	660	220	220	220	1,100	220	220	220	1,103	3,308	3,088	3,088	2,426	1,985	1,985	2,647	2,426	2,867	2,647	2,867
7	01/02/2015	1,544	1,764	1,323	1,323	1,764	1,323	1,544	1,544	1,764	1,544	1,544	1,323	1,764	2,206	3,088	2,426	2,426	2,426	2,426	3,088	2,206	3,088	2,647	2,867
1	02/02/2015	2,206	1,764	1,764	2,206	1,764	1,544	1,323	1,544	2,426	1,544	1,764	2,206	3,768	3,768	4,433	3,325	4,655	3,547	3,990	3,325	4,433	4,212	3,768	4,212
2	03/02/2015	1,995	2,217	1,995	2,217	2,217	2,438	2,217	2,217	1,995	2,217	2,217	2,438	4,020	4,467	4,467	4,690	4,020	3,127	2,680	3,797	3,573	3,573	3,350	4,020
3	04/02/2015	2,233	2,010	2,457	2,233	1,787	1,787	2,903	2,233	2,010	2,233	2,233	3,127	3,367	4,713	3,816	4,713	4,040	4,489	3,816	4,264	4,040	4,489	3,591	4,264
4	05/02/2015	2,244	1,796	2,020	2,469	2,244	2,020	2,020	2,020	2,020	2,020	1,796	2,693	3,547	4,212	3,768	4,212	3,768	4,212	3,990	3,325	3,990	3,768	3,768	3,547
5	06/02/2015	1,995	2,217	1,552	2,217	1,552	2,217	2,660	2,882	2,660	2,882	2,660	3,325	2,867	3,970	3,749	3,749	3,308	3,749	3,088	2,647	3,308	2,867	2,867	2,867
6	07/02/2015	221	662	221	1,103	221	441	441	221	662	221	221	2,426	3,064	2,846	2,627	2,189	2,189	2,189	1,970	2,189	2,189	1,751	1,751	1,313
7	08/02/2015	1,094	1,313	1,094	1,094	1,532	1,094	1,094	1,313	1,751	1,094	1,532	1,094	1,532	1,313	1,532	1,094	1,532	1,313	1,532	1,094	1,532	1,313	1,094	1,094
1	09/02/2015	1,313	1,313	1,094	1,313	1,313	1,313	1,970	1,751	1,751	1,313	876	1,532	2,194	2,853	3,292	3,072	3,072	2,853	3,072	3,072	3,511	3,731	3,292	3,511
2	10/02/2015	1,975	1,756	1,756	1,756	2,194	2,194	1,975	2,633	2,414	1,756	1,975	1,756	3,731	4,169	4,828	3,950	4,169	3,950	3,731	4,389	3,950	3,731	3,292	3,731
3	11/02/2015	1,975	2,853	1,975	1,975	1,756	1,975	2,194	2,414	1,975	3,072	2,414	2,194	3,768	3,990	4,212	4,655	4,877	4,212	3,547	3,768	3,103	4,433	3,768	3,990
4	12/02/2015	1,552	2,217	1,773	1,995	1,995	2,438	1,773	2,438	2,438	2,217	1,995	1,995	3,088	3,749	3,970	4,411	3,308	4,191	3,749	3,970	3,970	3,088	3,529	3,529
5	13/02/2015	2,206	1,985	1,764	1,764	1,764	2,206	2,426	1,985	2,206	1,985	3,088	3,088	3,317	3,538	3,317	3,980	4,201	4,422	4,201	3,538	3,980	3,538	2,874	2,874
6	14/02/2015	884	1,327	1,106	1,327	1,327	1,106	1,548	1,106	1,548	1,327	1,327	1,327	1,990	2,211	2,211	2,211	2,874	1,990	2,653	2,432	2,211	2,211	2,653	2,874
7	15/02/2015	1,548	1,548	1,327	1,327	1,548	1,327	1,327	1,548	1,769	1,106	1,548	1,327	1,544	1,764	1,544	1,764	1,544	2,426	1,985	2,426	1,985	1,985	2,426	2,206
1	16/02/2015	1,313	1,313	1,094	1,313	1,313	1,313	1,970	1,751	1,751	1,313	876	1,532	2,194	2,853	3,292	3,072	3,072	2,853	3,072	3,072	3,511	3,731	3,292	3,511
2	17/02/2015	1,975	1,756	1,756	1,756	2,194	2,194	1,975	2,633	2,414	1,756	1,975	1,756	3,731	4,169	4,828	3,950	4,169	3,950	3,731	4,389	3,950	3,731	3,292	3,731
3	18/02/2015	1,975	2,853	1,975	1,975	1,756	1,975	2,194	2,414	1,975	3,072	2,414	2,194	3,768	3,990	4,212	4,655	4,877	4,212	3,547	3,768	3,103	4,433	3,768	3,990
4	19/02/2015	2,728	1,606	1,826	1,848	2,046	1,606	2,046	2,288	1,848	2,046	2,310	1,826	2,068	2,970	4,356	4,598	4,136	3,894	3,674	2,992	3,894	3,652	3,432	3,652
5	20/02/2015	2,068	1,848	1,606	1,606	1,826	1,826	1,848	1,826	2,068	2,068	2,508	2,530	2,502	3,204	3,643	3,884	3,423	3,643	4,104	4,323	3,423	3,621	3,401	3,862
6	21/02/2015	1,361	680	702	680	1,602	1,141	1,141	1,141	900	1,383	900	1,602	1,821	2,063	2,743	2,282	4,104	2,721	3,884	3,643	3,643	3,401	2,963	2,941
7	22/02/2015	680	461	702	461	680	461	461	702	461	922	680	461	462	924	1,144	704	682	462	704	682	682	924	682	440
1	23/02/2015	2,024	1,782	1,562	1,122	902	1,122	902	1,584	2,002	2,024	1,782	2,464	2,948	2,483	4,034	3,613	2,704	2,926	3,813	3,591	3,369	3,569	4,012	3,347

Figure 61 - Gas double readings and missing data

5.4.1.3 Intrusive/non-intrusive data

Quick demand snapshots (intrusive/non-intrusive) can be used for long-term data syntheses. Intrusive methods can be impractical in manufacturing for reasons like disruption in the production process, therefore are generally avoided. Non-intrusive methods using CTs may be low-cost but these devices still need installation/access to the supply board. Due to cost constraints, buying/hiring such devices was even not practical. Clamp-on meters were luckily found in factory workshops, could be utilised to synthesise longer-term steady-state demands. Despite, limitations like sometimes requiring access to main supply board, these were the only no-cost and effective end-use demand measuring option. Key monitored technologies belonged to Weaving and Yarn production, as indicated in Table 39. One-off readings from individual technologies, assumed to be representing the rest of the identical technologies, as discussed above, were also taken. The CA system, however, was exceptionally monitored for few weeks on an hourly basis (as discussed in 5.3.2.3).

Table 39 - Non-intrusive demand monitoring of key technologies

Department/ utility	Section	No.	Technology	No. of techs.	Measurement type	Output	Structure	Nameplate demand (kW)	Measured demand (kW)
Weaving	Weaving	1	Jacquard staubuli	8	digital clamp-on	amps	almost identical	8 to 11.5	5
		2	Dornier	18	digital clamp-on	amps	almost identical	8 to 13	4.5
Yarn production	Carding	3	carding machines	8	intrusive digital electrical meter	amps	7 are almost identical	28	15
	Spinning	4	Bigagli machines	4	intrusive digital electrical meter	amps	all are identical	55	20
	Twisting	5	Savio twist	2	intrusive digital electrical meter	amps	almost identical	20	4
	Schlaphrost	6	Winding	2	intrusive digital electrical meter	amps	almost identical	19	9
	Cleaning/Fettling vacuum pumps	7	Fettling pumps	3	intrusive digital electrical meter	amps	various built	30	26
Compressed air	Supply throughout the factory	8	CompAir	2	digital clamp-on	amps	Identical	45	40

- *Amps were converted in to kWh*
- *The assumed load factor and rated efficiency=0.8*

Manufactured post-2000, all of the Weaving machines had multiple DC motors (many having VSDs) with some CA driven rotational components. The measured (clamp-on meter) demands, compared to rated power, were reasonably low (as in Table 39).

Data for Dornier and Jacquard machines was separately recorded. Out of the total eight carding machines only one machine had a significantly higher nameplate rating and the rest were almost identical. As it had built-in VSDs, therefore its demand was assumed no different from the others. The nameplate ratings, on all the four identical Bigagali spinning machines, were significantly higher than the measured values. This was due to inbuilt VSDs on them. Similar findings observed on the identical pairs of Schlafhrost and Savio machines, that had inbuilt VSDs. However, the readings on the vacuum/fettling pumps were not much different from the nameplate ratings. This was attributed to the absence of VSDs on them. Collection of such data provided a good opportunity to figure out the degree of difference between nameplate rating, real-time consumption, and the impact of VSD installation on motors. This is further discussed in Table 54.

5.4.1.4 Steam data

Steam, in addition to manufacturing can also be a cheaper source for building services' thermal demand. In the absence of steam metering systems, engineering principles and rules of thumb are generally applied for demand/quantification estimation and the associated losses. A bottom-up approach can facilitate the total demand estimation. Individual technology demands can be determined either through inbuilt or post-retrofitted metering systems. However, this happens rarely due to associated limitations with each method. Non-intrusive measurement is relatively cheaper when using pre-owned or rental meters. However, problems like high-temperature pipes, systems' locations at heights, and or just too many different technologies to monitor may be confronted. The other option is to get specialists' services. Such as Mars Food Company's steam measuring project subcontracted to RShydro (RS Hydro, 2018). Hence, if a comprehensive or short-term steam-metering/measuring is not possible, other methods are preferred. For example, nameplate/product manual based demand estimation for individual/aggregate demand/s can be used. However, such approaches are rarely possible due to the age of technology and the higher possibility of nameplate missing. Additionally, assuming steady-state steam consumption process can be technically challenging for many reasons. For example, for dyeing the first dye mixing stage triggers the temperature from ambient (15°C) to 40°C. This is followed by the second dye-fixing stage in which 98°C is constantly maintained. These two batch dyeing stages altogether may take up to six hours. Once 98˚C (equilibrium) is achieved, the amount of steam required to maintain it can be negligibly low (as evident from calculation assumptions in general engineering principles).

Estimating total steam, to realise end-use (top-down), can be another way of dealing with it. Depending on the availability of water and condensate return metering, one can estimate it from the total water consumption. However, it is impractical for the sites without such metering, like the case-study factory. Portable non-intrusive meters, with features like easy installation, and data storing and logging could be used to quantify the water. A portable flow meter—Portaflow-3000 (for liquid flow measuring) was acquired from the University lab. The plan was to monitor the water flow rates to the main boilers to estimate various aspects of steam production. Unfortunately, due to the faulty function, the meter could not be deployed.

Another way to estimate steam was through gas consumption in the boiler house. This again can be a difficult task for sites having poor energy metering/information but can be easier where boilers are the only gas users. However, a site with multiple boilers and sections can create more complexity. Once again portable flow meters can be a good tool for measuring. However, this was ignored for boilers having sub-meters (m^3) as discussed in Sections 5.3.2.1 and 5.4.1.2. The gas- and hour-readings on the boilers were recorded between 06:00−07:00 a.m daily between Monday−Friday by the staff and the researcher. This data became a useful source for gas/steam analyses.

Both water and gas demand estimations have a specific heat (specific thermal energy required to transform water into steam) of water (4.18kJ/kg-K) in common. The physical state parameters were checked through thermodynamic tables and graphs. Combustion efficiency of the fuel and the boiler efficiencies, such as heat transfer, and shell and flue gas heat loss could not be determined. Therefore, for total energy used/steam produced estimations for generic boilers (for which efficiency may vary between 78% ─85%) an 82% boiler efficiency is generally assumed (Spiraxsarco, 2012) so was for the site unless mentioned. It is also noteworthy to mention that in response to a high rate of TDS build-up in one of the boilers, it was being kept on a constant blow-down status. The key relevant information discussed above was considered to be useful enough to analyse and estimate thermal energy estimations.

As the site had a complicated steam distribution system, as shown in Figure 62, building services and process thermal (gas) demand disaggregation was challenging. To cope with this problem, a method based on various forms and sources of data and empirical observations was designed. Different forms of empirical gas consumption data (metered/H-H as discussed in Section 5.4.1.2) and nameplate based stenter's demand (Sections 5.3.2.1 and 5.4.2.3) were used. This total calculated gas demand was then compared with actual primary meter readings. Similarity/differences in values can verify the originality of empirical observations and calculations based on such information, as discussed in Chapter 6. The demand for the rest (five domestic-type hydroponic boilers and the coffee shop) was also measured when the main steam boilers were totally shut for maintenance, as shown in Table 35. After knowing all various routes of gas demand, the demand for boiler 2 was determined through in-direct metering methods. The total gas used in the boiler house indicated the quantity of water used for steam. This was double-checked with the water consumption in the boiler house (based on the water supply metering information around the factory) both values roughly matched each other, as discussed below in water Section 5.4.1.5.

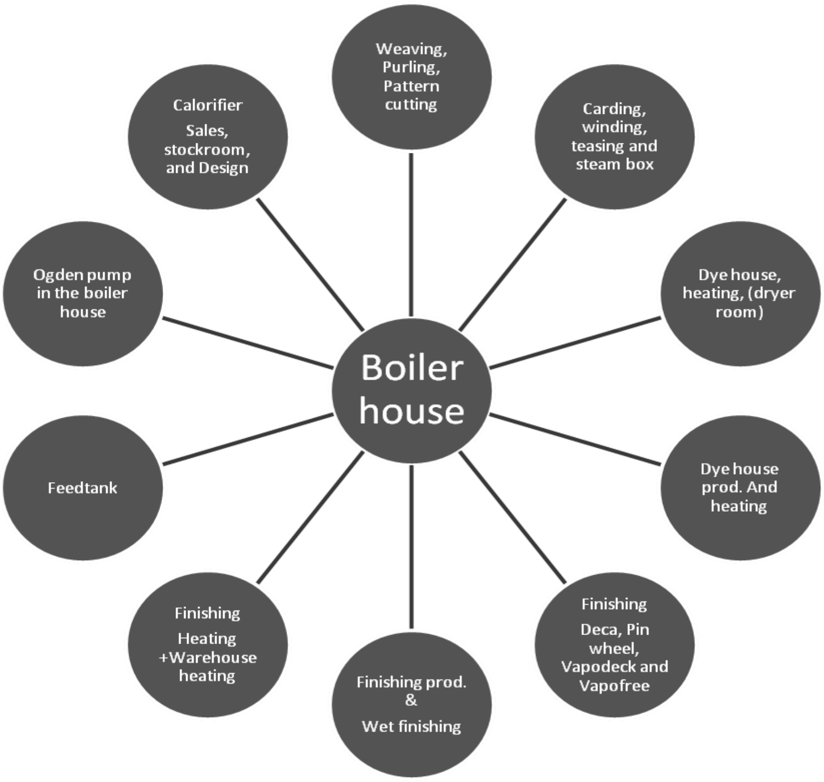


Figure 62 - Main steam distribution lines

Calculating and segregating the steam end-use for production and building heating was a challenging task. Since most of the factory's on-production season occurs in summer, therefore gas/steam consumption during this period can be associated with true production-related thermal demand (as opposed to other forms of heating). However, this season also shares some part of winter (October and November) requiring steam for building heating, which cannot be ignored. Also, even in off-production season (December–mid-March), a mixture of both building heating and production related demand exists. Addressing such type of complexity is only possible through more robust demand/production differentiation and segregation methods. This is where the need for H-H data along with appropriate methods emerges. For example, this can help to translate (include/exclude) steam demand in relation to end-use. Hence, despite the data limitations, the utilisation of H-H gas data along with the proposed method is used, when and where possible. In addition to that, however, for a complete year-long data analysis, another method, as stated below was used. Although the whole production and climate-dependent variability in thermal demand were complicated, summer could be assumed to be a true representation of on-season production demand. For building heating demand disaggregation regression models are normally applied (as discussed in Chapter 2) Degree-days method being one of them. However, due to limitations like steam providing building and production related thermal energy this method could not be applied. Nonetheless, a simple and more reliable method based on manually taken empirical data, observations, and assumptions was used. Analyses were carried out to differentiate and disaggregate between on- and off-production seasons.

5.4.1.5 Water and wastewater

Water consumption on a manufacturing site, specifically when involving wet thermal processes and steam generation, can have a direct impact on energy use. Accurate consumption figures such as measured by the supplier company, as discussed above, can help to estimate energy demand/costs. However, due to reasons like cheaper commodities, frequent meter calibration/replacement is not a general practice, resulting in a fixed amount invoice sometimes. Some industrial sites sometimes extract it from the underground aquifer and measure onsite, like the case-study. In addition to that, there are three utility-company water supply connections. The utility company’s water is generally used for building services and occasionally for peak-production process demands. The demand from these connections, during weekdays, is generally estimated to be 30m^3/day and fewer than 2m^3 for weekends. The meter readings on these may be misrepresentative due to their being old and never calibrated.

The averaged onsite borehole water extraction is 700m^3/day, and is estimated to be equally used (350m^3 each) by both dyeing and finishing departments. The boiler house’s water consumption is allocated to the average water supplied by the utility company as mentioned above. The use of building services is being ignored. The supply side for this borehole water around the factory is equipped with three water meters—located in the Dyehouse, Finishing, and beside the effluent treatment plant. Although none of the four meters have been recently calibrated, these are the only source and therefore used as the consumption indicator. To validate this data’s accuracy and the level of error, the wastewater production readings from the effluent plant were also utilised. However, the effluent plant readings were also subject to error due to faulty metering system, as discussed in 6.1.3. Keeping in view the scope of the project, measuring the use of water and the use of this data had limited use. However, the information obtained was utilised to crosscheck different empirical observation within the energy analysis. This included the water consumption in the boiler house, the water consumption and the hot effluent generation in the Dye house and in the (wet) Finishing (washing/scouring).

Empirical water consumption estimations, based on wet processes such as dyeing and (wet) Finishing, were made for further investigations as discussed in Section 5.3.2.2. These empirical figures alongside water metering data played a key role in producing steam/energy consumption and saving potential in these departments. Savings figures for (wet) Finishing were a useful source to estimate the saving potential for the washing processes as well as to match energy demand with energy recovered from the stenter (as discussed in Chapter 6).

5.4.1.6 Other fuel data

Other fuels used on site (such as liquefied petroleum gas (LPG) for forklifts) were accounted for carbon emission calculation as discussed in Section 5.4.2.5. The factory, in addition to leased vehicles, owns light commercial vehicles and factory cars (two each) for goods/passenger transportation. The consumption of fuel, through factory's fuel cards, was made available for 2014. Guidance on measuring and reporting GHG emissions from freight transport operations (Leonardi, McKinnon and Palmer, 2010) suggests that ideally emissions from fuel extraction and processing (well to tank, (WTT)) should also be used when accounting for tank to wheel (TTW) emissions. This should be noted that whether the WTT fuel was imported from a long haul or short haul destination, it is assumed that the factor used covers everything for the UK. The company has leased several vehicles for the company executives. These managed assets, not directly owned by the company, hence were treated as scope 3 type assessment.

5.4.2 Other data sources

5.4.2.1 Production and material consumption

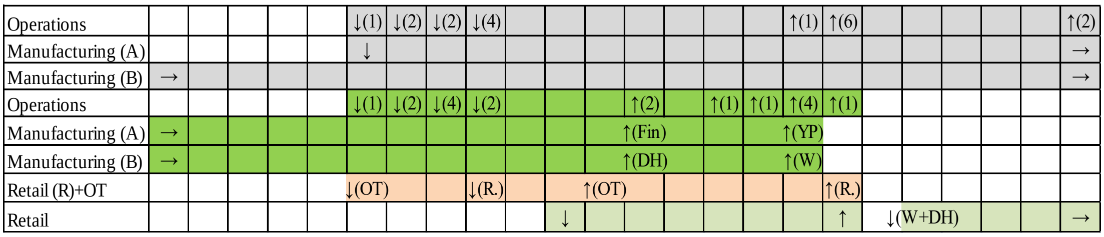
The unit length, e.g. metre, is widely used for fabric production. However, wool and cashmere both in raw and spun (yarn) form, involving dyeing and carding, is weighed in kilograms (kg). The yarn (kgs) woven into fabric (metres) is then divided into different product categories like scarves, rugs, and shawls at the case-study. The unit of each category, for example, a standard scarf which can be 2m x 0.25m is much smaller than a rug which can be 2.5m x 2m varies in size. Despite the internal production unit is metre, the factory invoices the buyers in units instead of metres unless selling big rolls of fabric. Both types of data are maintained in various formats on the Jomar system for factory analytics.

Billing of materials (BOM) department provided annual (material) consumption and production data (2011–2014) for all the four departments in two forms—one indicating monthly activity and the other having annual activity figures. Both accounted for production/processes internal (carried-out internally) and out-sourcing (carried-out externally) activities as well. Due to the difference of data retrieval methodologies both types slightly differed. This difference was natural and both sets of data were deemed to be accurate as had originated from the same source. The monthly data did not have separate production figures for article WA000608. Therefore both the sets—A) four-year-long (2011–2014) monthly consumption/production, and B) annual total production/consumption with separate WA000608 figures were used. The set “A” had data missing for the last three months for 2014 and was left as it is purposefully, unless otherwise mentioned. The monthly data was analysed to have a feeling of individual departmental production variations across four years in Section 6.1.5. The set “B” was utilised for total and product-specific CO_2 assessments (as discussed in Sections 5.3.5 and 6.5.2). It is known that over the years only slight changes have taken place in the design of WA000608 and the materials produced for this article however sometimes also contribute to the other products. The set “A” was also used for analyses such as energy/production regression, and SEC. This was because it had more details and the flexibility to expand the scope of the results.

5.4.2.2 Activity schedules

Detailed business operations’ knowledge can support an in-depth energy analysis even for complex and busy manufacturing and energy environments. This, for the case-study site, can be divided into two key areas—departmental/sectional operations and the technologies that operate accordingly. Although, the former is discussed in Chapter 4, it is necessary to highlight a few more issues in this chapter. A more generalised form of Figure 52 is adapted in Table 40 for the linear representation of energy profiles. This helps to visualise the impact of starting/finishing of individual activities on an hourly basis. In the Table and the legend, the arrows indicate the relevant department/section activity times. The numeric in the brackets represents the number of departments, sections, and or departmental sections starting/finishing at that time.

Table 40 - Generalised manufacturing and Operations schedule



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑		↓(W+DH)				→

Legend

→	Continued
↓	Starting
↑	Finishing
▨	Mon-Thursday
🟩	Friday
🟧	Saturday
▧	Sunday

To numerically differentiate daily peak- and off-peak demands, another way, based on daily key activity change points, was devised. Numerous time slots representing start/end of key activity pursuits during a day (weekdays (Monday–Friday) and weekends (Saturday and Sunday)) were formed. These with the key activities are shown in Table 41 and Table 42. These timeslots helped to estimate numerical data across 24-hour daily demand variation. The figures obtained were also crosschecked with 24-hour energy profiles (gas/electricity) obtained through analyses from Section 5.3.3. These obtained values also helped for department-level demand disaggregation, which was also compared with values obtained through Sections 5.3.1.2 and 5.3.3.

Table 41- Weekday activities time slots

Time	Departments/Sections working
00:30-06:00	Dye house, Weaving, & Yarn store
06:30-08:30	All Production and most of the Operations
09:00-12:30	All the Production and the Operations
13:00-15:00	All the Production and the Operations, different for Friday
15:30-17:30	All the Production and the Operations, different for Friday
18:00-00:00	All the Production departments

Table 42 - Weekend activity time slots

Time	Departments/Sections working
00:30-06:00	Base load
06:30-12:00	Retail shops+Sat O-T
12:30-18:00	Retail shops
18:30-20:00	Base load
20:30-00:00	Dye house and Weaving for Sunday

The technology/equipment involved in facilities and services like HVAC, lighting, IT and kitchen are also dictated by the activity. Some of these go on standby mode during closing time-periods (IT and HVAC). Looking at the running and activity patterns on site, some equipment management actions were devised and implemented. The HVAC on the BEMS was constantly running and timers on the standalone systems were also set at 24-hr operation. In addition to the change in room temperature settings the schedules on the BEMS system were slightly altered. For IT, a policy was designed to ensure the switching off schemes formed for the equipment. For lighting and kitchen equipment awareness was raised and traffic light switchboard display system (red, amber, and green) was formed. All of these measures were implemented by departmental energy representatives.

Two out of the three boilers run alternately during summer (May-September, for five months). The need for heating generally starts in mid-October, right after the holidays requiring all of the three boilers running until Mid-April (for seven months). The stenter operates 78-hours (two 9-hour shifts between Monday-Thursday and six-hours on Friday (2011-2013)). Each shift has one-hour lunch and two 15-mins tea breaks. One CA system continuously operates 24 × 7 at one time. For further understanding of operational hours refer to Table 30.

5.4.2.3 Nameplate rating and operational data

For such demand calculations a nameplate rating based database was established as discussed above nameplate, cumulative, and for technology with missing nameplates expert’s estimation, were used. An example of spinning machines is indicated in Appendix 1 (Table 105). To enhance the level of analysis an in-depth individual department technology mapping was carried out. After developing this database, it became easier to categorise key contributing technologies such as lighting (indoor/outdoor), technologies contributing towards baseline load, and technologies that in addition to electricity used CA or gas or both. This extended the analyses from nameplate demand to departmental segregation and end-use category.

5.4.2.4 Weather data

Weather data plays an important role in identifying heating/cooling related demands. The most up-to-date weather data sources can be recorded on site through daily manual temperature readings to a dedicated weather station installation. A weather station model Vantage-Pro2 was acquired to install on site, but operational problems occurred with this unit. Another source of weather data was onsite recorded BEMS system's degree-day files but did not opt for due to the limitations discussed above. MetOffice's weather files were used for weather-related demand regression analyses, as discussed in Sections 2.2.4.2, 5.3.4.3 and 6.1.4.1.

5.4.2.5 Supply chain related secondary and other relevant data for carbon accounting

For carbon accounting, it is useful to identify energy hot spots within the supply chain. Various textile up-stream supply chain areas are discussed in Figure 58 and in Section 5.3.5. Due to process complexity and data limitations, only limited data sets were made available. The boundary for wool/cashmere buying-in was determined and confined between China and UK for simplicity and to minimise complexity. The second step was to determine CO_2-e/kg for wool production. Due to data scarcity, it was not possible to use UK-specific CO_2-e/kg wool benchmarks. Cashmere (a different type of wool) imported (as dry, clean, and degreased) mainly from China was another issue. A reasonable quantity of yarn is imported from Italian manufacturers however it can be assumed that their source of Cashmere/wool producers being the same. For this CO_2-e/kg wool of greasy wool was derived from a research-based Australian study, as discussed in Section 2.3.2. Energy used for degreasing the wool and treating the resulting wastewater produced figures were derived from a UK study as discussed in Section 2.3.2. For port-to-port wool transport, carbon emissions (from China to the UK) and then transportation and storage on the UK mainland could not be established due to complexity and data unavailability. For consistency and relevancy, Defra's emission factors published for the relevant years where possible were used.

5.4.3 Dealing with inconsistent data —preparation, rectification, collation, and understanding

For utilities invoices one may come across estimated/missing readings which can be rectified through different ways such as; using daily readings or using historical values (for the same/previous month/s). On the other hand, if the estimate bill covers more than one month, one may split it over the period using similar approach, with some adjustments, as discussed below.

For the missing manual data (more likely to happen at the weekend) the value from the previous reading can be repeated. However, if the weekend consists of two days (Saturday and Sunday) and the weekend operation is not smooth (e.g. overtimes) individual day's demand dissociation is harder. If circumstances allow, one can record some representative demands (e.g. Saturday and Sunday summer and winter values), and then repeat them accordingly. However, if values obtained through these methods, cover a large number of gaps, can be conflicting to the true values (e.g. not consistent with total actual consumption based readings on start and end of the year). Such types of techniques are applied to deal with gaps in the manually taken utility data. Another way to deal with such data gaps is by using statistical techniques i.e. interpolation to predict/estimate the value/s. These are normally carried out for both manual and digitally acquired data.

Numerous forms of gas data—estimated invoices, manual primary meter and sub-meters on boilers, and some short-term H-H data, was dealt with for improved analysis. Manual primary meter gas data was the most comprehensive, long-term (2011–2013), and reliable among these. However, this data had some issues like consumption measurement (in cubic feet and then later on in cubic meters). The readings until mid-2012, were from the analogue meter. This meant that these were not adjusted for pressure and temperature. The problem was corrected by applying a generally used constant correction factor of 1.02264 as defined by the British Gas' glossary of terms (British Gas, 2016). The variations in CV values were taken from the past gas invoices. Gaps between dates were adjusted (with equal figures) by calculating the total difference between the two readings and then dividing it by the number of days. A similar exercise was repeated for the weekends where necessary (for example, when a reading for Saturday/Sunday needed to fill the gap at the start/end of a month). This was necessary for calculating the monthly consumption however this method was not used to disaggregate weekend demand on a daily basis. The volumetric values of gas consumption were then calculated through an engineering method based simple calculations, as shown in Equation 13 below;

Equation 13

For volume in cubic feet ($ft.^3$) and cubic meters (m^3)

Step 1

$$Corrected\ consumption$$
$$= \ Total\ units\ (ft.^3\ )\ used \times 1.02264\ (correction\ factor)$$

Step 2

$$Converted\ into\ cubic\ meters = \ corrected\ consumtion\ (ft.^3\ ) \times$$
$$2.83\ (conversion\ factor\ for\ m^3)$$
$$(as\ the\ reading\ is\ in\ 100ft.^3\ )$$

Step 3

$$Total\ number\ of\ kWh\ used = \ cubic\ meters \times calorific\ value\ MJ/m^3(CV)/3.6$$

where, 3.6 is kWh conversion factor

Another approach was adapted to calculate weekend demands on a daily basis, in conjunction with another study involving the monitoring of the boiler house on a sub-daily basis. Different demand values were taken from the primary- and sub-meters, specifically at the weekends. Different types of boiler operation and control measures along with steam supply were taken to observe the energy and boiler control relationships. The data obtained was then used to make recommendations for energy saving through boiler operation management, as discussed in Section 5.3.2.1. The data set organised, rectified, and completed through the above methods played a key role in finding out daily, monthly, and annual demands. The fault in the AMR installation on gas, as discussed in the next paragraph and in Section 5.4.1.2, was also pinpointed through this analysis. The data set was also used to rectify the monthly/annual estimation based gas charges issues. It was through sub-meters on boilers data analysis that over-consumption of boiler 4 noticed and reported that came out to be due to the faulty burner on it.

The format of 24-hour H-H data (gas and electricity) is discussed above in Sections 5.4.1.1 and 5.4.1.2. The data, for detailed analysis (i.e. demand on a particular day basis, weekends, particular months/seasons), needed to be organised in particular arrangements. First of all, the data was subject to two situations—clock change in the UK (one-hour forward and one-hour backward in the ends of March and October respectively), and leap year. Such data gap was filled with the previous value, whereas the leap year was counted as it is (366 days instead).

Segregations for individual weekday's data and seasonality (such as climate and rate of production based) were carried out. These categories such as (on- and off-production and winter/summer seasons) are already established in Chapter 4. Another form of such data categorisation was based on the change in activity within the 24-hours (peak- and off-peak demands). For this purpose, the 24-hourly data segregated on a daily basis was further divided into different high- and low-demand categories (as discussed earlier in Section 5.4.2.2).

5.5 Conclusion

Deciding the most suitable energy auditing method remains a challenge, where suitability might relate to more accurate savings without any compromise on other factors, such as product quality or the type of data availability. There are a few things, if scope and circumstances allow, that must be avoided to improve the audit quality, such as the use of estimate billing, missing the inclusion of major energy users (where the process of proper technology mapping helps), taking their energy use into account either collectively or individually, and giving minimum time to empirical data collection and observations. These types of mistakes can only be avoided through a wider scope of energy audit and dedicating more time to learning the site/process. Technology mapping classification and observation time onsite with engineers are key towards that, alongside the mining of various types of data and designing suitable analyses and measures for better EM.

It is also observed that general EM projects (either government policy/funding based or quick-fix commercial energy solutions) can somehow offer energy efficiency. However, distinguishing and quantifying between the roles of behaviour- and technology-change related measures and savings can be ambiguous. The research-based EM projects however are more logical, informed by up-to-date knowledge, and comparatively more powerful tools to clearly distinguish, identify, and achieve results. Therefore, empiricism and more thorough engineering principles are needed to be used in these auditing systems under a well-defined, standardised framework. The increasing quantities of good quality energy data, as a result of enhanced IT use in the area, requires new analytical methods and techniques to be implemented to raise the existing disposition of such energy audits and well trained and skilled auditors to compliment this.

Through empiricism and site information more saving opportunities may be identified. Numerous measuring and monitoring methods can be used for relevant energy data collection to establish baseline demand, paybacks, and savings investment. Enhanced level of energy profiling at both site and individual technology level is mainly based on the enhanced resolution of relevant energy and activity data. Energy profiles calculated through such data can pinpoint and identify those waste events and saving opportunities that is hardly achievable by any other method even for complex manufacturing systems. Establishment and comparison of energy performance categorisation, based on various indicators, is necessary to assess where we are starting from and what we target for as a realistic aim. This in terms of SEC or carbon accounting is a useful tool for an organisation's sustainability credential as well as developing a business case for cost-saving.

Chapter 6 – REVIEW OF RESULTS AND SAVING MEASURES

The collected data is analysed to present results into five distinct sections; each indicating components that significantly contribute towards the (detailed/comprehensive) energy auditing process. The approach facilitates organisations, having a range of limitations relating to data, resources, skills, and funds, to undertake (tailor-make according to specific-needs/category/ies) energy audits and related process. Technical, energy reduction measures, and the associated savings along with factory-wide and specific-product CO_2 accounting evaluations are assessed, with the results obtained through basic audit analyses and high-resolution data and micro-audits.

The following is therefore intended as a best-practice approach for understanding the baseline energy use of an industrial site, to the extent that any decisions on energy efficiency are better informed and more likely to succeed. Whilst the data used is from a specific textile factory, the work carried out is explained in a way that should be translatable to other sites where manufacturing around process-specific technology is important.

6.1 Assessment using low-resolution utility, weather, and process data

This section analyses onsite month/year-long or manually taken daily readings to identify energy-saving actions. Table 43 shows key variables along with some supply chain related impact on the SEC, shown in Table 44. The discussion in the sub-sections enters into detailed analyses such as variation in production versus consumption patterns, and weather.

Table 43 - Total energy, cost, carbon emissions, and SEC

	2011	2012	2013	2014
Electricty (kWh)	4,147,615	4,120,238	4,164,058	4,540,442
Electricity cost (£)	378,361	364,435	446,217	465,194
Avg. electricity cost/unit (£)	0.091	0.088	0.107	0.102
Gas actual (kWh)	16,996,067	16,846,851	15,454,705	15,636,079
Gas cost (£)	440,109	—	—	361,092
Gas estimate (kWh)	17,313,047	16,028,036	—	15,636,079
Avg. gas cost/unit (£)	0.03	—	—	0.02
Total energy used with actual gas	21,143,682	20,967,089	19,618,763	20,176,520
Total energy cost with estimate gas (£)	818,470			826,286
Meters produced	1,210,664	953,576	1,122,540	1,138,137
SEC electricity (kWh/metre)	3.43	4.32	3.71	3.99
SEC gas (actual) (kWh/metre)	14.04	17.67	13.77	13.74
SEC total (kWh/metre)	17.46	21.99	17.48	17.73
Total carbon (tonne) with actual gas	5,368	5,357	5,011	5,458

- *Red figures for gas cost are estimate*
- *Red figures for metres produced for 2014 indicates data gap filled from 2013 for the last three months*
- *Gas actual= manually recorded meter data*
- *Electricity emission factors are based on generation only*
- *Gas net CV emission factors are used for gas emission*
- *Due to unavailability for 2011 gas emission factors figures from 2012 (Defra) are used*

Table 44 - Oganisational energy use

Scope	Energy source	kWh			
		2011	2012	2013	2014
1	Gas	16,996,067	16,846,851	15,454,705	15,636,079
	LPG (liquified petroleum gas) on site	–	–	–	18,014
	Transit vans	–	–	–	–
2	Electric	4,147,615	4,120,238	4,164,058	4,540,442
3	Company cars for executives	–	–	–	–
	Electricity for degreasing	100,408	84,097	91,332	97,627
	Gas for degreasing	321,305	269,110	292,261	312,407
	Wastewater generation 5 kg of per 1kg of wool (kWh) for degreasing	2,101	1,759	1,911	2,042
	Sheep rearing for wool	–	–	–	–
	Total kWh	21,567,495	21,322,054	20,004,265	20,606,612
	SEC	17.81	22.36	17.82	18.11

Fractional conversion to kWh for company cars could not be undertaken
kWh values for sheep rearing could not be established, hence no significant difference between pre-established SEC and this one is seen

Another form of low-resolution data, shown in Table 45, is compared against CIBSE's (CIBSE Guide F, 2012) textile energy benchmark. The variation in 2011and 2014 values could be due to improved gas efficiency, though in both cases the factory shows underperformance. However, with CIBSE's approach to categorisation, such as for shifts, how the process/es for energy have been distinguished is unclear.

Table 45 - Energy use/m^2 at the factory

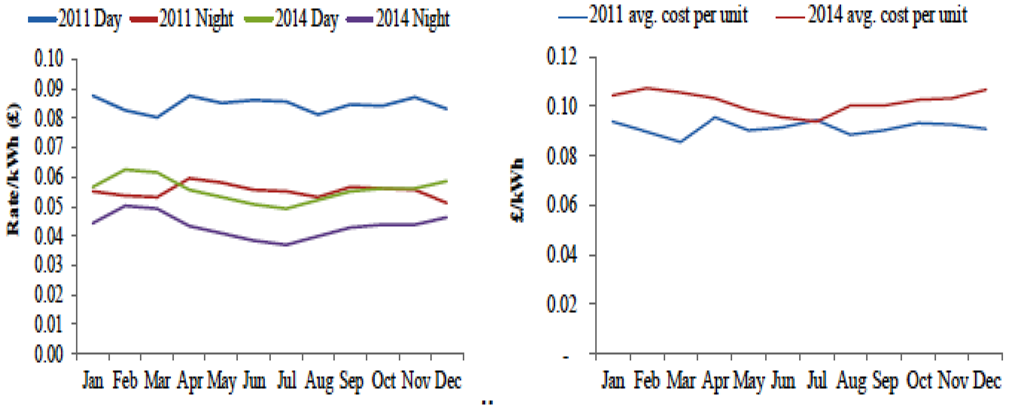
Site	Shifts	Building related energy /(kW.h.m^{-2}) per year			Process energy/(kW.h.m^{-2}) per year	Total /(kW.h.m^{-2}) per year
		Space heating	Other uses	Total		
CIBSE	2.5	303	38	341	479	820
Case study site (2011)	–	–	–	–	–	927
Case study site (2014)						885

6.1.1 Electricity

Historically two electricity-intensive departments (Manufacturing “A”) will stop working at midnight. Due to 2012 and 2013 invoicing disputes, as discussed in Chapter 5, 2011 and 2014 is being mainly discussed. However, minimum demand differences between 2011 and these years, as discussed in Sections 4.4 and 5.3.3, except for 2014 (due to operational changes to improve efficiency and cost-effectiveness) is observed. A more detailed knowledge of electricity used at different production steps (onsite/off-site) can help to measure and compare energy and cost-effectiveness of the measure. However, the associated increase in electricity-related CO_2 and increase in night-time labour cost and reduced labour efficiency cannot be ignored. On the other hand, the reduced electric-heating related load is likely, for small periods only though. As the lighting load remains the same in production buildings, throughout the day and night, no increased number of lighting will be needed for the night-time visibility enhancement.

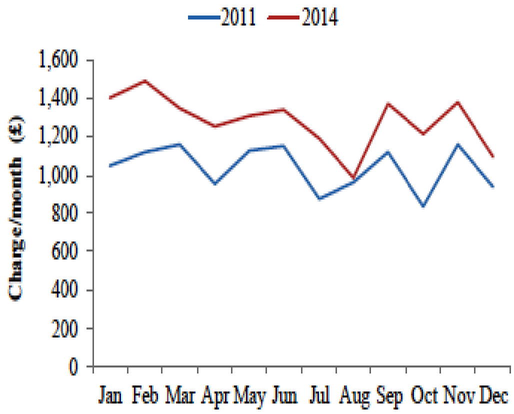
6.1.1.1 Energy cost and consumption

The unit (kWh) cost has decreased (as indicated in Figure 63 (A)), but energy levies through EMR (Electricity Market Reforms, April 2013) have increased the total cost by £0.005–0.01/kWh (as indicated in Figure 63 (B)). This clearly indicates an increasing trend in electricity prices. This is likely to go higher (as shown in Figure 63 (C) excluding VAT) when associated with middle-market facilitators, supply, network, and environmental compliance (such as (CCL)). However, one must not ignore the other factors (like increased consumption in 2014 (shown in Figure 64), and the associated reactive and excess capacity charges).



A) Monthly electricity rates excluding other charges

B) Average unit cost including all charges and without VAT



C) Extra charges including CCL

Figure 63 - 2011-2014 electricity cost attributes

The intensity of activity, seasonality, and holiday determine the demand patterns. Other factors (mostly micro) like material types, processes, weights, measurements, and design/patterns also affect the demand but are out of scope. Total usage and cost for 2011 and 2014 are shown in Figure 64. Larger price gaps, for 2014 between Mar–June, may be associated with generation cost volatility or due to increased night-time activity during this period (higher consumption but lower cost).

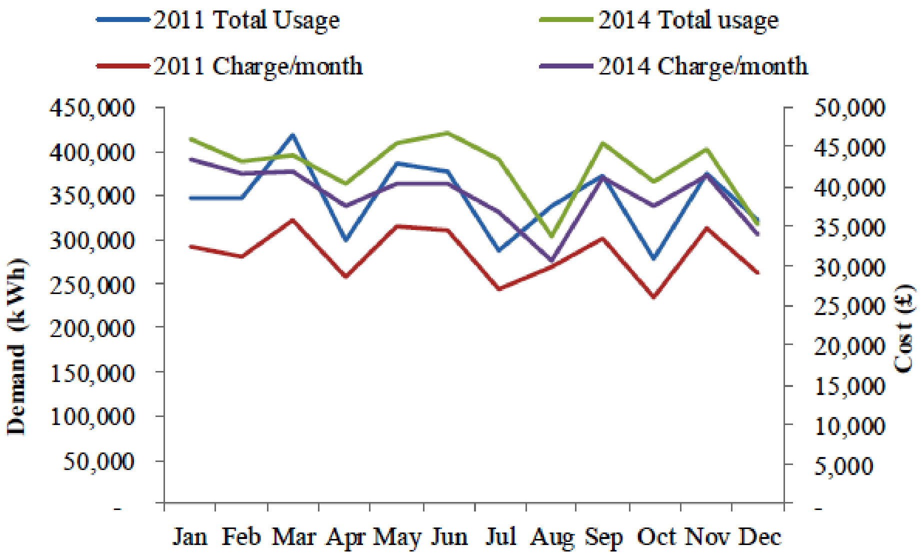


Figure 64 - Usage and monthly charge

Charges include CCL and other charges (excluding taxes)

Figure 65 shows 2011–2014 demand comparisons. Despite reduced production (metres) rates in 2012 and 2013 (as in Table 43), noticeable demand differences are hardly seen. Slightly higher 2013 demand can be indicative of production rate not being directly proportional to the consumption. Factors such as increased/decreased activity of electricity-intensive processes (yarn manufacturing), however, are noteworthy as highlighted in Section 6.1.5. In addition to that is the significance of the associated complicated supply chain resulting in a less controllable off-site management (production) and process/sub-processes (like expertise, technology, and skills) (as in Section 6.1.5). This makes the overall rate of production and demand evaluation less directly correlated, with the specific energy of the offsite processes unknown. Weather is another factor, influencing electric heating/blowing, hot water, and air conditioning. The detailed consumption data relating to these technologies and weather will be useful to know more, as further discussed below. These limiting factors sometimes affect more accurate estimations following a scientific procedure and methodology. The other influencing factors such as demand variation in response to a detailed outdoor temperature or production data of individual activity/process on shift or weekly basis are not possible.

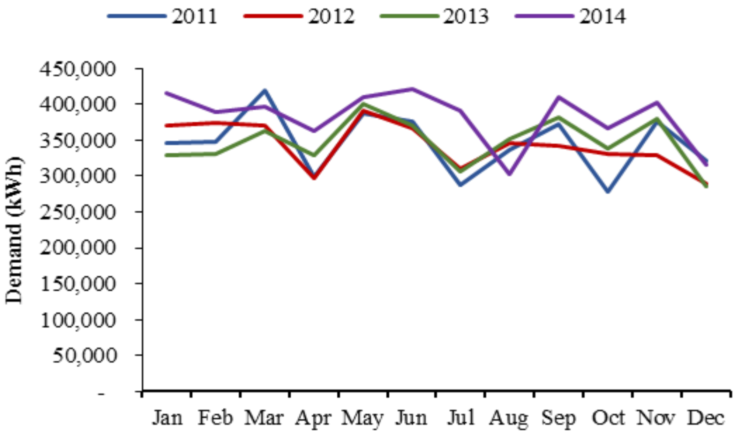


Figure 65 - Yearly demand comparison

How operations (i.e. production management) can affect the energy and cost is indicated in Figure 64 and Figure 66. Though the factory's 24hrs×5day operation from 2014 has increased, the consumption in terms of cost is effective (reduced night-time tariff). The night-time consumption has increased three times (812MWh in 2011 to 2,200MWh in 2014) as compared to day-time which has reduced when compared with the past (3,335MWh in 2011 to 2,381MWh in 2014). The total metres produced in 2014 are less than in 2011 however the production/activity intensity within the departments (Manufacturing "A"), as discussed further in Section 6.1.5, reveals the impact on energy in real terms.

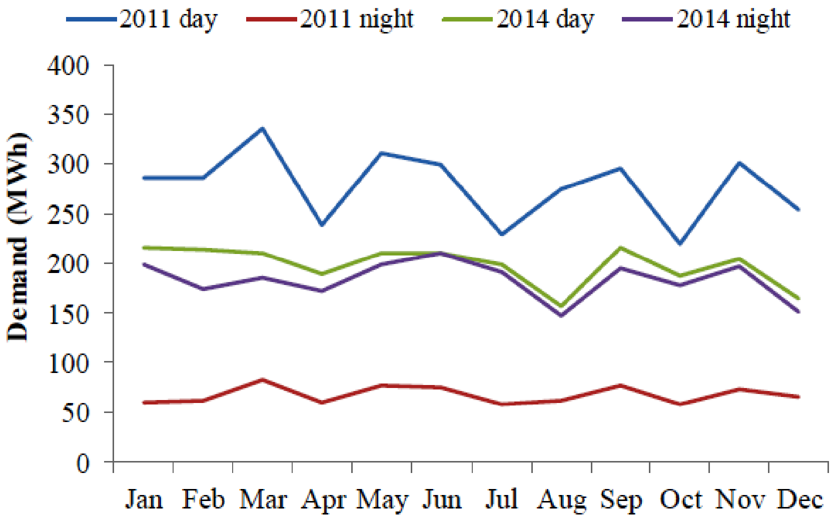


Figure 66 - Day and night demand

Based on production seasonality, as mentioned in Chapter 4, a comparison for 2011 and 2014 is shown in Figure 67. The on-production (seven-month) average demand is reasonably higher than the off-production (five-month). The reason for higher than 2011 averages (both) for 2014 is already mentioned above.

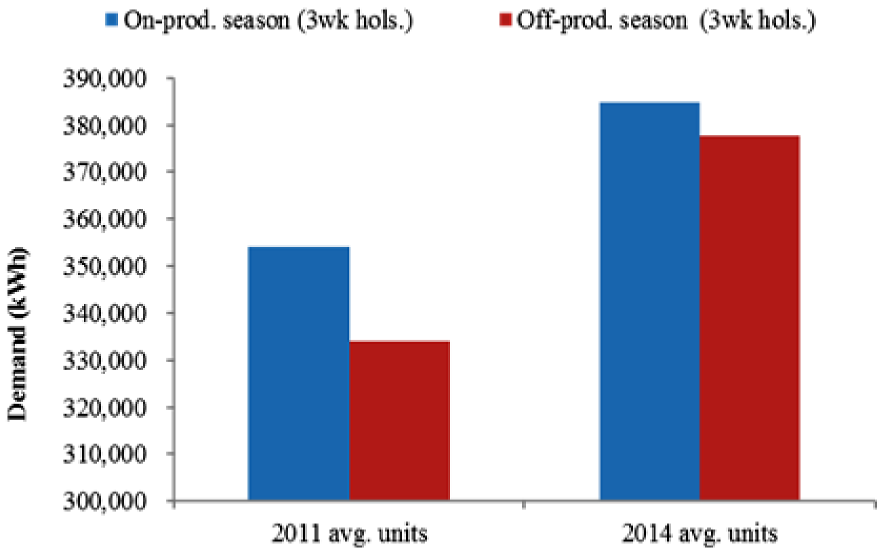


Figure 67 - 2011 and 2014 production seasons' average demands

On the basis of weather, Figure 68 evaluates and compares average consumption between 2011-2014. The monthly average summer demand (five-month) as compared to winter (seven-month) is quite high, though this is unlikely to be due to increased building cooling demand, which is trivial for the particular location and building type.

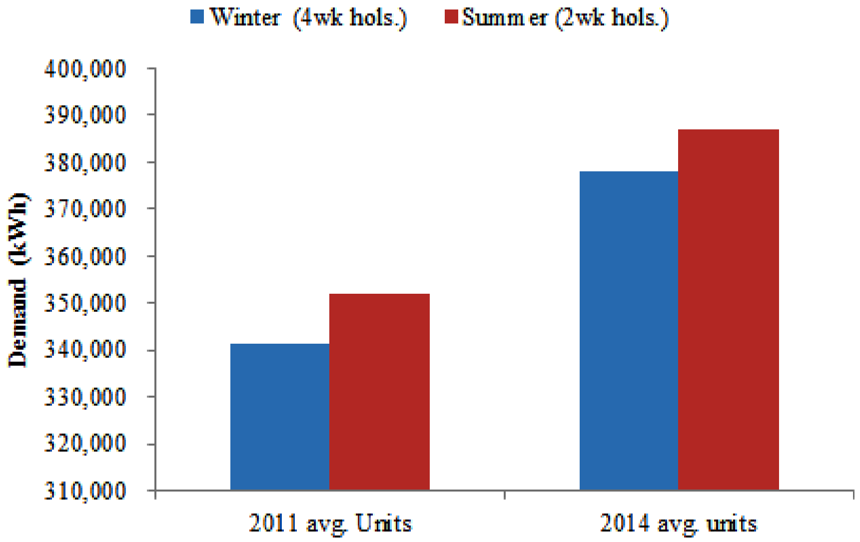


Figure 68 - 2011 and 2014 average weather seasons demand

As the average is based on monthly invoices, therefore, the middle of the month such as October or May was not possible hence summer holidays are for two weeks

Electric cost and consumption assessed in this section revealed the importance of numerous variables such as EMR and the reduced night-time tariff as discussed above. The impact of weather is poorly understood, as discussed in Section 6.1.4.1 (a drawback of using low-resolution data). As mentioned in Chapter 5, keeping within the scope of this thesis, simple regression (Section 6.1.4.1) and a method (as in Section 6.3) identifying trends in high-resolution data is implemented. Some recommendations for electricity saving, specific to the organisation, are indicated in Sections 6.2 and 6.4.

6.1.2 Gas

On standard tariff and 1bar supply pressure, the gas had estimate invoicing until end 2014 when AMR metering started working without any issues.

6.1.2.1 Energy cost and consumption

Gaps in the estimated invoices create conflicts, for example as shown in Figure 69 with manual readings, i.e. consumption and cost deviation from September onwards. Although corrected at some point (e.g. July covering the missed out May), such invoicing lacks accurate monthly cost information for certain analyses. It can clearly be seen that estimated invoices are less sensitive to seasonality (production-related in this case) as compared to manual readings. Such conflicts become even more pronounced for 2012 (not included in Figure 69) when a three-month-long estimate invoice was generated. For 2013, the invoicing becomes more transparent due to the installation of AMR system with monthly actual. Indicating the significance of using actual utility measurements for manufacturing energy analyses, Figure 69 illustrates one of the key outcomes of the thesis.

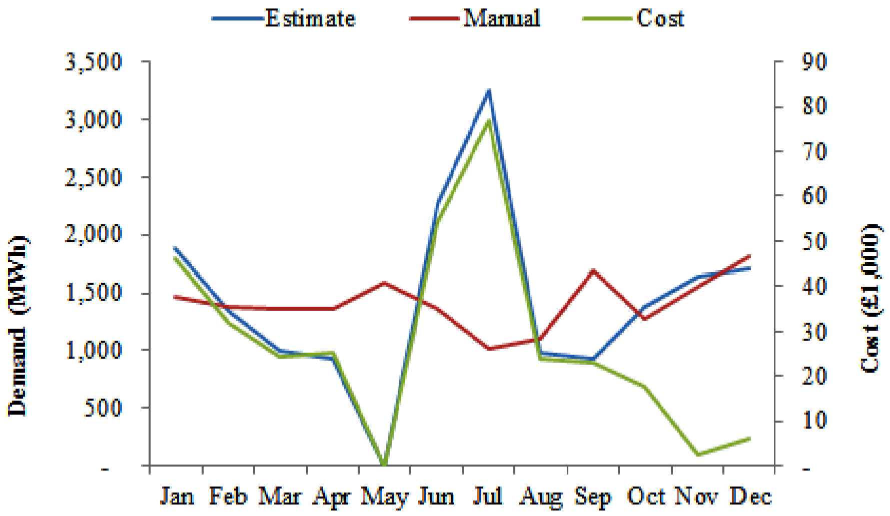


Figure 69 - 2011 estimate consumption vs. cost

Charge including CCL and other charges (excluding taxes)

(Jan-Mar and Oct-Dec off-season and Apr-Sep on-season

Despite cost/kWh stability for recent years, a fractional reduction in average cost (excluding additional charges) has been noticed in 2014 (historically from £0.02284 to £0.02039). Monthly consumption and cost for 2014 based on actual meter readings, is incomparable with the past as discussed above, and shown in Figure 70. The reduction in annual consumption is already known through Table 43.

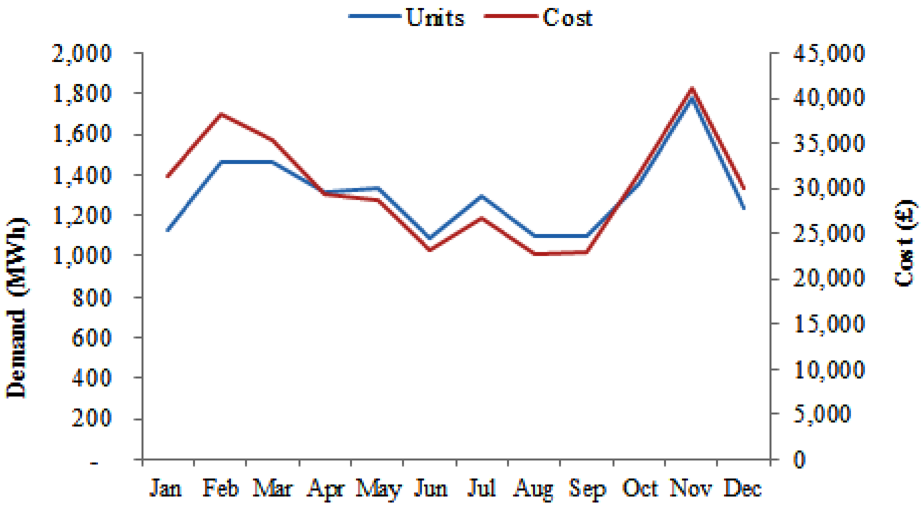


Figure 70 - 2014 actual cost and consumption for gas

Theoretically, gas demand should have increased in 2014 in response to the increased production hours. However, this is contrary to 2011 and 2012 with slightly higher demands for 2013, as in Table 43. This can be attributed to management based (see Section 6.2.2.2) saving measures initiated in early 2013. Another gas saving route through end-use efficiency (i.e. micro-audit) was explored for both steam and gas technology. Management and technical improvement opportunities are suggested in Sections 6.2 and 6.4.

Monthly manual (2011–2013) and AMR system (2014) demands shown in Figure 71, clearly show reduction (2013 onwards for some months). The minimum demand in July and August in 2013 could be due to different factors such as holiday with no overtime even at the weekends. Contrary to that is the significant demand increase in July 2014 which may be due to increased workloads during these holidays and weekends. The reduced load in December 2013 and 2014 indicates the effectiveness of management measures such as shutting down the boilers, when possible, during this period as discussed in Sections 6.2.2.2 and 6.4.2.2.

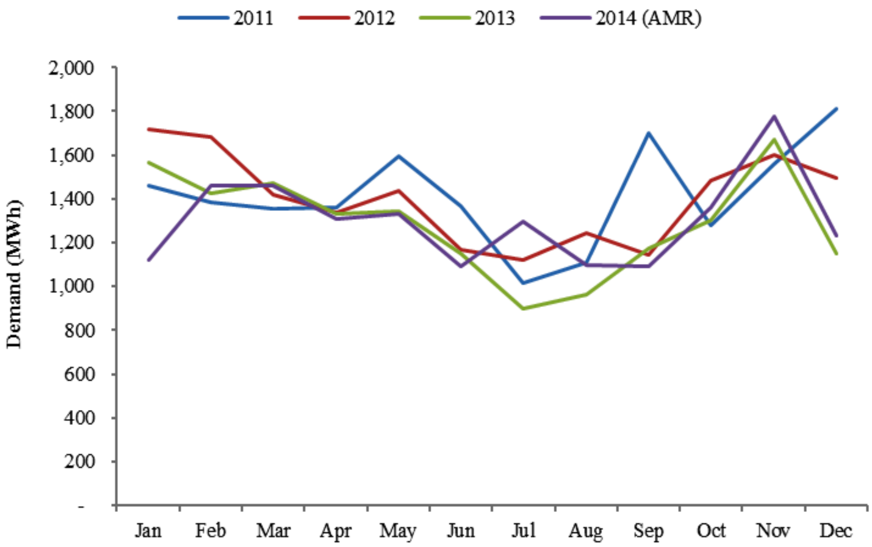


Figure 71 - Monthly consumption over the years

Using 2011 manual data, statistical high-and-low demands are calculated, as shown in the box and whisker boxes in Figure 72. Due to unavailability of weekend readings, demand for these days is collectively covered (Friday production (between 07:00–17:00), any Saturday overtimes (usually between 06:00–12:00), and no production on Sunday until 20:00). Monday's lower and higher demands could be due to a fresh start (more winter heating required) and reduced activity. Thursdays' significant demand reduction, as compared to the other days, can be associated with Finishing's, and Yarn production's (thermal intensive) departments finishing an hour earlier. Tuesdays and Wednesdays show similar characteristics due to being peak production weekdays.

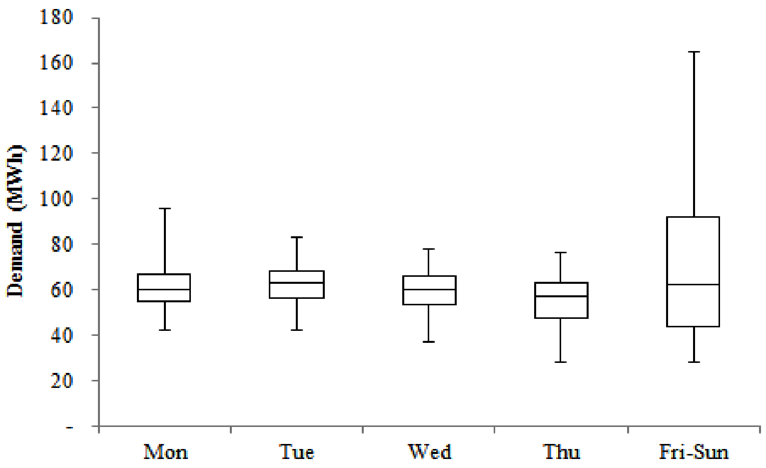


Figure 72 - 2011 weekday max. and min. gas demands

Figure 73 evaluates production season based demands. Despite the missing figure for May both 2011 manual and estimated on-production seasons' demands look similar indicating the utility company's annual demand approximations being reasonable. Similar data when used in Figure 74 (A&B) showed reduced consumption for on-production season which can be due to only two boilers operating mostly during this (summer) period. Although demand can be high during on-production season, this is the minimum energy (noticed to be significantly high on site in the Figures with seasonality effect below) required to keep the boiler/s on regardless of the steam being drawn. This led to a technology replacement being recommended with (at the end of life of existing boilers) two modulating boilers (9-tonne/hour steam capacity each). The boilers at the factory supply over 75% of total thermal energy, as further discussed in Sections 6.2.2.2 and 6.4.2.2.

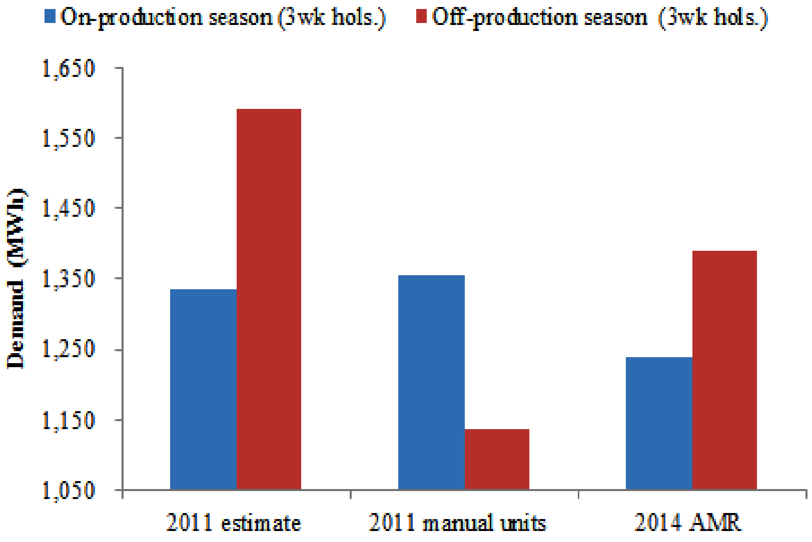
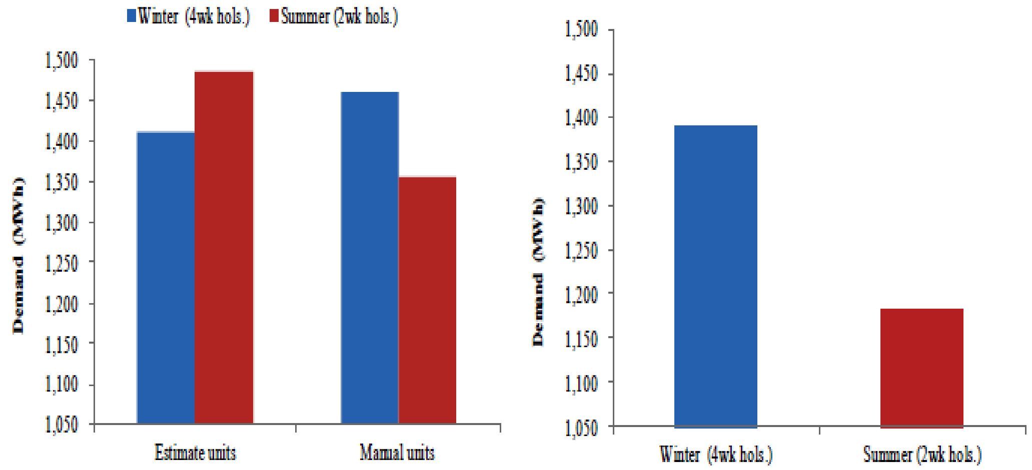


Figure 73 - 2011 and 2014 production seasons based demand

Figure 74 indicates the 2011 and 2014 winter effect on demand. The main reason for the demand increase is building heating, despite the season having a month-long holiday period. The lower than 2011 consumption in 2014 is already known. However, the other existing end-use saving potentials for HVAC, steam, and gas user technology is discussed in relevant sections.



A) 2011 average winter thermal demand B) 2014 average winter thermal demand

Figure 74 - Average winter thermal demands yearly comparison

6.1.3 Water consumption

This section estimates total borehole (generation) and utility company water supply and consumption, where possible.

6.1.3.1 Consumption based on low-resolution metering and observed estimations

Due to missing water extraction and effluent information data for 2013 was built to represent one full year as in Figure 75. Values from 2014 were utilised to indicate a full representative year. The dye house consumption is clearly less than in the finishing department (despite the working hours' difference). The higher extraction and lower effluent values (in addition to utility water supply) can be associated with the process- and steam-related losses. The increased effluent towards the start and the end of the year indicates anomalies with the effluent metering system.

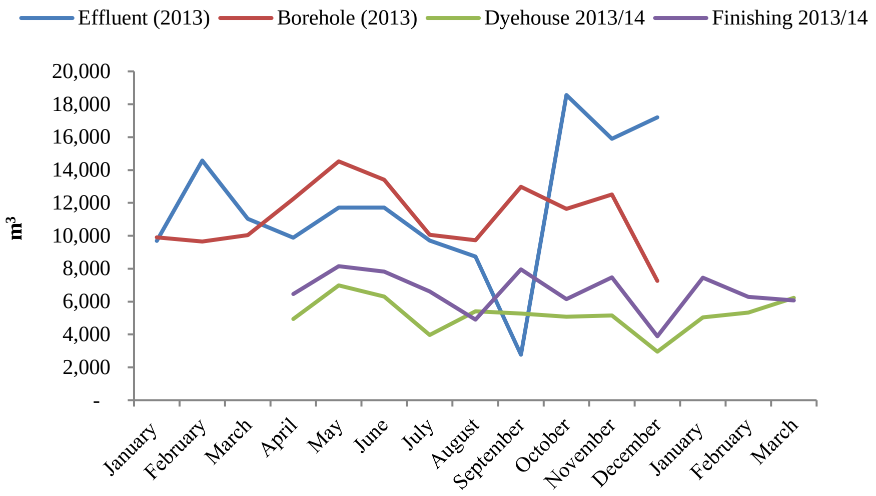


Figure 75 - 2013/14 water extraction and consumption

The noticeable small differences, when water consumption (Dyhouse and Finishing), extraction, and effluent were drawn (in Figure 76), can be associated with the boiler house demand. However, the utility water mixing (for peak-hours demand surge) into the main water tank cannot be ignored. The spontaneous fall in August and a persistent rise in October onwards (despite representing the end of peak-production season) in the effluent refers to effluent meter breakdown in August 2013. This also explains the importance of the departmental managers' observations-based consumption estimations.

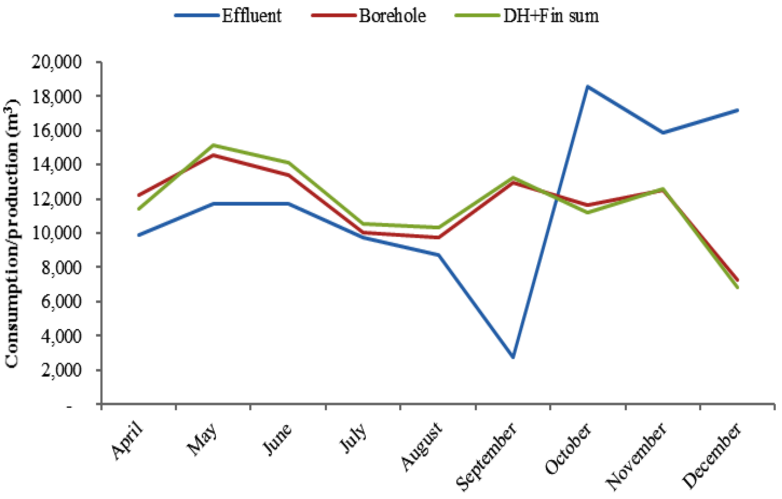


Figure 76 - 2013 variation in water generation, consumption, and effluent

6.1.4 Weather and production related energy intensity

The building heating demand in manufacturing is not always as high a contributor to energy usage as for other non-domestic sectors. It can also be difficult (due to site complexity) to calculate through standard methods, and the assessment cost higher than foreseeable savings. The estimated building heating thermal demand at the factory is around 19% of the total steam, (see section 6.2.2 for a limited analysis). The SEC as indicated in Table 43 is further discussed below

6.1.4.1 Demand and weather

Monthly gas and electric demands (MWh) are individually compared against Met Office's monthly average weather data (from East of Scotland at Lossimouth) (Metoffice, 2017). Linear regression relationship is shown in Figure 77 and Figure 78. The 2014 increased electric demand is known from the Table 43. The effect of new bought-in (between 2011–2014) technology (thermal/electric) on demand is negligible, as can be observed in historical demands, thus minimum savings can be associated. The increased building occupancy hours could possibly result in a slight increase in heating-related electricity use when compared with production. Therefore, the rise in electric demand will mainly be due to the rise in activity/shift hours. Unchanged working/activity hours in Dyehouse with higher thermal/steam demand is already known. Figure 77 (representing R^2 and P values from 2011 onwards) indicates overall regression accuracy, the strength of correlation, and the probability of chance in obtaining these values. Weak strength of correlation is observable for all of the years. The highest R^2 value is for 2014 (0.060) with a 44% probability of obtaining this value by random chance. The weather and consumption trend for this indicates an increase in energy use with increasing temperature. This is true as summer is peak production time and electricity use has increased for this year as well. 2012 indicates increasing energy use with increasing temperature and for 2013 the demand stays constant. This can be associated with the energy (electricity) saving measures that helped to reduce overall monthly consumption this year.

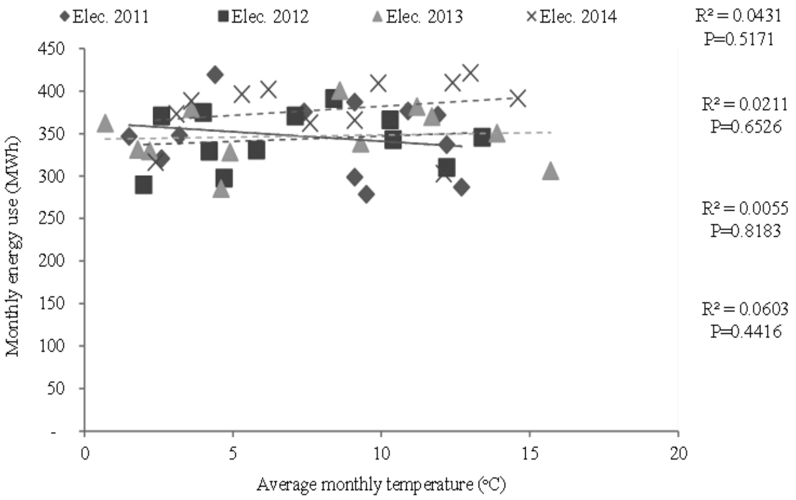


Figure 77 - Electricity versus temperature

Elec.=electricity

Weather and demand relationship is also weak. Other factors such as change in production and processes' capacity, variation in individual year's weather, process management (like batches/sizes, holidays, overtimes), and type of product/s produced are arguably more important to the shape and magnitude of the electricity demand. One should also consider other factors such as the number of holidays during a season, overtime, and reduced activity (which can usually be alike for the off-production season) process. Based on all these factors it would not be fair to epitomise on these analyses and conclude that a strong relationship exists between weather and electricity consumption. It can be seen that the rate of production is a stronger electric demand controlling factor.

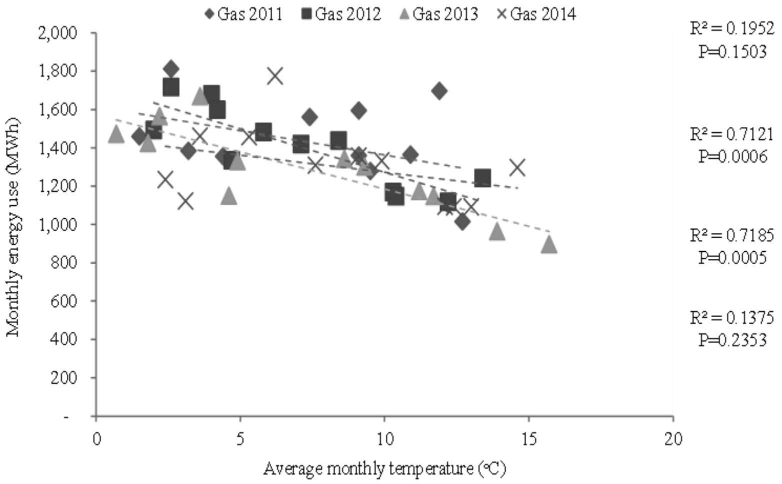


Figure 78 - Gas versus temperature

The increased number of working hours in 2014 would have increased the gas load, at least, through one department (finishing). Contrarily, in response to saving measures in 2013 onwards that have significantly hindered the corresponding growth in demand, the overall consumption has decreased. Therefore, the trend lines for all of the years, shown in Figure 78, indicate a reasonably strong relationship with temperature (increase in demand at a lower temperature). This in terms of R^2 and P values is different for 2011 and 2014, theoretically weak despite the trend line showing a measurable relationship. Contrary to that the R^2 for 2012 and 2013 (0.712 and 0.718 respectively) is reasonably good indicating a strong relationship with reduced probability (P) of random chance (0.0006 and 0.0005 respectively). The trend lines clearly show that production, as discussed above, and weather have a reasonable impact on demand. This can be confirmed through the onsite observation—two boilers operate instead of three in summer.

To understand production impacts on energy, at large, it is important to understand the production and activity at department-level—discussed in the following sections. These reviews help to understand and establish relationships, within and based on different factors such as discussed above. However, through low-resolution data establishing firm causations among multiple variables (energy, weather, and production rates) is challenging. In such cases, analyses of other data sources such as high-resolution consumption and activity data can be useful. Aiding to understand key factors influencing energy trends and patterns the analysis can facilitate robust energy efficiency recommendations, as discussed in Section 6.3.

6.1.4.2 Specifying energy efficiency recommendations

Reason for disruptions in the graphs for 2014 i.e. in Section 6.1.5 are already known. Figure 79 shows individual SEC/unit production (metre). The SEC (electric) remains almost the same during peak production season (between June–August) even for 2014, despite a more intense individual production process conditions. However, for 2012, between January–May, it is the highest indicating lowest production rates, as discussed in Section 6.1.5.3. The graph later on, from September through to end of the year, attains a higher position. The SEC for 2011 is the lowest for most of the months (year-round higher production). When compared with the others 2013, which production-wise is the second largest year, shows slightly elevated SEC for June and July. For the rest of the years, except for June and July, demand is always lower (despite less quantity of total metres produced in 2014). This can be due to more metres being produced in these months, which can further be seen in Section 6.1.5.3. Otherwise, this can be in response to two types of impacts: firstly, the increase in departmental hours/week (mostly for electricity-intensive processes and increased production capacity of the relevant processes/goods, as can be seen for yarn manufacturing-in for 2014 in Figure 86 in Section 6.1.5.2) and, secondly, the implementation of the electricity-saving measures (though this has a small impact as relatively small savings are observed). However, the reduction in response to saving measures is equally valid for 2014 as well.

Despite the lower production rate, the SEC for gas, Figure 79, in 2012 is higher for most of the months which could be attributed to weather. However, other factors such as small batches, below-standard housekeeping, and the other management measures (mostly out of scope) cannot be ignored. After March 2011 demand mostly remains higher, which can be attributed to higher production rates and the absence of saving measures like in 2013. June 2014 shows the lowest SEC, which is in response to the metres produced (Section 6.1.5.3) or reduced intensity of thermal processes internally (Sections 6.1.5.1–6.1.5.4). Additionally, the third boiler being shut down, optimum conditions for avoiding overtimes (naturally suited), number and quantity of material/batch (existed by chance), and better enforcement of gas-saving weekend measures could be factors.

Figure 80 shows the combined SEC indicating the cumulative demands of both electricity and gas-intensive departments. 2012 shows the highest values throughout the year. Between March to May, 2014 demand is higher than for 2011 and 2013. The contributing factors are already discussed above and are further highlighted in individual process sections below. The zero values for 2014 last three months is due to missing data as discussed in Section 5.4.2.1.

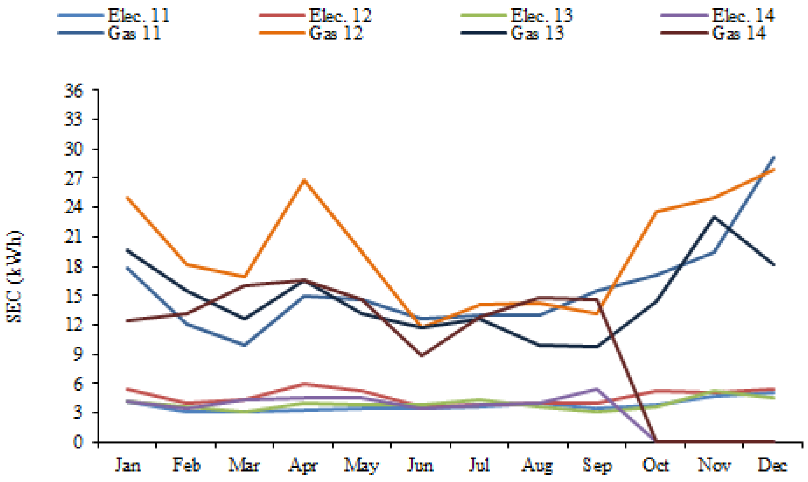


Figure 79 - 2011-2014 SEC for gas and electricity

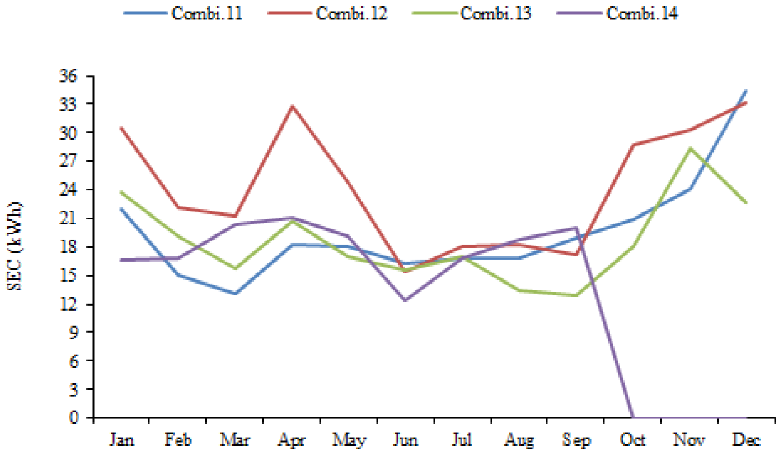


Figure 80 - 2011-2014 combined SEC for gas and electricity

Deviation of individual month’s total consumption (electric and gas) and monthly woven metres from their monthly averages (combined total of 12 months divided by 12) is drawn in Figure 81 and Figure 82 respectively. This was to see any invisible impacts of seasonality (production and weather) that might not be visible in Figure 79 and Figure 80. Figure 81 shows that more than the average production rate is achieved in general after January (off-production season) for the next two months. In April however, the production rate goes below average (holiday). Recouped in May it continues until a fall below average in July and August (summer holidays). Despite belonging to on-production season and without any holidays, production for June 2011 and 2013 is below average. This can be due to virtually lower production rates during these months or reasonably higher production rates during other months. In 2011, 2012, and 2013, the production rate goes above average for September. Metres produced in September 2014 might not be above average but the factor of increased intensity of activity cannot be ignored (as discussed in Chapter 4). This implies that the number of metres produced may not be the definitive indicator for efficiency improvement in certain measures (such as specific energy, carbon emission reduction, and energy efficiency) for such a complicated manufacturing process. The higher and lower (compared to average) production rates even within the peak production seasons are also evident. Therefore, an in-depth understanding of factors affecting and the availability of relevant data is highly important for a reasonable level of review like this. During the last three months in general, regardless of how busy the whole year was, the production rate remains below average.

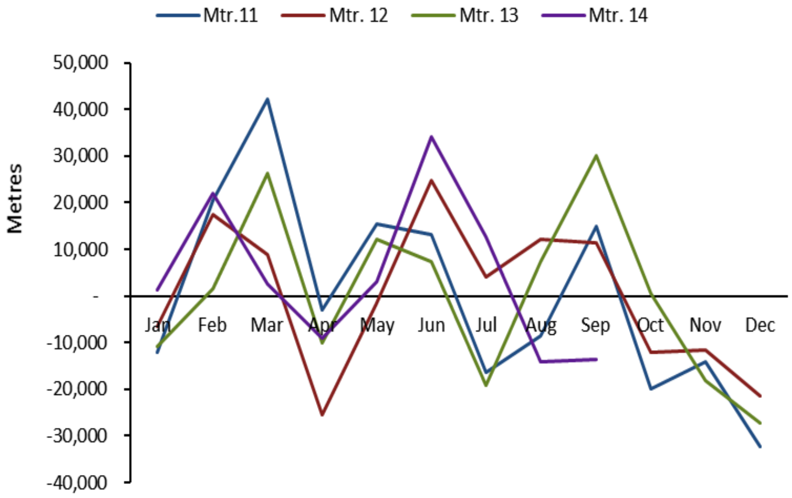


Figure 81 - Monthly metres deviation from average

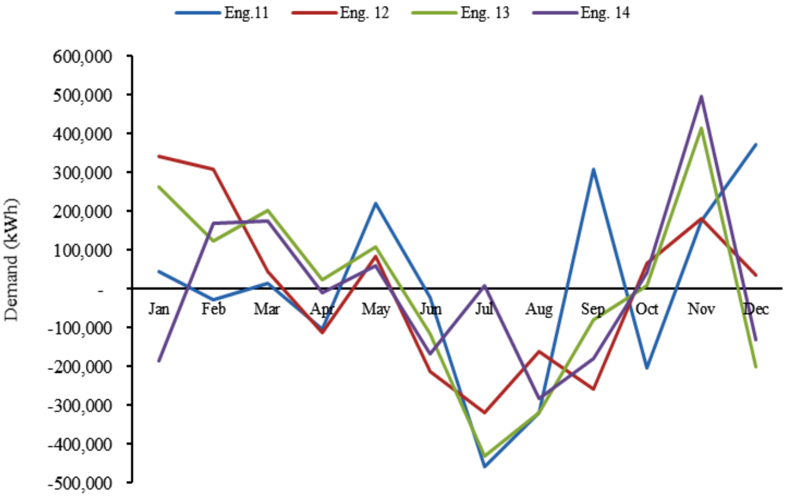


Figure 82 - Monthly energy deviation from the average

The deviation of monthly total energy use from the average, shown in Figure 82, shows a higher demand in January except for 2014 (indicating electricity and gas-saving measures). Tangible efficiency improvement effect (below average demand) is visible in December 2013 and in January and December 2014 (despite increased average production rate and cold weather). February and March for 2012, 2013, and 2014 show above-average demand which is justified for 2012 and 2013 (meters produced). However, for 2014 the extent of the rate of increase in energy demand is comparatively very high when compared with the total metres produced. This again indicates the increased energy demand in response to increased department-level (sub-stage) activity. In other words, less buying-in/outsourcing **(**as defined in Chapter 4) of different sub-stage materials/processes have occurred, some of which are discussed in the following sections. Interestingly, the production rate (metres) in 2011 for these months is significantly above average whereas the energy demand is lower. This can be due to prevailing ideal/efficient work conditions (linked to process management, batch sizing, reduced energy waste, etc), or the work (towards metres produced) being carried out off-site, or reduced sub-stage activity. Contrary to that, a significantly higher quantity of energy (compared to average) is used in May 2011 but the total number of woven metres is slightly above average. Since May initiates summer, therefore, it would not be wiser to dedicate a large quantity of energy towards building heating. It can be, once again, assumed that the prevailing working conditions, as mentioned above may not be favourable this time or other factors affecting (such as reduced activity, more energy used to meet the baseload than to produce for example production and consumption below breakeven point) are prevailing. Similar types of energy demand deviations, indicating above- or below-average demand, incurring can be seen throughout Figure 82. It may be true that increasing the rate of production (up to a certain level), most of the times, increases the energy demand but it is difficult to understand it when dealing with manufacturers having such a complicated supply chain. This is, however, observable for October and November in 2013 and 2014. It can be seen that the rise in energy demand is due to cold weather in December (although low production) which cannot be ignored. As the discussion above identifies the relationship between the production rates, weather, and the energy is complicated and poses various scenarios to ascertain the analytical dimension. Therefore, reviewing the individual processes in terms of production becomes necessary to further clarify the energy picture.

6.1.5 Production process, activity, and supply chain

Production processes, activity, and complicated supply chain can greatly impact the manufacturing energy use. For example, individual processes carried out externally of an organisation usually will have a different energy value. This, if individually calculated for a holistic energy calculation, can create a considerably different but in-depth energy picture (out of the scope of this study). However, to understand general and the impact of 2014 operational change on supply chain and the associated energy (on- and off-site) subs-stage energy/processes are briefly reviewed below. It also helps to understand activity (monthly/annual) and process output/SEC over various years.

6.1.5.1 Wool and dyeing

Figure 83 indicates that between 2011 to 2013 less in-house dyeing takes place in the beginning and end of the year, whereas for 2014 the inverse is true. The quite high loose dyeing-out (externally) until mid-2011 rate reduces afterwards whereas 2012 is inverse to this pattern. The rate of external and internal dying for 2013 is notably high, as is the aggregate total (however production (metres) is relatively low) further shown in Figure 84. Therefore, this indicates that relating total meters produced with the total energy consumed may be a reasonable approach, specifically in relation to thermal energy demand. However, there may be many reasons and uses for higher in- and out-house buying/production. For example, this may be an act of efficient management (keeping busy), or producing key items for future (i.e. black and white for common colour blends), or purchasing cheaply available wool. Of note, depending on the shade/type of dye, the length of various dyeing programmes varies from one–six hours. Therefore, even the choice of fabric shades and colours can impact the overall energy, thus different product lines can shape the energy demand. The rate of wool dyeing (in/out) for 2014 is mostly stable until September (after which the data is missing). This can be due to several factors such as stock from the last year still being in place, more woven material is bought-in (refer to Section 6.1.5.3`), dyeing-in is taking place only on an as-needed basis no stocking for the years to come. In the total dyeing (in/out) in Figure 84 2013 is at the top and 2014 is at the bottom, the reasons are already known. Despite 2014 weekly dyeing hours did not change. 2014 hank dyeing (in/out) rate (shown in Figure 85) is also quite low. Several factors like specialist dyeing processes that are only available offsite, more yarn bought in as in Section 6.1.5.2, or longer dyeing programmes used frequently, may be affecting. The discussion shows that a large number of factors and variables (known fully or partially) have a knock-on effect on the main and sub-stage dyeing and other processes. For example, more wool dyeing requires more yarn produced (on- or off-site) depending on the production requirements.

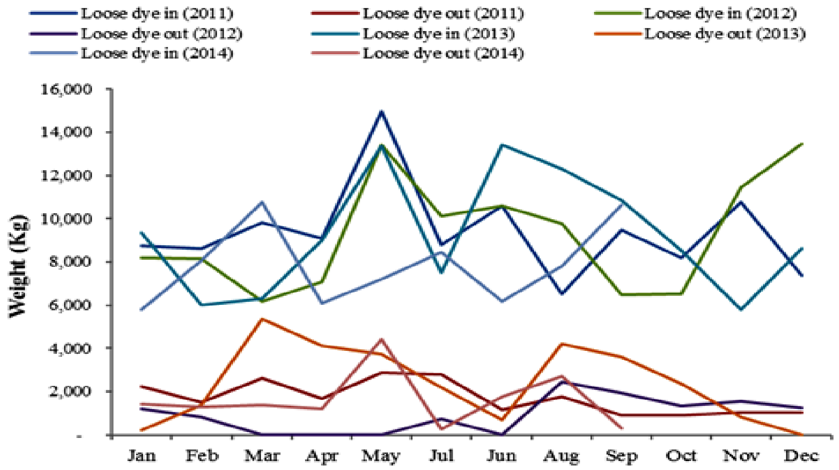


Figure 83 - Monthly loose wool dyeing

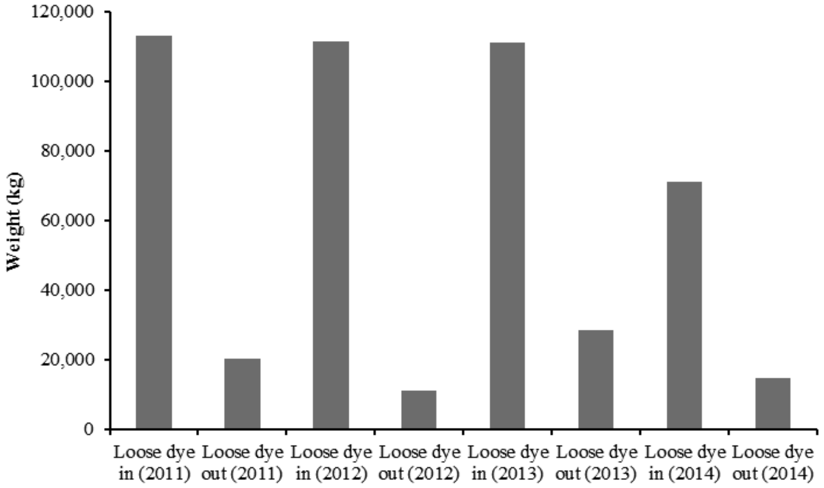


Figure 84 - Total dyeing in and out of the loose raw material

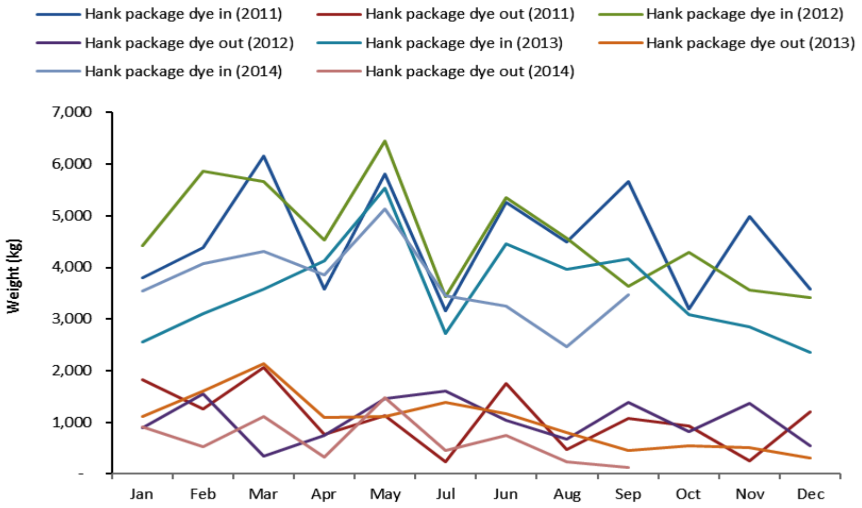


Figure 85 - Hank dyeing

6.1.5.2 Yarn manufacturing

Figure 86 indicates increased and decreased rate for in-house manufacuring and buying-in respectively for 2014 (perhaps internal yarn from 2013 is utlised) also clearly shown in Figure 87. Total internally and externally manufactured yarn in 2011 (highest metres produced) and in 2012 is relatively less than 2013 (and presumeably for 2014 as well) as indicated in Figure 87. Therefore, it can be assumed that metres produced in 2013 and 2014 would have greater quantity of internally produced yarn. The company's decision to produce more yarn internally in 2013-2014 could be due to cost-effectiveness.

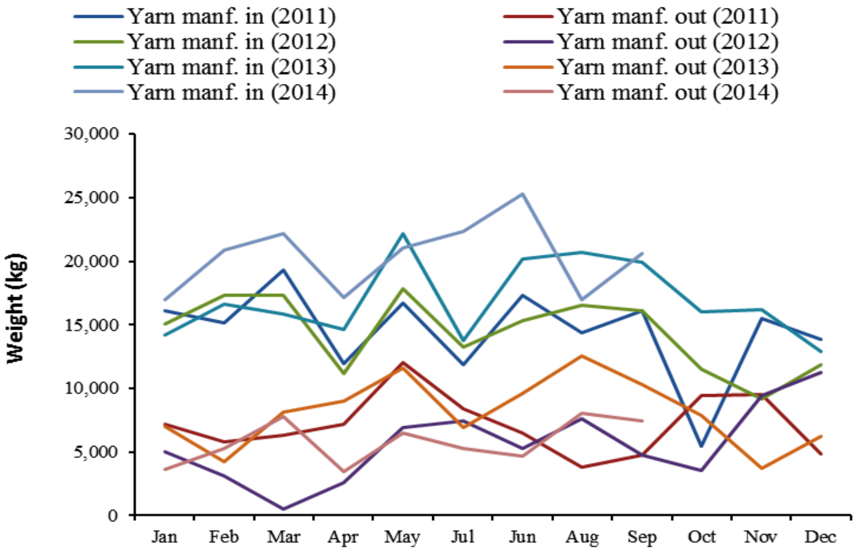


Figure 86 - Yarn manufacturing in- and out-house

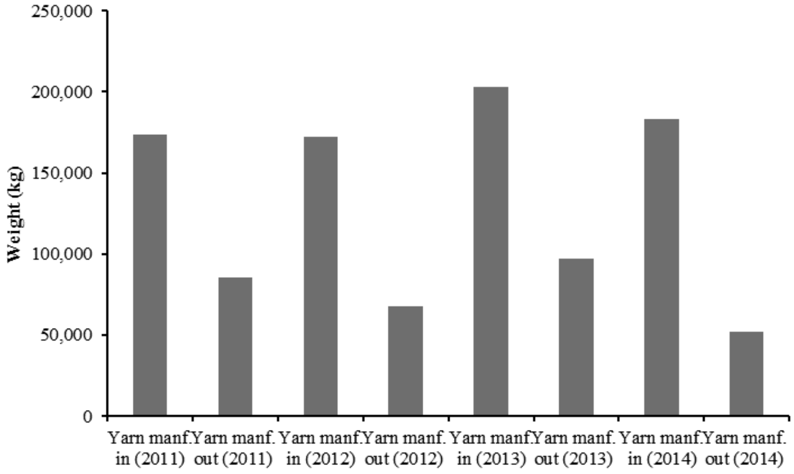


Figure 87 - Total yarn manufactured in and outside of the factory

The processing frequency, shown in Figure 88, indicates various aspects such as fabric type, seasonality, fashion, or the manufacturer's specialty. 2012 and 2014 indicate the highest twisting rates (on- and off-site), which for 2011 is the minimum as shown in Figure 89. This also indicates the thickness variation of the finished metres and the resultant variation in energy used (as discussed in Section 4.3). This leads to concerns for the SEC benchmarking for such complex product lines (scarves, rugs, throws, and shawls).

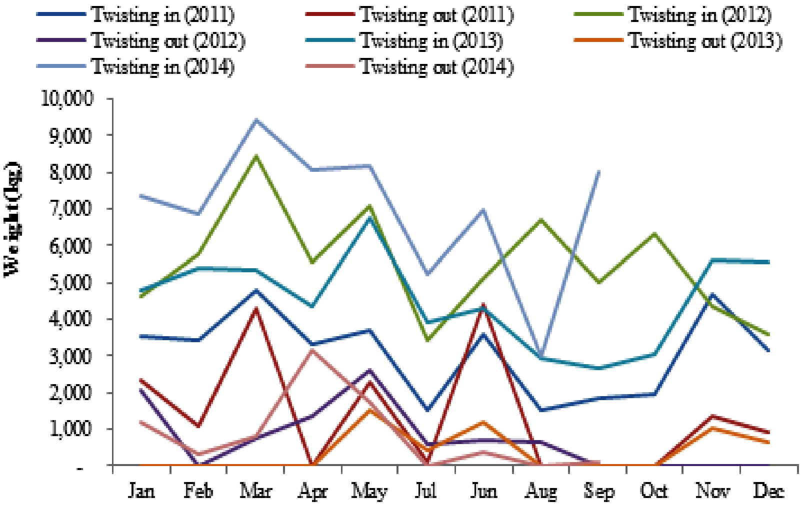


Figure 88 - Twisting-in and -out over the years

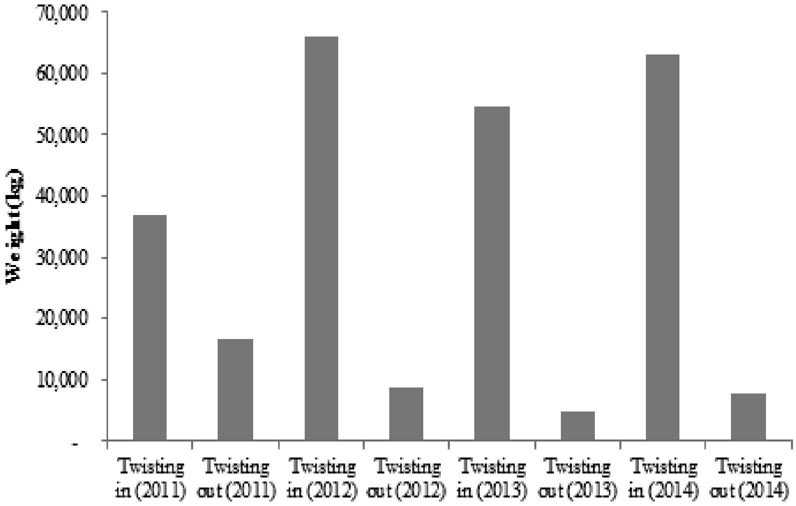


Figure 89 - On- and off-site twisting

6.1.5.3 Weaving

Production (metres) for 2011 and 2013 remain the highest compared to 2012 and 2014 over various months, as shown in Figure 90. Clearly following the factory's peak- (including holidays) and off-peak production seasons Figure 91 indicates external and internal metres produced. 2011 shows maximum metres produced internally/externally whereas apparently more internal/external metres were produced in 2013 than in 2014 (three-month data missing). Metres produced internally/externally shape the energy curve for the year like the other key processes will do. It can be seen, once again, that the same amount of energy usage is being assumed for the processes taking place externally. This indicates the importance of having, at least, benchmarks for individual processes (for calculation uniformity) or knowing participating suppliers' individual processes' energy values (internal/external) for a detailed analysis. Knowing the article WA000608's total metres, indicated in Figure 92, is useful for the CO_2 footprint assessment (as in Section 6.5).

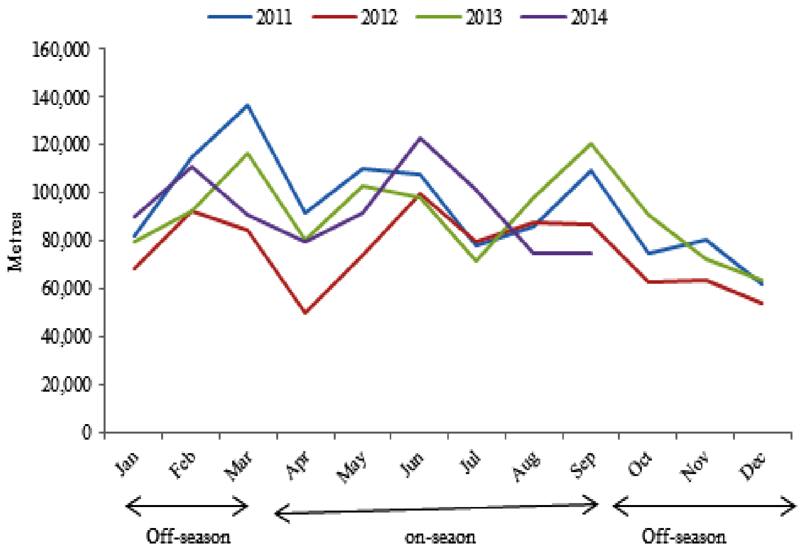


Figure 90 - Monthly woven metres

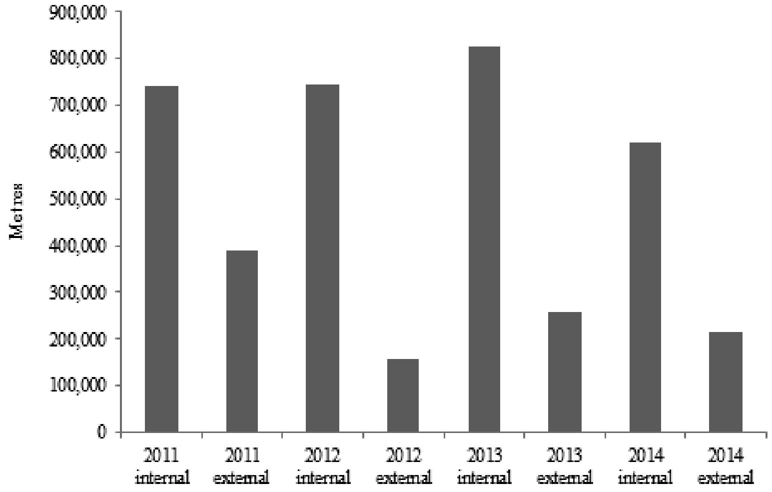


Figure 91 - Metres woven on- and off-site

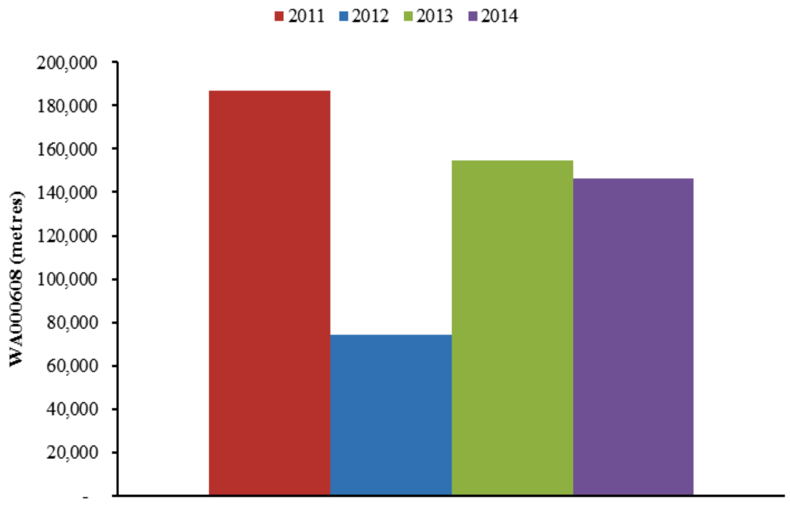


Figure 92 - Metres produced for article WA000608

6.1.5.4 Finishing

Taking an account of various Finishing processes, as mentioned above, towards the final finished product is not possible. The department, in the factory, collectively is the highest energy user. Figure 93 shows monthly total finished metres (including WA000608). Peak-production months for 2011, 2013 and 2014 show reasonably high activity. It is the other department that started working more weekly hours in 2014. Due to the process diversity, one must not assume that every single process is represented by metres finished in the department alone. To reflect this, relatively more detailed data (finishing in/out) is presented in Figure 94. Metres finished in and out for 2011 are slightly more than in 2013. 2014 indicates reduced activity in-house as well as off-site (may be due to the data gap).

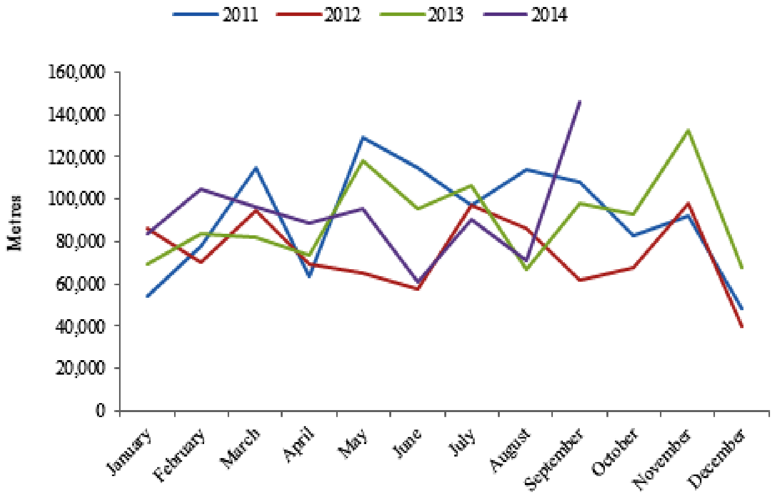


Figure 93 - Total metres finished per month

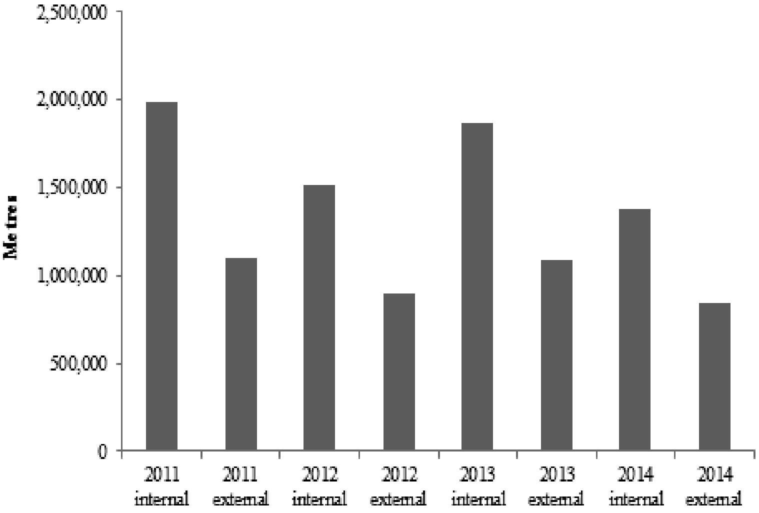


Figure 94 - Metres finished internally and externally

6.1.5.5 Significance of production processes and the supply chain

After discussing the production processes above, knowing the raw materials' consumption helps to understand material flows (stage-wise materials transformation). It is also useful for CO_2 accounting in Section 6.5. Yearly total raw materials used for the whole factory, Figure 95, and specifically for WA000608, Figure 96, (total kgs of wool internally/externally) are shown. Note some suppliers would use their own wool/yarn making the whole calculation more complicated. The higher consumption rates for 2013 and 2014 support the idea of increased dyeing and yarn production activity to meet future (2013) and present demand (2014) as established above. Despite the highest wool consumption in 2014, total metres produced in 2013 and in 2014 are slightly less than in 2011, as shown in Table 43. Several factors could be linked to this, some discussed above, such as the production of lighter fabric in 2011, more yarn was bought-in that year, or the average width of the fabric produced was much less than in 2013 and 2014. Many of these variables (as indicated in 6.3.2.4), can impact the energy use significantly, and highlight how manufacturing activity can drive demand characteristics in such buildings (and thus distinguish these buildings from the rest of the non-domestic sector) as further elaborated in 6.3.

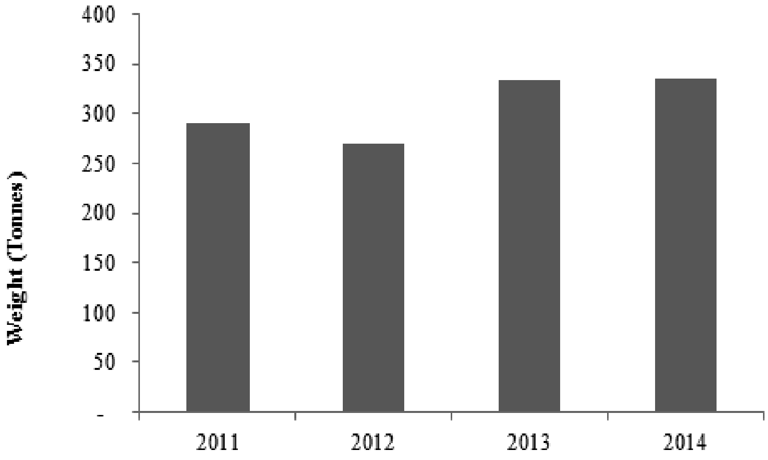


Figure 95 - Annual wool use

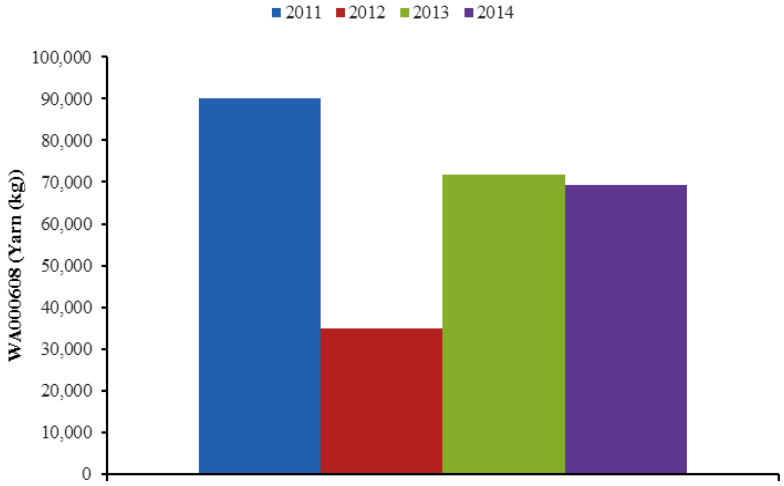


Figure 96 - Wool used for WA000608 making

6.2 Selected technology assessment analysis based on micro-audit

Regardless of rise/fall in the intensity of various production processes, the demand between 2011 and 2013 remains relatively low. The identified causes and the controlling strategies, as discussed above, have helped to considerably reduce gas demand (between 2013–3014) with some success for electricity as well. This was only possible through understanding the site thoroughly and then tailoring site-specific saving strategies. It can be assumed through the experience that such sites will have some saving potential, albeit in-depth understanding of how energy is used/wasted is required. High-resolution data analysis has facilitated such investigation to an even more in-depth level as discussed in Section 6.3.

In this section some key technology performances, based on monitored or measured data where possible, are assessed. The energy savings related recommendations are discussed in Section 6.4. The key steam user technology's demand estimation (which was not possible) was reflected through possible air-to-air (air/air) and liquid-to-liquid (water/water) heat recovery estimations. Production process and building heating related thermal demand was also estimated

The study's groundwork and the identification of the site-specific saving measures (behavioural- and technology-change strategies, communicated through several reports) were undertaken during the researcher's course of study onsite. The overall energy management options reported and implemented are briefed in Appendix 1 (b). The use of departmental energy representatives, to support onsite EM process, was one of the strategic initiatives. Operated and maintained by the researcher and the maintenance staff, the EM measures included rolling out of a traffic light system for electricity switches, energy waste incident reporting, and equipment switching off at weekends. Implemented in February 2013, these measures significantly reduced electric demand (observable at the weekends) as in Section 6.3.1.2. Managed by the maintenance team, weekend boilers' operations control, as discussed in Section 6.2.2.2, are further discussed in Section 6.4.2.2 was the other.

6.2.1 Electric

6.2.1.1 End-use demand

For the simplification of end-use demand categorisation technology/equipment/systems and components are distinguished on the basis of their functionality, using their nameplate rating. Categorical demand contributions (aggregate rated power) are indicated in Figure 97. As discussed in Section 5.3.1.1 an 80% load factor and rated efficiency, where applicable such as for motors, is assumed. The resultant total demand (1,524kW) is 21% higher than the contracted (1,200kW) capacity, which has not exceeded 1,130kW in the last four years (as shown in Table 68 (Section 6.3.1.1)). In the partial presence of rated efficiency and the load factors such level of error is not a big surprise. "Others" include electric heaters, fans, hot water dispensers, and fridges. With the lowest load, replacement of less efficient IT equipment with more efficient (printers/monitors) started off in phases from 2014. The total demand when multiplied by total annual hours was 2.6 times higher than the actual (kWh) consumption for 2011. For 2014 with the effect of increased hours, this demand was 2.8 times higher.

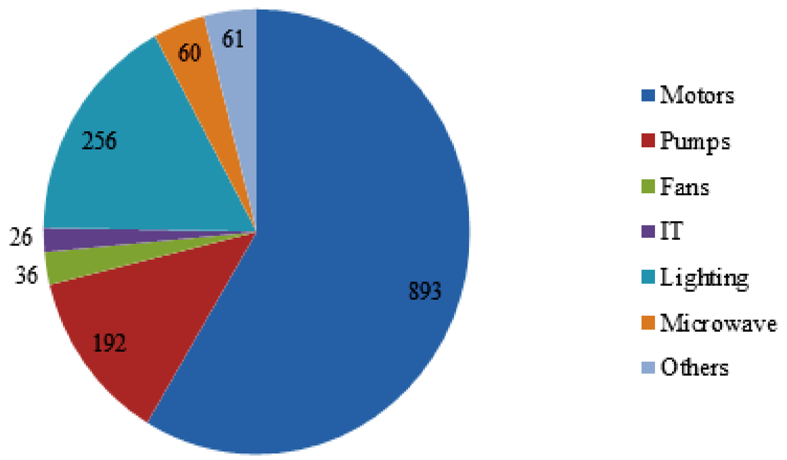
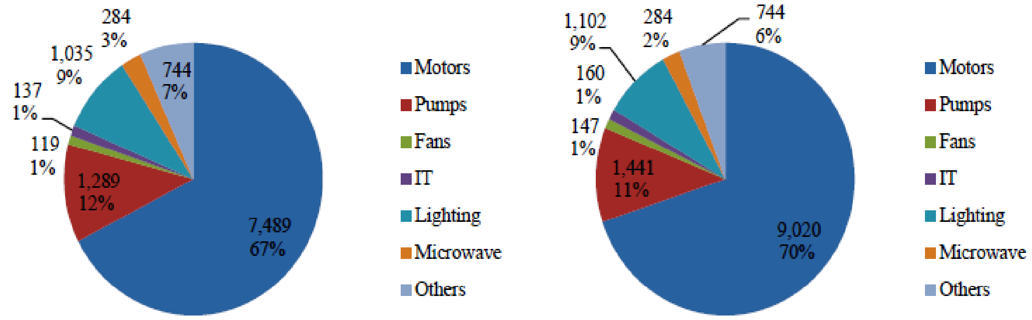


Figure 97 - 2011 total load (kW) contribution

As discussed in Chapter 2, these demand estimation methods have limitations, for example the complexity of running modes of IT equipment (active, low power, and off). Similarly, accurate load factor and efficiency of the motors, if available, can help reduce error in load calculations. However, for simple calculation method the scope of the enquiry requires a degree of generalisation for use of such machines, as, discussed in Chapter 3 and indicated in Table 30. This is where measuring and monitoring becomes a more powerful tool.

Figure 98 (A) shows 2011 nameplate ratings and percentage demand contribution. This is different than the nameplate load (kW) contribution (Figure 97) as the utilisation factor (derived for individual category from Table 30) is included. The values are different than for 2014 in Figure 98 (B), reflecting the change in operating hours. Of note, some items such as lighting, pumps, and others have been running permanently for both years. There are certain categories such as Motors and IT whose demands have increased for this year. Though the difference is relatively small but is helpful to understand the impact of organisational operational change.



A) 2011 annual demand % contribution B) 2014 annual demand % contribution

Figure 98 - 2011 and 2014 demand comparison (MWh)

Due to security reasons, the IT server room is not considered

This change in demand can further be understood by calculating and comparing the total annual demand for 2011 (total 11,097MWh) and 2014 (total 12,899MWh) as in Figure 98 (A&B, respectively). Although these are nameplate based estimations, the impact can still be perceived. It can be seen that the calculation's sensitivity towards activity is more tangible towards the number of hours as compared to load factor and the intensity.

Figure 99 indicates nameplate ratings of department load (technology and lighting only). Yarn production is at the top and despite mainly running on electricity, Weaving is lower than the Dyehouse and background demand due to various factors (discussed in Sections 4.3.1 and 6.1.5.3). The reason for Dyehouse being higher could be associated with more use of agitating and pumping power and the higher demand for raw material drying technology.

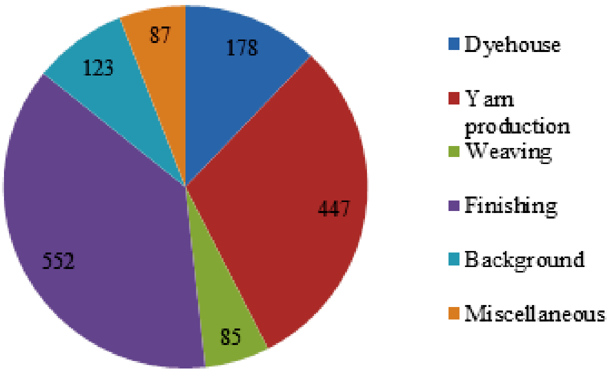


Figure 99 - 2011 nameplate rating based end use

Miscellaneous include all the leftover departments/sections as indicated in operations in Table 30

Figure 100 indicates 2011 total annual departmental contribution complementing the Yarn production and Finishing demands concluded in Figure 99.

However, the total consumption of Weaving is much higher than the Dyehouse (greater weekly operating hours) and the background load (due to consistent demand). If such calculations carried out for 2014, it can be concluded that the values obtained will be significantly different. However, it can be seen that Yarn production has the highest electric demand among the other departments. Through such steady-state calculations (with some limitations) demand estimations at various levels are relatively straightforward, and therefore can be used in the absence of H-H data.

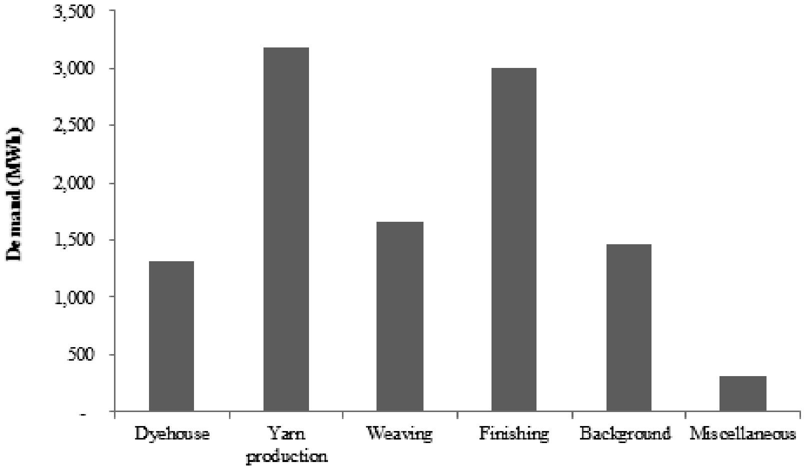


Figure 100 - 2011 nameplate rating based annual demand

6.2.1.2 Air compressors

Specified in Table 46 the factory has two identical CA units. These reasonably advanced air-cooled and oil-lubricated stationary screw type air compressors have inbuilt VSDs and trim controls (as discussed in Section 3.2.2) and can display instantaneous motor speed and air volume. These have individual air receivers (at 7bars), fitted with refrigerated type air-dryers. Weaving receives CA direct from the system whereas Finishing, Dyehouse, and the Warehouse receive it through the storage vessel (at 6bars for weekdays and 7bars for weekends) located in the boiler house. Yarn production has a separate air storage vessel (at 6.5bars).

Table 46 - Factory's CA system specifications

Category	Description
Air compressor name and model	CompAir Delcos 3100 (L45SR)
Model year	2008
Motor power	45 kW (95amp)
Max. Revolution	4250 rpm (50Hz.)
Max. allowed pressure	16 bar
Max. working pressure	13 bar
Max. air volume	8.02 m^3/min

A month-long clamp-on meter monitoring exercise (at hourly resolution) revealed maximum and minimum instantaneous air volumes of 7.3m^3/min and 3.3m^3/min respectively. One-week hourly monitoring, (September 16–23, 2014 mostly between 08:00 am–midnight), was used to estimate average weekday, weekend, and annual air volumes as indicated in Table 47. Average total electricity demand estimation was found to be 6.5% of the factory's total consumption, as shown in Table 48. The compressor runs constantly at the weekends (equaling 22% of the weekday energy demand), though at lower loads, to feed the leaks. Despite this load being less than half of the weekday load, the average energy consumption is more than the half. This could be due to lower load-related motor efficiency.

Table 47 - Air volume production

Days	Average volume (m^3/min)	Daily volume (1,000m^3)	Annual volume (1,000m^3)
Weekday	6.1	9	2,297
Weekend	3.3	5	494
Total			2,791

Based on 24X5 shift patterns with no weekend overtimes

Table 48 - Average energy and cost

	Average hourly consumption (kW/h)	Average daily consumption (kWh)	Average daily cost (£)	Average annual energy consumption (kWh)	Annual cost (£)	CO$_2$** (tonne)	Average consumption/ 1000m^3 (kWh)	Average cost /1000m^3 (£)
Weekday	37	897	90	234,107	23,411	108		
Weekend	21	493	49	51,291	5,129	24		
*Refrigeration (weekday)	1	27	3	7,023	702	3		
*Refrigeration (weekend)	1	15	1	3,862	386	2		
Total				296,283	29,628	136	106.14	10.61

- *Based on 24X5 shift patterns with no weekend overtimes (where 261 weekday and 104 weekend days)*
- **Energy consumed for refrigeration is 3% of the compressor (The Carbon Trust, 2012b)*
- ***CO_2 factor derived from Defra's 2012 emissions table*
- *90% of the total energy is turned in to recoverable heat (EEBPP, 1998)*

To better understand the overall technology operations, running- and loaded-hours and air volumes were monitored (with gaps filled by repeating previous values where necessary). Selected weekday and weekend dates' (with maximum readings taken, legend shown with Figure 101) profiles are shown in Figure 101 and Figure 102.

Figure 101 shows weekday air volumes and energy demands ranging 350–450m^3/hour and 33–42kWh respectively, with the noticeable fall indicating mid-day (lunch) to 14:00 (end of shift). The next change of shift, though mainly visible for Tuesdays, is at around 22:00.

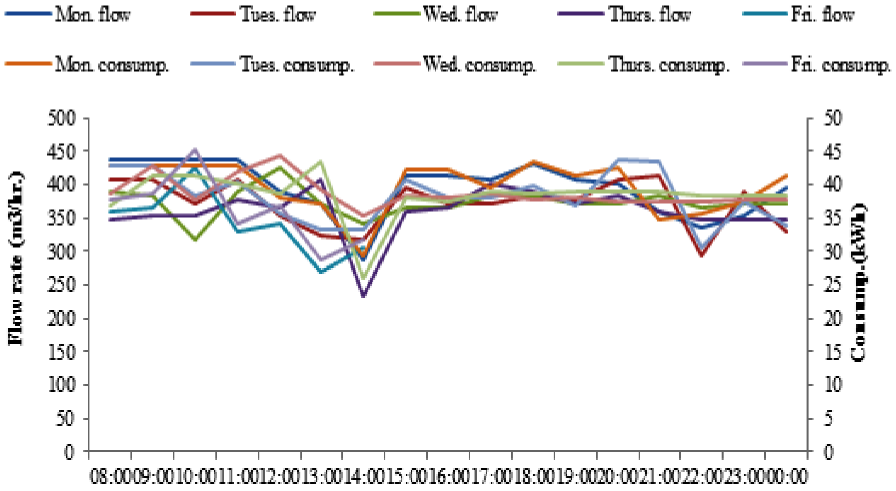


Figure 101 - Average weekday energy and compressed air demand

Dates monitored

Legend	
Monday	22/09/2014
Tuesday	23/09/2014
Wednesday	17/09/2014
Thursday	18/09/2014
Friday	19/09/2014

Two Sundays' limited data for 21/09/14 (between 16:00–18:00) and for 28/09/14 (between 18:00–21:00) are used to indicate demand and volume, as shown in Figure 102. The energy and the air demand between 16:00–20:00 are between 18–22kWh and 175–200m^3/hour respectively, used to only feed leaks and maintains system pressure (no-cost saving opportunity). Dyehouse (starting between 20:00–23:00) and Weaving shifts starting at 20:00 raise demand. Limitations, such as long-term system shutdowns (condensation prevention) and odd weekend shifts starting time, should also be noted. The identified energy saving opportunities, which are only possible through in-depth micro-audit, are further discussed in Section 6.4.1.2. These were also communicated through an internal report to the company, briefed in Appendix 1 (c).

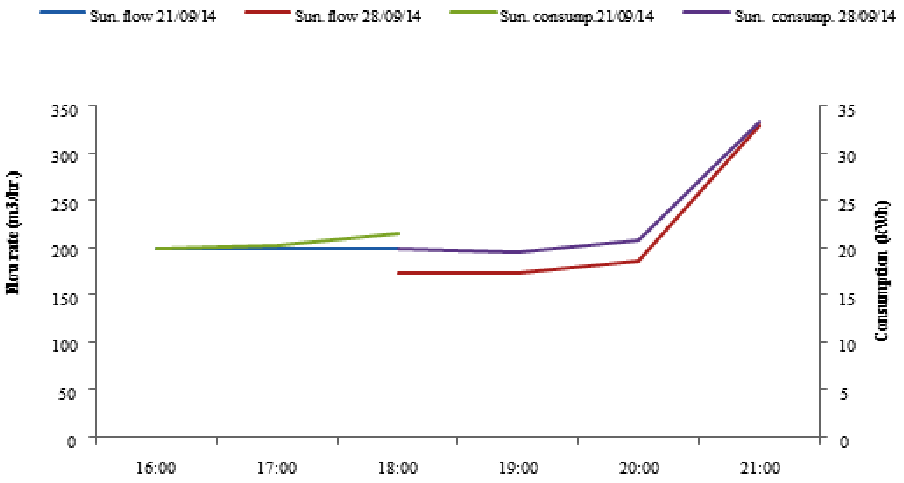


Figure 102 - Average weekend energy and compressed air demand

Due to limitations only some Sunday (afternoon and evening) readings were taken

6.2.1.3 Lighting evaluation of a case-study building

Peak lighting load (representing installed capacity), as indicated in Appendix 1 (d), is 256kW. Almost all of the buildings offered savings options including retrofitting more efficient lighting (5ft. T5 tri-phosphor and LEDs), day-light optimisation, control switch relocation/rewiring, timers, and occupancy sensors around the factory as indicated in Table 49. The demonstration of such estimation (repeatable on all buildings) is performed on a case-study Yarn manufacturing building as discussed Sections in 5.3.2 and 6.4.1.3. The summary of the internal evaluation report is given in Appendix 1 (e). The assessment assumes existing illuminance levels and the lighting arrangements in the sub-sections are satisfactory. The building lighting load density is indicated in Appendix 1 (f).

Installed at a 3m height, as shown in Table 50, the majority of these lights are over 25-year old thus likely to have magnetic ballasts. Measured from 1m floor height and at around 15 spots, during an overcast day with a lux meter (model ISO-TECH ILM350, never calibrated), lighting levels ranged between 150lux–1,440lux. Therefore these readings are likely to be inaccurate however are compared with the benchmarks in Table 51.

Table 49 - Lighting efficiency saving potential in various buildings

Building no./section	Estimated load (kW)	Weekly hours	Cost per hour (£)*	Estimated daily saving potential	Proposed measure	Details
05/06 shops	15.4	63	1.54	50%	LED lighting	replace existing lights with LED spot lights
10 retail warehouse	6.3	78	0.63	50%	occupancy sensors/pull switches/rewiring	this area needs different controlling measures
12 teasling, stenter	15	78	1.5	below 50%	replacement of 8ft tubes with efficient tubes	these tubelights could also be replaced with LED tubelights
14 wet finishing	5	78	0.5	below 50%	consider LED lighting	future project
18 warehouse, main	10.5	78	1.05	reasonable	consider LED lighting	future project
19 stock room	17.6	78	1.76	over 50%	occupancy sensors/pull switches	a detailed study is planned for the future
23 weaving	19.4	103	1.94	not evaluated yet	automatic modulating ligthing sensors/narrow lighting reflectors	a detailed study is planned for the future
26 drying house	0.84		0.084	over 50%	occupancy sensors/pull switches	one side of the area is normally not used
34 wool breaking	0.68	103	0.068	50%	occupancy sensors	this area is used only on as needed basis
36 yarn store	9.1	103	0.91	over 50%	occupancy sensors/pull switches	only one to two aisles are in use at a time
37 yarn store B	1.5	103		over 50%	occupancy sensors/pull switches	this area is used only on as needed basis
38 yarn production	21.7	78	2.17	as demnostrated in the section below	LED lighting/automaic modulating lighting sensors	details are discussed in the thesis
39 teasing	2.2	78	0.22	50%	rewiring	one out of two rooms is being used at a time
39 fettling and mezzanine area	3.4	78	0.34	over 50%	occupancy sensors	this area is used only on as needed basis
43 wool store	1.8	103	0.18	50%	rewiring	this area is used only on as needed basis
Total	138					

Table 50 - Number and types of lighting in Yarn production

Section	Area (m^2)	Number of lights (ft.)			Number of lights in a ro
		5	6	8	
Carding	442		27S+3D	77S+7D	5−6
Spinning	1,512	33S	6D	30S	6
Winding	494	5D	45S	6S	8−9
Total	2,448	43	90	127	–

S=single

D=double

Table 51 - Lux levels in yarn production

Illuminance maintenance value lux (on site at 1 meter above floor level)					
Carding		Spinning		Winding	
best practice	onsite	best practice	onsite	best practice	onsite
300	180-700	500	150-1,440	500	150-950

The nighttime lux is unknown

Best practice denotes benchmarks (SLL, 2012b)

The existing system lumen output capacity has been used as a benchmark to estimate saving potential. The estimated number of T5 (5ft. fluorescent) and the number of LED tubes required (from the manufacturer A's quote) are indicated in Table 52 and further explained in Table 53. The suggested number (like-for-like) of LEDs, however, shows a significantly low total lumen output density. This upon recalculation (to equalise the existing lumen density) indicates a much higher number of the LEDs than quoted (in Table 52). Considering the shape of the manufacturer A's product, it can be assumed that they may have considered the beam angle (100°−160°)—sufficient to fulfil the incident lighting requirements (discussed in Section 3.2.4). This indicates the significance of using lighting simulation software. The installation options and the saving calculations are further discussed in Section 6.4.1.3.

Table 52 - Number of luminaires required to meet existing lumen density

Type	5ft. (T8)	6ft. (T8)	8ft. (T12)	Total
Existing	43	90	127	260
5ft. T5		510		510
LEDs	106	252	339	697
LEDs*	150	290	75	515

- *LEDs calculated to meet the existing lux values (nameplate based)*
- **number of LED's required (according to manufacturer A)*
- *Since the LEDs will use the existing lighting apparatus, therefore 250 new LED light fittings will be required*

Table 53 - Proposed LED lighting

LED Type	Number	Total circuit load (kW)	First year lm density	Total lm density depreciation after 3000 h.	lm/m2
4ft. (T8)	10	n/a			
5ft. (T8)	65	2	146,250	143,325	
6ft. (T8)	290	9	696,000	682,080	
8ft. (T12)	150	6	450,000	441,000	
Total	515	17	1,292,250	1,266,405	517

- *250 new LED light fitting apparatus may be requried as the existing 260 fittings are less*
- *The LEDs are significantly higher than the exisitng lights*

6.2.1.4 Energy demands for Weaving and Yarn production technology

Due to limitations as discussed in Chapter 2, clamp-on meter spot measuring was only possible on Weaving and Yarn production (selected) technologies, as shown in Table 54. All the (spinning, Schalphrost, Dornier, and Jacquard) machines were similar to their respective technologies, as discussed in Section 5.3.2.3, hence only one representative measurement was taken for each type. There were three fettling machines with demand ratings (between 30–45kW). The one with the 30kW demand in Table 54, which demonstrates the discussion in Section 3.1.4.1.

Table 54 - Nameplate rating and clamp meter measurements

Section/Department	Technology	Total number	Running hours	Nameplate info (kW)	Weekly demand (kWh)	Annual demand (kWh)	Clamp meter (kW)	Weekly demand (kWh)	Annual demand (kWh)	Annual saving (kWh)	CO2 saving (T)
Spinning	Spinning	4	78	55	17,160	789,360	20	6,216	285,937	503,423	232
Carding	Carding	7	78	28	15,288	703,248	15	7,938	365,149	338,099	156
Winding	Schlaphrost	2	78	19	2,964	136,344	9	1,428	65,688	70,656	33
Twisting	Savio twist	1	78	20	1,560	71,760	4	294	13,524	58,236	27
Yarn production (YP)	Fettling	1	78	30	2,340	107,640	26	2,016	92,736	14,904	7
Weaving	Dornier machines	18	117	8	16,848	775,008	4	8,951	411,723	363,285	167
Weaving	Jacquard machine	6	117	11	7,371	339,066	5	3,391	155,970	183,096	84

The blue rows in the Table indicate technologies with VSDs, therefore, show lower (50%–80%) than the rated demands unlike the ones without. As the load factor affects the demand, this improves the comparison. For in-depth and accurate analysis, such as demand versus activity, measuring transient loads is more useful however is impractical for this study. To cope with this problem, the chosen method for the thesis—high-resolution data based analysis, is less onerous, more practical, cost-effective, and can be frequently applied. However, the significance of clamp-meter studies in certain perspectives (such as no high-resolution data available, or monitoring individual technologies being impractical) cannot be ignored. Such in-depth studies can yield fruitful results for the manufacturing industry, therefore, may be suggested for future work for the case-study or similar sites. The measuring is also helpful to compare rated power based individual technologies, and departmental demands studies as indicated in Figure 100.

6.2.2 Gas

Boilers (steam and hydroponic) and stenters are two key gas users (discussed in Sections 4.3.1, 5.3.2.1, and 6.4). Section 6.2.2.2, calculates steam demand and generation and its various end-uses even at individual technology-level where possible.

6.2.2.1 Stenter

This direct-fired Italian Santa Lucia was built in 1998 and has three chambers and six (three pairs) burners. The maximum rated demand is 200,000kCal/hour/chamber and 60kW for gas and electric respectively (discussed in Sections 6.4.1.2, 6.4.2.1, and 6.4.3.2). Used for drying and size setting only, the machine has a touch-screen display control. The stenter's first zone has a Corino weft straightener, and with infrared sensors, the middle zone is similar to as described in Section 3.1.2.2. A redundant modular process control system—Mahlo Optipac VMC10, was retrofitted a few years ago and can reduce energy waste by controlling different variables such as exhaust air humidity (future investigation recommended). A brief of the factory internal assessment report is shown in Appendix 1 (g).

With a 14–15% fabric moisture retention allowance the system is set at 170°C. The exhaust air damper is manually set at 55% open permanently. The fabric dwell-time/speed (12–30 meters/min) is altered as per the product line requirements. The burner and the other motors do not have VSDs. The machine's cooling down chamber before the third plaiter zone is not used. On Mondays, the operators undertake general air filter cleaning and oiling. A pad mangling machine, consisting of two pressurised (6bars) rubber rollers, is used for cloth stretching (lengthwise) and pre-dehydrate/rehydrate (cashmere usually).

Short-term indirect gas metering (between generic and the boilers' sub-meters) assessment in June 2013, revealed approximately 55m^3/h demand (indicating the stenter's demand). However, due to calibration issues with the generic meter data logger, it must be carefully used. The rated consumption figures, 51m^3/h (as calculated in Appendix 1 (h)) however, closely matched the observed estimation. Based on these figures, the weekly gas use (over 78 hours) is 3,978 m^3 or 42,166 kWh, resulting in a cost of £1,054 or £14/hour. The total (including electric) hourly cost will be £20.

Performance monitoring, July 2013, revealed complex running patterns (e.g. no work, operator away, table/tool unavailability, and breakdown), making the actual daily downtime prediction difficult. "X" in Table 55 shows the operators' response towards these and shutting down the gas for 10–15-minute intervals (costing up to £5) such as for smoking is ignored. The key technical electric and gas saving opportunities usually exist in the middle zone of the machine and are discussed in Sections 6.4.1.2, 6.4.2.1, and 6.4.3.2. Some savings through measures on auxiliary technology (such as pre-drying through mangler, or CA before loading) and O&M measures are possible but due to limitations are being suggested for future work.

Table 55 - Operators' response during downtime

Action	Breakdown	Lunch break (30-40 min)	Tea break (10-15 min)	No work	No tool/table	Change of shift	Smoking break (10-15 min)
Gas off	X	X		X		X	
Exhaust damper off	X			X			

The shift patterns (two/day onsite) and payback can be calculated using Table 14. Some parameters, e.g. exhaust gas flow rate and drying temperature, are the same as in the factory and some, such as the number of chambers are unknown. Therefore, the example to a certain extent could be used to imagine the stenter's costs and benefits. Calibrating and enabling (quoted £5,000 a few years ago) the Mahlo can improve the energy efficiency significantly. Changing the fabric's moisture content ratio from 14−15% to 16% as mentioned above (to natural moisture regain) can reduce energy use.

6.2.2.2 Boilers

Only the main boilers, roughly demanding 75% total gas, are discussed. These, tagged as number 2, 3, and 4, have a total rated steam capacity of 8.8 tonne/hour (at 9.5bars(g)). All the three boilers operate in winter and only two (running in combination) in summer. Therefore, it can be assumed that two boilers are sufficient for production and, at least, one boiler is needed for building heating demand. According to site engineers running boilers 2 and 4 together in summer is not a good combination. Further boilers' specifications are given in Appendix 1 (i) (extracted from the factory's steam system audit report, (Spiraxsarco, 2012). A brief summary of the internal report on boilers is given in Appendix 1 (j).

For average gas consumption/total steam generation estimation, 2013 daily monitored (sub-meters on boilers 3 and 4), and hours data were used, as shown in Table 56 and Table 57. This data along with the stenter's and the other's (averaged hydroponic boilers' and the coffee shop estimate) demand estimations helped to disaggregate end uses. Indirect-metering based demand (orange) for boiler 2 (without sub-meter) was obtained by subtracting the total estimated demands/volume (boilers 3, 4, others, and the stenter's) from the total volume, as indicated in Table 56. The calculations also helped to estimate total and average steam demand 42tonne/day (assuming the boilers run 365days/year). To produce one tonne of steam 855kWh were estimated (as indicated in energy calculation i below). The fuel cost and true cost of steam generation is estimated to be around £21/tonne (as shown in Table 56) and £25/tonne (as assumed in Section 5.3.1.2) respectively.

Energy calculation i)

By using values from (Action Energy, 2004c)
We get,

$$A = \text{ Specific enthalpy of steam system pressure at 9.5 bars}$$

$$= 2{,}774\,\frac{\text{kJ}}{\text{kg}}\,\text{(taken from steam tables@9bars)}$$

$$B = \text{Specific enthalpy of feed water } = 251\,\frac{\text{kJ}}{\text{kg}}$$

$$Heat\ absorbed\ per\ kg\ of\ steam\ (A) - (B) = 2{,}774 - 251$$

$$\left(\begin{array}{c} feedwater\ enthalpy\ at\ 60℃, since\ the\ feed\ water\ temperature\ is\ found\ to\ b \\ 56℃\ in\ the\ adiut\ report \end{array}\right.$$

$$Heat\ absorbed\ per\ kg\ of\ steam\ 2{,}523 kJ/kg\ \text{(as 1 kJ is equal to 0.000278 kWh)}$$

$$Heat\ absorbed\ to\ produce\ \ 1{,}000 kg\ of\ steam\ in\ kWh$$

$$= 2{,}523 \times 0.0002777 \times 1{,}000 = 701.39 kWh$$

$$Since\ 82\%\ boiler\ efficiecny\ equates\ to, assumed\ for\ the\ factory, 1.2195$$

$$therefore, heat$$

$$(kWh)\ used\ to\ raise\ 1\ tonne\ of\ steam = 855.7\ kWh$$

Table 56 - 2013 total gas consumption and steam demand

Technology	Annual hours	Gas (m^3)	Average consumption (m^3/h)	Total consumption (MWh)	Cost(£)	Total steam produced (tonne)	Average steam produced (tonne/h)	Steam cost (£/tonne)	Carbon (tonne)
Boiler 2	not known	347,129	-	3,761	94,014	4,398	–	21	696
Boiler 3	3,839	230,608	60	2,537	63,417	2,967	1	21	470
Boiler 4	5,011	604,289	121	6,647	166,179	7,774	2	21	1,231
Other		45,220		497	12,436		–	–	92
Stenter	3,588	182,988	51	2,013	50,322		–	–	373
Total		1,410,233		15,455	386,368	15,140			2,862

The total metered volume of gas, based on variable CV values over the year is 1,409,020m3 and equates to 15,454,705kWh. This created confusion/error for volume and energy consumed generalisation. This was fixed, to an acceptable level of error, by assuming constant CV value of 39.6, as highlighted orange (total) in column 3.

Table 57 - 2013 boilers' total gas consumption and steam production

Technology	Annual hours	Gas (m3)	Average consumption (m3/h)	Total consumption (MWh)	Cost(£)	Total steam produced (tonne)	Average steam produced (tonne/h)	Steam cost (£/tonne)	Carbon (tonne)
Boiler 2	not known	347,129	-	3,761	94,014	4,398	–	21	696
Boiler 3	3,839	230,608	60	2,537	63,417	2,967	1	21	470
Boiler 4	5,011	604,289	121	6,647	166,179	7,774	2	21	1,231
Total		1,182,025	-	12,944	323,610	15,140	-	-	2,397

Derived from the Table 56

Table 57 indicates that boiler 4 leads whereas number 3 is least used and the availability of boiler 2's real data can improve the analysis. In relation to average hourly gas consumption and steam production rate is higher in summer for boilers 3 and 4. This is due to increased load (only two boilers) to meet peak season demand. Since three boilers are running in winter, slightly less gas consumption and steam production is taking place. Looking at this scenario there may be a decline in individual boilers efficiency, mainly associated with baseload (to keep the boiler up and running or to produce relatively less steam). However, these are only assumptions, and are challengeable when data for boiler 2 becomes available. Summer and winter demands are indicated in Table 58.

Table 58 - Boilers' seasonal demands

Boiler	Annual hours	Gas (m^3)	Average consumption (m^3/h)	Consumption (MWh)	Cost(£)	Steam produced (tonne)	Average steam produced (tonne/h)	Steam cost (£/tonne)
Summer (May-Sep)								
2	not known	not known	–	–	–	–	–	–
3	1,841	113,252	62	1,219	30,465	1,472	0.80	20.70
4	1,392	195,959	141	2,109	52,713	2,547	1.83	20.70
Winter (Oct-Apr)								
2	not known	not known	–	–	–	–	–	–
3	1,998	117,355	59	1,263	31,569	1,523	0.76	20.73
4	3,129	408,329	130	4,394	109,841	5,306	1.70	20.70

A glimpse of recent steam distribution system survey report by (Spiraxsarco, 2012) indicates the existence of several hundred metres long supply lines and its components (e.g. traps, pressure regulators, etc) schematic shown in Section 5.4.1.4. It also reports that 20% of traps had stopped functioning, accounting for 306 tonnes/year CO_2. An 82% average boiler efficiency, and 85°C feedwater temperature in the tank, is recorded to be 56°C at boiler feeding pump point (these figures being key inputs for calculation). These faults/failures estimated to cause a £28,000/annum loss.

In early 2013 some no-cost saving measures involving operation strategies (based on the level of boiler control and controlling systems) such as running at low flame, disconnecting the steam supply, and running them after long intervals were implemented. Despite limitations such as weekend overtime and unavailability of maintenance staff, and building heating requirements in operations sections, these measures were implemented through most of the weekends. These worked well as indicated (for 2013) in Figure 103 (for gradual annual reduction figures refer to Table 43) and became a regular (recommended as not to stop ever) practice since then, hence not being suggested in Section 6.4.

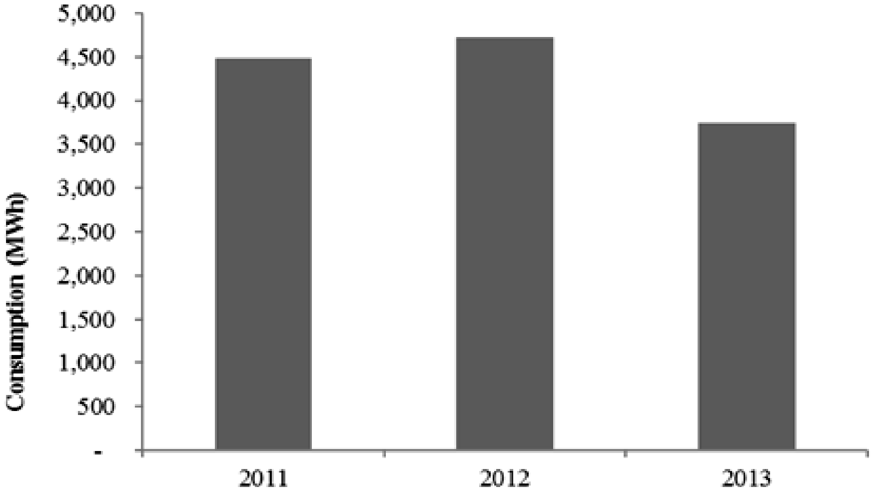


Figure 103 - Yearly weekend energy consumption

Data was usually collected between Friday (07-00-am) and Monday (07-00 am). As these manual readings are incomparable with 2014 (hence not included)

6.2.2.3 Disaggregating thermal energy for consumption and recovery

Based on estimations above the boilers consume 12,944 MWh/annum or on average of 35,463kWh/day total or 11,821kWh/day individually (assuming all the three boilers run all year round). This is helpful to calculate the end-use thermal demand; for example, the total demand for building heating will be 2,234MWh/annum

(£67,025) as one sole boiler is used for 7months (three-week holidays). This could be estimated more accurately by using the demand factors of the other systems (as in Table 56). However, due to concerns about increasing the level of uncertainty in the calculation (as the coffee shop operates throughout the year whereas the hydroponic boilers operate only for seven months) it is being ignored. Using the process hot water consumption values in each department (based on real-time data or estimations) the thermal demands are calculated. The annual thermal process demand for the dyeing house and wet finishing is approximated to be 650MWh (as calculated through Table 59 and energy calculation ii) and 1,000MWh (as calculated through Table 60 and energy calculation iii) costing, £19,525 and £30,017 respectively.

Table 59 - Thermal demand and cost in the dye house

Batch per week	Hot water consumpiton per batch (kg)	Total hot water consump.(kg)/wk.	Intial temp. (°C)	Final temp. (°C)	ΔT
80	1,500	120,000	15	98	83

Energy calculation ii)

Using values from Table 59

$$Specific\ heat\ capcity\ of\ wtaer = 4.19\frac{kJ}{kg}\ (°C)$$

$$Specific\ enthalpy\ (hg) of\ super\ saturated\ steam\ at\ 4\ bar$$
$$= 2648.63\ \frac{kJ}{kg}\ (as\ 4bar\ is\ the\ end-use\ pressure)$$

$$1kWh = 0.000278\ joules$$

$$Cost\ of\ gas = \frac{£0.025}{kWh}$$

$$\frac{Cost}{unit} energy\ rounded\ up\ including\ maintenancae\ \frac{£0.03}{kWh}$$

$$Amount\ of\ energy\ required\ to\ produce\ 1\ tonne\ steam\ at\ 82\%\ boiler\ efficienc$$
$$= 855kWh$$

$$Number\ of\ operating\ weeks = 46$$

$$2012\ Defra\ CO_2 factor\ for\ gas = 0.18521\ \frac{kg}{kWh}$$

$$\boldsymbol{Weekly\ energy\ consumed}$$
$$\boldsymbol{Q = m \cdot cp \cdot \Delta T}$$

$$or\ Q = 120{,}000 \times 4.19 \times 83 = 41{,}732{,}400\ \frac{kJ}{week}$$

$$or\ 11{,}602\ \frac{kWh}{week}$$

$$or\ 14{,}148\ \frac{kWh}{week}\ (considering\ 82\%\ boiler\ efficiency)$$

$$or\ \frac{£424}{week}$$

$$or\ 650{,}822\ \frac{kWh}{annum}$$

$$or\ \frac{£19{,}525}{annum}$$

$$Steam\ used = 761\ tonne$$

$$Carbon\ emissions = 121\ tonne$$

$$\boldsymbol{Calculating\ the\ steam\ consumption\ through\ other\ way}\ (\boldsymbol{as\ a\ cross\ chec}$$

$$\boldsymbol{Total\ steam\ needed = Q = hg\ \times\ M}$$

$$Where\ Q = total\ energy\ and\ hg = total\ enthalpy\ of\ steam, and\ M = Mass$$

$$or\ M = \frac{Q}{hg}\ 15{,}756\ \frac{kg}{week}$$

$$or\ \frac{£438}{Week}$$

$$Therefore\ annaul\ dyehouse\ steam\ demand = 725\ \frac{tonne}{annum}$$

$$CO_2 = 121\ tonne/annum$$

Table 60 - Thermal demand and cost in the wet finishing

Daily consumption (m^3)	% of hot water	Total hot water consump. (kg)	Initial temp. (°C)	Final temp. (°C)	ΔT
350	35	122,500	15	40	25

Energy calculation iii)

$$Using\ values\ from\ \text{Table 60}$$

$$Specific\ heat\ capacity\ of\ water\ \ =\ \ 4.19\frac{kJ}{kg}(°C)$$

$$\text{Specific enthalpy (hg)of super saturated steam at 4bar} = 2547.855\ \text{kJ/kg}$$

$$1kWh = 0.000278\ joules$$

$$Cost\ of\ gas = £0.025/kWh$$

$$\frac{Cost}{unit}energy\ rounded\ up\ including\ maintenance = \frac{£0.03}{kWh}$$

$$Amount\ of\ energy\ required\ to\ produce\ 1\ tonne\ steam\ at\ 82\%\ boiler\ efficienc$$

$$(as\ calculated) = 855kWh$$

$$\because Q = 122{,}500 \times 4.19 \times 25 = 12{,}831{,}875\ kJ$$

$$Q = 122{,}500 \times 4.19 \times 25 = 12{,}831{,}875\ kJ$$

$$or\ \ 3{,}567\frac{kWh}{day}$$

$$or\ £\ 107\ (considering\ 82\%\ boiler\ efficiency)$$

$$or\ 4{,}350\frac{kWh}{day}$$

$$or\ £\frac{131}{day}$$

$$or\ 1{,}000{,}573\frac{kWh}{annum}$$

$$or\ £\frac{30{,}017}{annum}$$

$$Steam\ used =\ 1{,}170\ tonne$$

$$Carbon\ emissions = 185\ tonne$$

$$\boldsymbol{Calculating\ the\ steam\ consumption\ through\ other\ way}\ (\boldsymbol{as\ a\ cross\ -\ check})\ \boldsymbol{we\ get}$$

$$\boldsymbol{Total\ steam\ needed = Q = hg \times M}$$

$$or\ M = \frac{Q}{hg}$$

$$Steam\ used = 5{,}036\,\frac{kg}{day}$$

$$Carbon\ emissions = 1{,}158\,\frac{tonne}{annum}$$

$$There\ is\ little\ difference\ between\ the\ steam\ demand\ values\ evaluated\ throug$$

$$ways$$

$$\mathbf{10\%\ savings\ equate\ to}$$

$$Energy\ (kWh) =\ 100{,}057\ kWh/annum$$

$$Cost\ (£) =\ 3{,}002/annum$$

$$Carbon\ emissions\ = 19\ tonne/annum$$

The low-grade energy in the wastewater through dyeing and washing processes (98°C and 40°C, respectively) can be recovered and reutilised for system/s efficiency improvement. These units are 200metres apart. Of note, almost all batch dyeing programmes have two thermal stages, as discussed in Section 5.4.1.4. Through the calculations above key data information such as boiler efficiency, and boiler house's (including maintenance and running energy cost), (Energy calculation i) have been identified to calculate total thermal demand and heat recovery potential. This explains theoretical (maximum available work/energy) and actual energy and cost savings, and energy required for other uses (see also Section 6.4.3).

Table 59 and the energy calculation ii estimate the dyeing house's energy and steam demand with maximum recoverable heat opportunity discussed above. The estimated (steady-state) cost to heat one big dyeing pot to 98°C throughout the process is £5.31 as shown in Table 61 and energy calculation iv. However due to process limitations (first stage limited to 40°C), cost-effective recovery system design, and the other restrictions, only a portion of heat is recoverable. The annual quantity is (196,031kWh or £5,881/annum) as calculated in Table 62 and energy calculation v is suggested in Section 6.4.3.2. The estimated thermal demand and saving for wet finishing is shown in Table 60 and energy calculation iii). However, to ensure this level of recovery an efficient heat recovery system is desired. The total and the area-wise steam demand distribution is indicated in Table 63. It can be seen that the gas-saving measures (excluding stenter) suggested in the thesis address most of the aspects of Table 63.

Table 61 - Thermal cost for a dye pot

Steam energy cost per dyepot		
Volume of dyepot	2.35	m^3
Amount of water filled	1500	litres
Temperature raised	83	°C

Volume of dyepot	Meters
Diameter of the pot	2.02
Radius of the pot	1.01
Depth of the pot	1.15
Thickness of the steel plate	0.009

Energy calculation iv)

$$\text{Using Table 61, e}\mathit{nergy\ required\ to\ warm\ a\ dye\ pot}$$
$$Q = m \cdot cp \cdot \Delta T = 521{,}655\ kJ$$
$$Or\ 145 kWh$$
$$Or\ £3.63$$
$$When\ 82\%\ boiler\ efficiency\ is\ considered\ then\ 177 kWh$$
$$Or\ £4.42$$
$$Cost\ per\ unit\ energy\ including\ maintenance = £\ 0.03/kWh$$
$$Then\ £5.31$$

Table 62 - Heat recovery potential in dyehouse

Batch per week	Consumpiton per batch	Total hot water consump.(kg)	Intial temp. (°C)	Final temp. (°C)	ΔT
80	1,500	120,000	15	40	25

Energy calculation v)

$$Using\ \text{Table 622}\ we\ can\ calculate\ below,$$
$$Since\ 40°C\ is\ the\ temperature\ required\ for\ the\ first\ stage\ of\ dyeing, hence\ tc$$
$$suit\ the\ existing\ heat\ recovery\ facility\ design\ only\ a\ certain\ amount\ of\ heat$$
$$can\ be\ recovered\ (25°C)$$
$$Specific\ heat\ capacity\ of\ water =\ 4.19\ kJ/kg\ (°C)$$
$$Specific\ enthalpy\ (hg)\ of\ super\ saturated\ steam\ at\ 4bar =\ 2{,}648.63\ kJ/kg$$
$$1kWh = 0.000278\ joules$$
$$Cost\ of\ gas\ =\ £0.025/kWh$$
$$\frac{Cost}{unit}\ energy\ including\ system\ maintenance\ = £0.03/kWh$$
$$Amount\ of\ energy\ required\ to\ produce\ 1\ tonne\ steam\ at\ 82\%\ boiler\ efficienc$$
$$(as\ calculated)\ =\ 855kWh$$
$$Number\ of\ operating\ weeks\ =\ 46$$
$$2012\ Defra\ carbon\ emission\ factor\ for\ gas\ =\ 0.18521\ (kg/kWh)$$
$$\boldsymbol{Weekly\ energy\ saving\ potential}$$
$$Q = m \cdot cp \cdot \Delta T$$
$$Or\ Q = 120{,}000 \times 4.19 \times 25 = 12{,}570{,}000\ kJ/week$$
$$Or\ 3{,}494\ kWh/week$$
$$Or\ 4{,}262\ kWh/week\ (considering\ 82\%\ boiler\ efficiency)$$
$$Or\ £\ 128/week$$
$$Or\ 196{,}031\ kWh/annum$$
$$Or\ £5{,}881/annum$$
$$Carbon\ emissions\ 36\ tonne/annum$$
$$\boldsymbol{Total\ steam\ needed = Q = hg \times M}$$
$$(where\ Q = total\ energy, hg = specific\ enthalpy\ of\ steam\ and\ M = mass)$$
$$Or\ M = Q/hg\ \ 4{,}746\ kg/week$$

$$Or\ £142/week$$
$$Therefore, annual\ dyehouse\ team\ savings = 218\ tonne/annum$$
$$Carbon\ emission\ saving = 36\ tonne/annum$$

Table 63 - Total steam demand with end uses (assuming 2013 values)

Total annual steam production for the whole factory=	15,140
Disaggregated annual steam consumption	Tonnes
Wet finishing	1,158
Dyhouse	725
Heating*	2,640
Others**	10,617

- **Assuming one boiler is needed for building heating for 7months in winter with three-weeks holidays*
- ***Decatiser, Vapodec, Pinwheel, Padders, distribution system losses and leaks, direct steam (e.g. blower, and hot water tanks (e.g. combi-steam immersion heater), weekends loads, and various losses such as boiler break downs, inefficient burning processes and burners, energy used to carry out different tests for example non-destructive test*
- *Note, having steam meters on these technologies is the better estimation option*
- *Heating based on 189days × one-third of 42tonne steam/day*

Thermal end-use demand total and percentage is indicated in Table 64. This is hardly comparable to Figure 17 (A) in Section 2.1.4 due to the format obtained and building heating related thermal demand being ignored.

Table 64 - Departmental and technology gas demand %

Area/technology	Demand (steam/gas)kWh	%
Wet finishing	990,090	6
Dyehouse	622,440	4
Heating	2,257,200	15
Others	9,077,535	59
Total steam based	12,947,265	
Difference or total gas based (stenter demand)	2,507,440	16

Where steam-based gas demand is calculated through steam use and gas demand obtained through the remaining kWh which is slightly different than in Table 35

Others refer to the others in Table 63

6.3 Energy assessment using high-resolution data

6.3.1 Electric

Serving as a comprehensive analytical process this section helps to diagnose periods of energy wastage. Had the production figures at such a high resolution been available, the analysis of individual days of the year would have been more valuable. Hence, high-resolution data of production metrics (e.g. daily production versus consumption and daily activity versus production) are recommended for future EM operation.

6.3.1.1 Establishing the baseline consumption

Identified key 24-hour period time periods (as in 5.4.2.2) are presented in Table 65 and Table 66. As only two departments operate after midnight (00:30–06:00) the demand is low, which gradually increases in response to the increasing activity. The decline after 17:30 results from the shutting of the offices. A small demand difference in peak- and off-peak production seasons can be due to increased demand in winter as discussed above. Friday on- and off-season demands go up and down accordingly. The exercise helps to estimate average empirical demands and to disaggregate and associate these values to major end-uses.

Table 65 - 2011 average peak and off-peak weekday loads (kW)

Time	Departments/Sections working	Average load Monday-Thursday on-season production	Average load Monday-Thursday Off-season production	Average weekday (Mon.Thu)	Average load Friday on- season production	Average load Friday Off-season	Average Friday
00:30-06:00	Dye house, Weaving, & Yarn store	386	370	378	381	361	371
06:30-08:30	All Production and most of the Operations	835	844	840	800	739	769
09:00-12:30	All the Production and the Operations	903	916	910	890	845	868
13:00-15:00	All the Production and the Operations, different for Friday	875	888	881	518	504	511
15:30-17:30	All the Production and the Operations, different for Friday	858	847	852	335	332	334
18:00-00:00	All the Production departments	731	712	722	111	118	114

Saturday and Sunday demands differ due to frequent overtimes on Saturdays as shown in Table 66. The calculation allows calculation of base load due to no work between 00:30–06:00 during Saturday and Sundays. The on- and off-production seasons' difference can be due to the winter-related demand increase. A better base load assessment is possible through Sunday timeslots (between 03:00–06:00 and 18:30–20:00).

Table 66 - 2011 24-hour average weekend loads (kW)

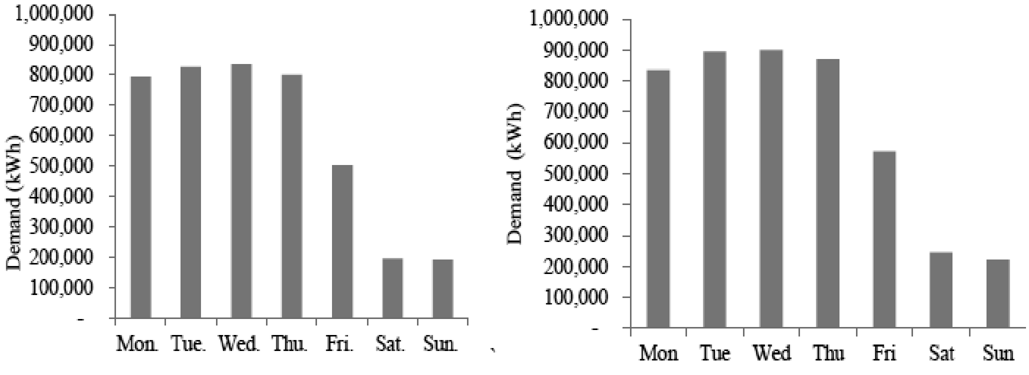
Time	Departments/Sections working	Avg. load on-season Saturday	Avg. load Off-season Saturday	Average Saturday	Avg. load on-season Sunday	Avg. load Off-season Sunday	Average Sunday
00:30-06:00	Base load	109	116	116	104	111	111
06:30-12:00	Retail shops+Sat O-T	219	236	236	120	130	130
12:30-18:00	Retail shops	144	152	152	136	163	145
18:30-20:00	Base load	101	113	113	109	120	120
20:30-00:00	Dye house and Weaving for Sunday	102	111	111	300	281	281

Using natural operating modes (i.e. no work for Manufacturing “A” between 00:00–06:00) departmental demands (in pairs) can be segregated. Using Table 65 this load can be attributed to Weaving and Dyeing. However, the background load for non-operating buildings is still ongoing. The information, as indicated in Table 67, has been utilised to assess and predict the energy (electricity) use by changing the number of hours. The calculated load percentage in the Table could have been compared with Figure 17 (B) had the detailed departmental demand segregation was made. The total consumption calculated through this is 4,318MWh which is slightly higher than the actual 2011. This is one of the indications of the results being quite close to empirical consumption.

Table 67 - 2011 average departmental/sectional daily/annual load

Measure	Base load	Production and operation	Production only	Operations only	Dye house + Weaving+ Yarn store	Finishing an Yarn producti
Average kW	111	889	722	167	375	347
Annual hours	8,736	—	—	1,950	4,738	3,588
Annual MWh	972	—	—	325	1,775	1,245
Percentage towards total	23%			8%	43%	30%

Figure 104 compares 2011 and 2014 weekday demands showing the impact of increased hours in 2014 including the triggered weekend overtime and the increased demand (further explained in Section 6.3.1.2). Both demand patterns, however, indicate that starting from the lowest on Sunday the gradual rise in peaks on Wednesday reflect the intensity of activity, hours and production.

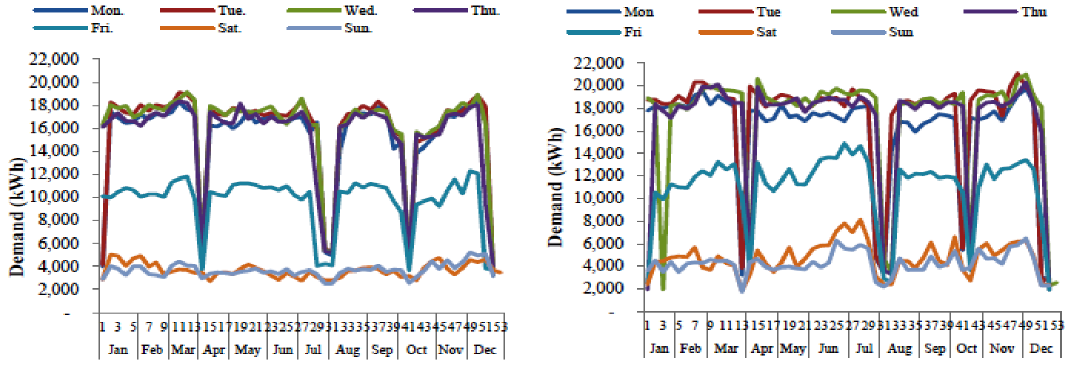


2011 total weekdays demand

2014 total weekdays demand

Figure 104 - Total demand daily profiles

Comparing whole years' individual weekday consumption Figure 105 reveals (Monday-Thursday) demand difference from 18,000kWh–19,000kWh for some days between 2011 and 2014. This is also visible for Fridays between around 10,000kWh (2011) to always over 10,000kWh for 2014 (hours increased). This is also visible for 2014 Weekends.



2011 daily consumption including holiday

2014 daily consumption including holiday

Figure 105 - Daily weekday profiles

For understanding the detail of demand variation, the 2011 Monday percentile is shown in Figure 106. The 75% percentile demand is below 1,000kW, as established in Table 65, Table 66, and Table 67. The abnormal fall at 19:30 in the min (minimum) can be attributed to a short-term power cut.

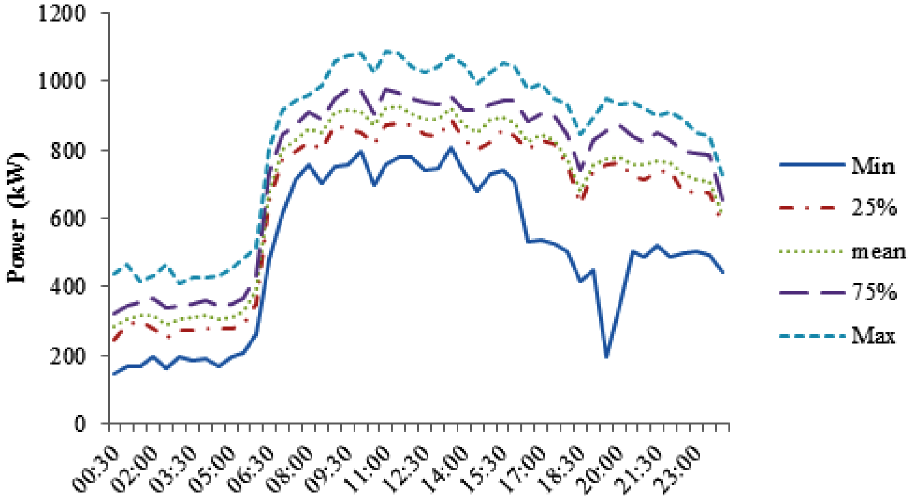


Figure 106 - 2011 Monday percentile

Table 68 shows an historical demand summary. Equaling to 2011 and 2012 the highest daily consumption for 2014 is 19MWh, which is slightly less than in 2013 (and can be due to energy-saving measures taken that year). Peak demand, for 2014 (1,127kW), is similar to previous years, indicating no change in total load capacity. Any possible increase from recorded changes in technology (e.g. Zonco 2 in Table 29 (2013)) would appear to have been partly cancelled out by energy efficiency measures applied (e.g. efficient lighting in stockroom (2012), Finishing inspection table (2013), and main Dyehouse (2014), and other electricity saving measures as discussed above. Relating energy factors at such a detailed manner has only been possible through the researcher’s long-term observation, stay, and in-depth understanding of the site.

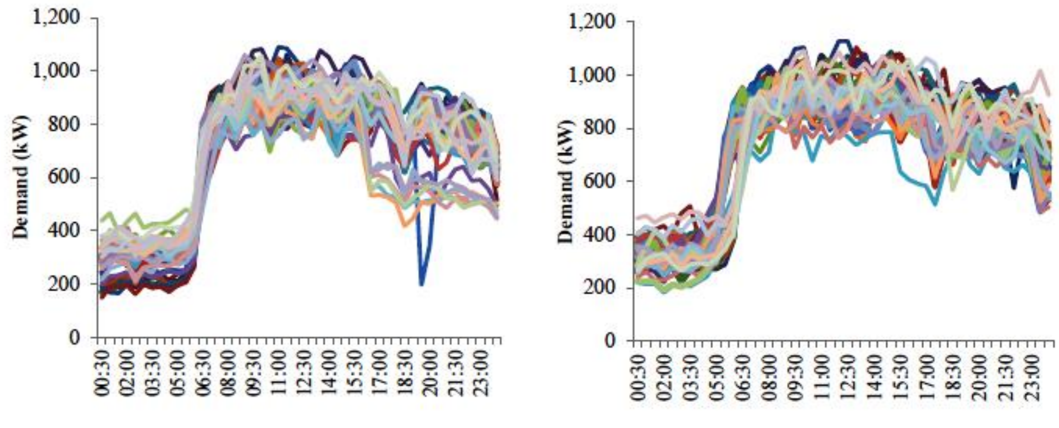
Table 68 - Yearly demand summary

Parameter	2011				2012				2013				2014			
	Value	Unit	Date	Time	Value	Unit	Date	Time	Value	Unit	Date	Time	Value	Unit	Date	Time
Total energy consumption	4,148	MWh/yr.			4,120	MWh/yr.			4,161	MWh/yr.			4,540	MWh/yr.		
Average daily consumption	11	MWh/yr.			11	MWh/yr.			11	MWh/yr.			12	MWh/yr.		
Total weekday consumption	3,760	MWh/yr.			3,736	MWh/yr.			3,826	MWh/yr.			4,073	MWh/yr.		
Total weekend consumption	387	MWh/yr.			384	MWh/yr.			335	MWh/yr.			467	MWh/yr.		
Consumption of highest day	19	MWh/yr.	23-Mar		19	MWh/yr.	13-Jun		21	MWh/yr.	04-Jun		19	MWh/yr.	23-Mar	
Peak electrical consumption	1,110	kW	14-Dec	12:00	1,130	kW	18-Jan	09:30	1,122	kW	25-Nov	12:00	1,127	kW	14-Dec	12:00
Total carbon emissions	2,176	T/yr.			2,162	T/yr.			1,854	T/yr.			2,244	T/yr.		
Weekday carbon emissions	1,973	T/yr.			1,960	T/yr.			1,704	T/yr.			2,013	T/yr.		
Weekend carbon emissions	203	T/yr.			201	T/yr.			149	T/yr.			231	T/yr.		

6.3.1.2 Daily demand profiles

Monday-Thursday (2011-2014) graphs, below, indicate peak-time demand between 700–1000kW. Significant variation in off-peak times demand, ranging from 200–500kW (2011) and 200–650kW (2014) is noticed.

Figure 107 shows 2011 and 2014 Mondays with little demand and trend differences. The slight rise relating to 2014 increased hours (after 18:00) is observable and the off-peak (00:30–06:00) load unlike 2011 remains above 200kW. This indicates an increased rate of activity. The steep fall for Monday 2011 is already discussed above.



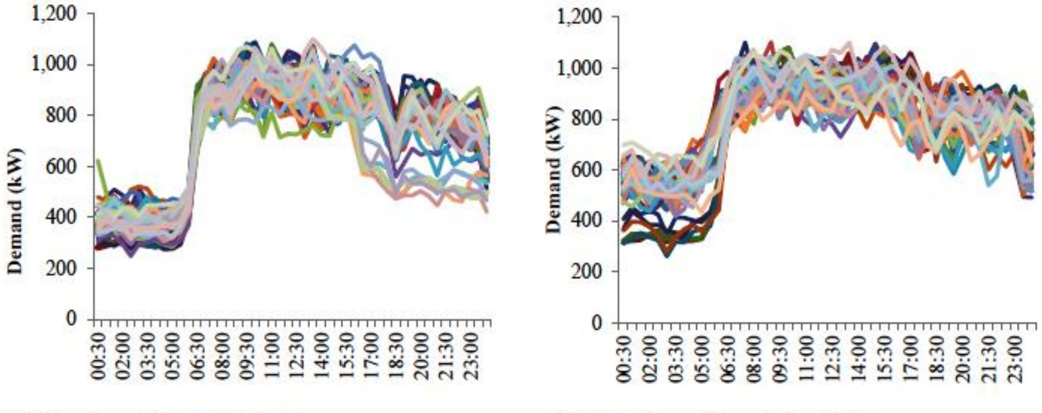
2011 Monday profile excluding holiday

2014 Monday profile excluding holiday

Figure 107 - Monday profiles

Graphs for 2011 show reduced demand (between 17:00–midnight) for some lines indicating four-week long period (end of October and start of November) associated with reduced activity in Yarn production (less production demand). This was managed by good (EM) management practice by sending most of the staff away (off/early) during this period to make-up these hours in peak-production. Graphs for 2014 show a small congregation of lines (between 00:30–06:00), less visible for Mondays and more for the other days, representing off-peak production season after Christmas. Monday, being the start of the week, has relatively less demand. The trend has already been established among the weekdays (refer to Figure 104).

Figure 108 shows Tuesday for the corresponding years. The demand for off-peak 2014 is significantly higher than in 2011 (indicating key work patterns changes) as expected. Similar observations can be noticed in Figure 109 for Wednesday and Figure 110 for Thursday.

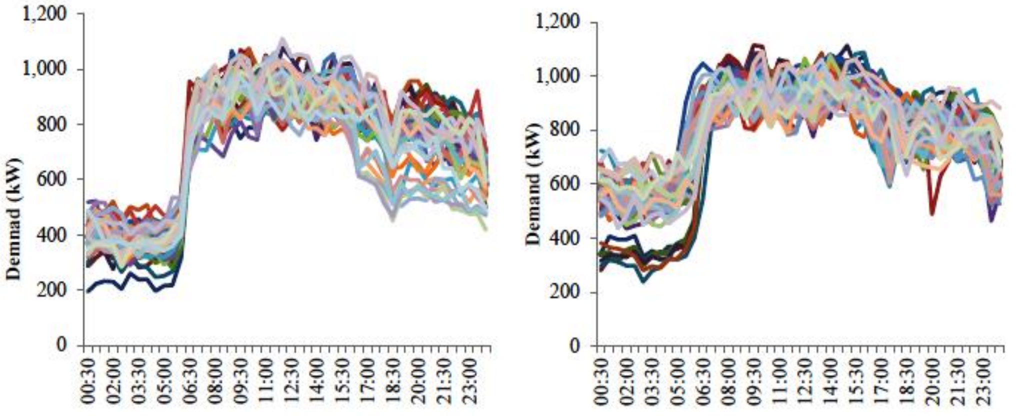


2011 Tuesday profile excluding holiday

2014 Tuesday profile excluding holiday

Figure 108 - Tuesday profiles

The unusual fall at 20:00 on Wednesday 16 April 2014 may be due to a short-term power cut. The blue line at the bottom between 00:30-06:00 is 05 and 06 January 2011 (first day back after Christmas) Wednesday and Thursday respectively.

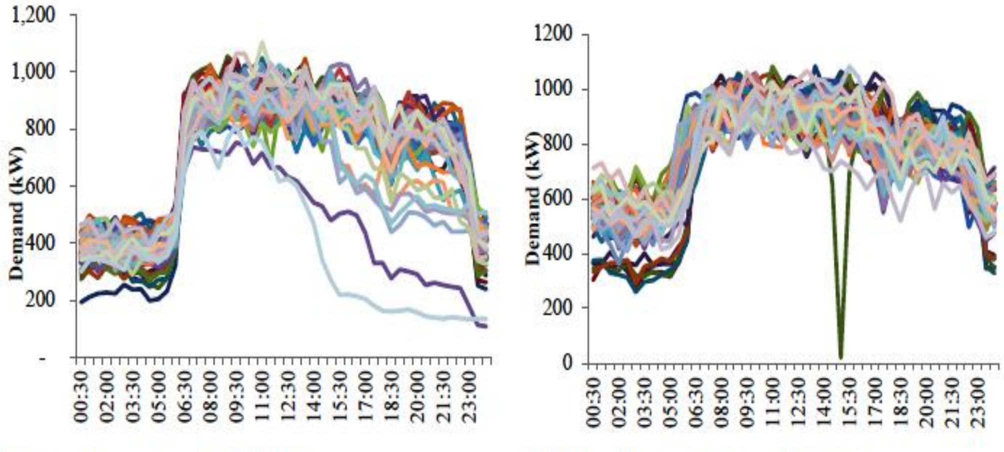


2011 Wednesday profile excluding holiday

2014 Wednesday profile excluding holiday

Figure 109 - Wednesday profiles

The unusually low blue and purple lines in Thursday 2011 graph (from 07:30 onwards) are for 21 July and 22 December. The case for 2014 Thursday, with different production activity model, is slightly different as indicated by light grey line (between midday onwards) on 18 December, just a day before breaking for holiday. This indicates how it may be like a day before a two-week-long holiday especially when the staff consists of both local and foreign workers. The unusual fall (green) in Thursday 2014 graph at 15:00 can again be a short-term power cut.

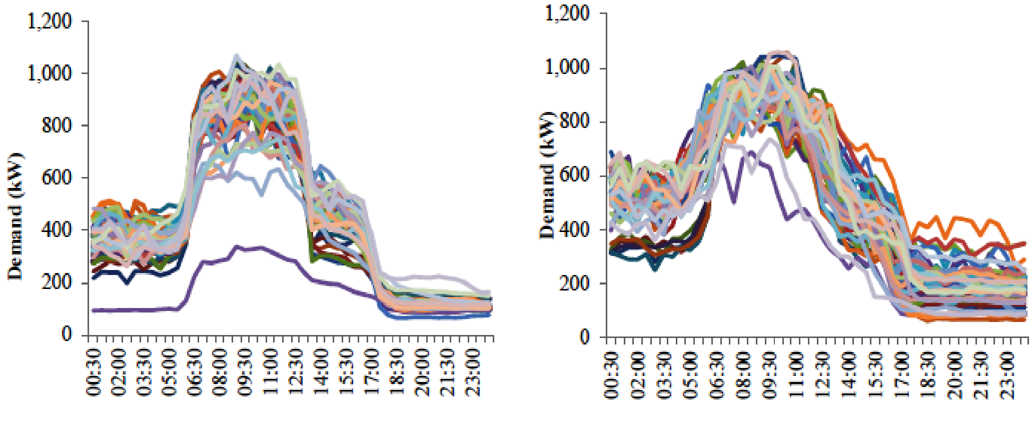


2011 Thursday profile excluding holiday

2014 Thursday profile excluding holiday

Figure 110 - Thursday profiles

The impact of change in operation can be seen in Figure 111. For 2011 Fridays there is a sudden fall in demand at 17:00 whereas for 2014 it is gradual and smooth. The 2011 below average profile is likely to be a day before holiday breakdown for 22 July (i.e. workers leaving early to go abroad). For 2014 the case is similar for purple profiles for 25 July and 19 December (a day before two-week holiday).

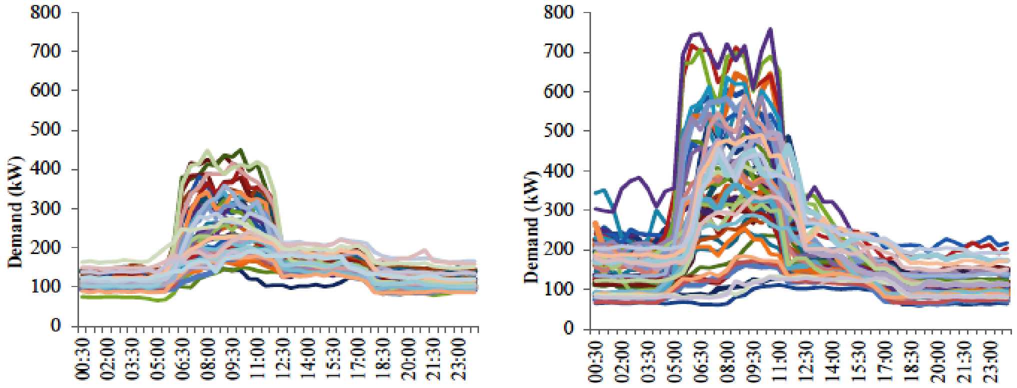


2011 Friday profile excluding holiday

2014 Friday profile excluding holiday

Figure 111 - Friday profiles

A significant difference is observable between 2011 and 2014 Saturdays as in Figure 112. The increased overtime frequency and rise in demand (between 06:00–12:00) for 2014 is visible which is as high as 700kW for some cases. This, according to Table 67, is equivalent to production only and indicates the level of overtime intensity during the early six hours. Through this indication, it can be assumed that the boilers would be working near full capacity during these hours. Therefore, no weekend operations control-related savings would have been possible in such cases. Gas is further discussed in Section 6.3.2.

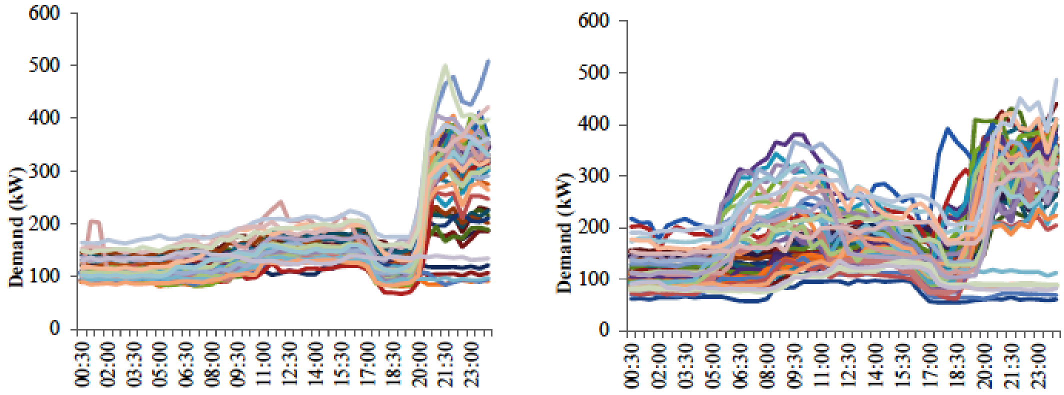


2011 Saturday profile

2014 Saturday profile

Figure 112 - Saturday profiles

Sundays demands are also quite unusual as indicated in Figure 113. The 2014 overtime intensity during 06:00–12:00 has resulted in a demand between 200–400kW. The slight demand rise, between 08:00–18:00, for 2011 can be attributed to the retail shop, due to the absence of overtime. The unusual lines at the bottom (between 20:00–00:00) in 2011 indicate holiday weeks such as for April, July, August, October, and December. This indicates the then background load of around 100kW during the holiday. The reduced 2014 holiday demand, between 50–70kW (between 20:00–00:00), at the bottom of the graph is the result of the weekend energy-saving measures. The rise in demand from 20:00 onwards for both years indicates the shift starting for the next week.



2011 Sunday profile

2014 Sunday profile

Figure 113 - Sunday profiles

Weekends were the main targets for the no-cost energy-saving programme in February 2013. Frequent weekend overtimes tended to cancel out the resultant electricity savings as indicated in Figure 114. However, if holiday weekends, before and after February 2013, are compared a clearer trend can be observed in Figure 115.

Although some overtime is evident for some Saturdays in 2013, there is still visible fall in demand specifically during baseload periods. The rise in demands for 2011 for some Sundays indicates the start of shift at 20:00. For 2013, however none of the Sundays show a rise in demand after 20:00. This could be due to the shift starting on Monday at either 00:00 (less likely due to the absence of prior activity) or 06:00. This once again indicates the unpredictability of working patterns and the proportionality of production activity with the sales orders.

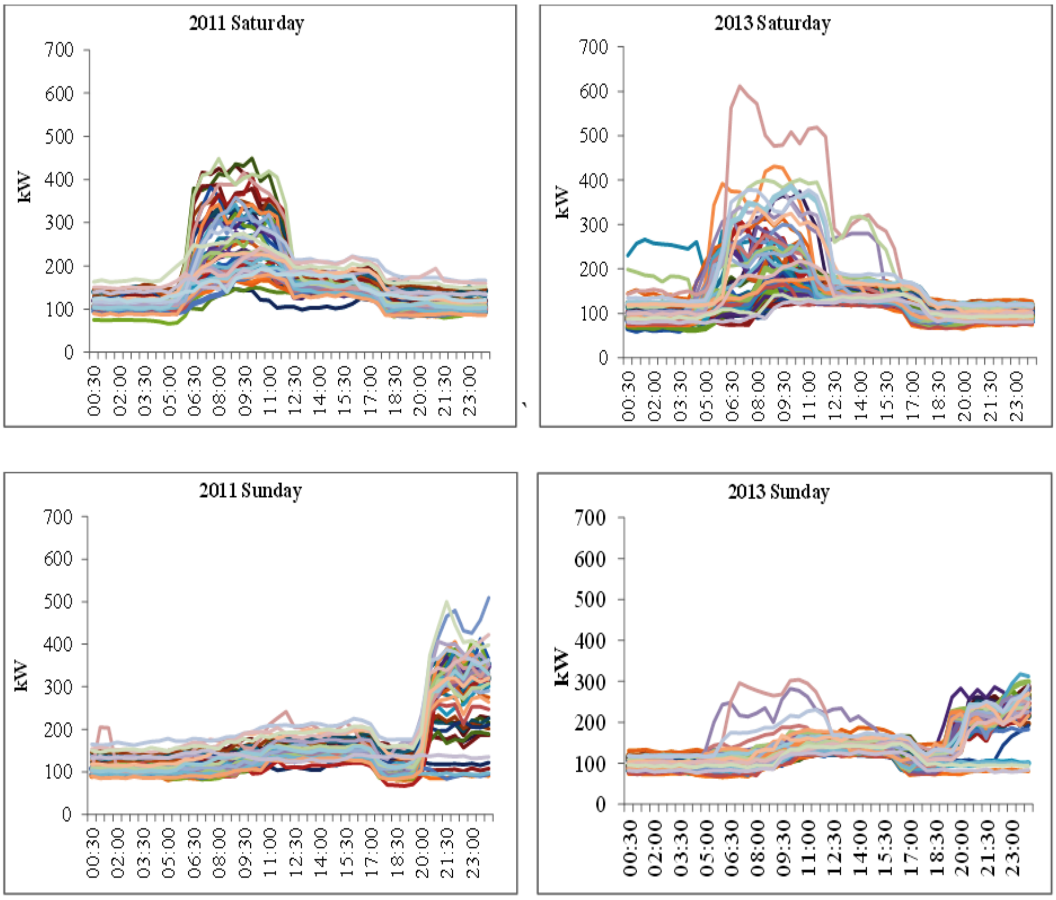


Figure 114 - Comparison of weekend demands before and after taking weekend saving measures

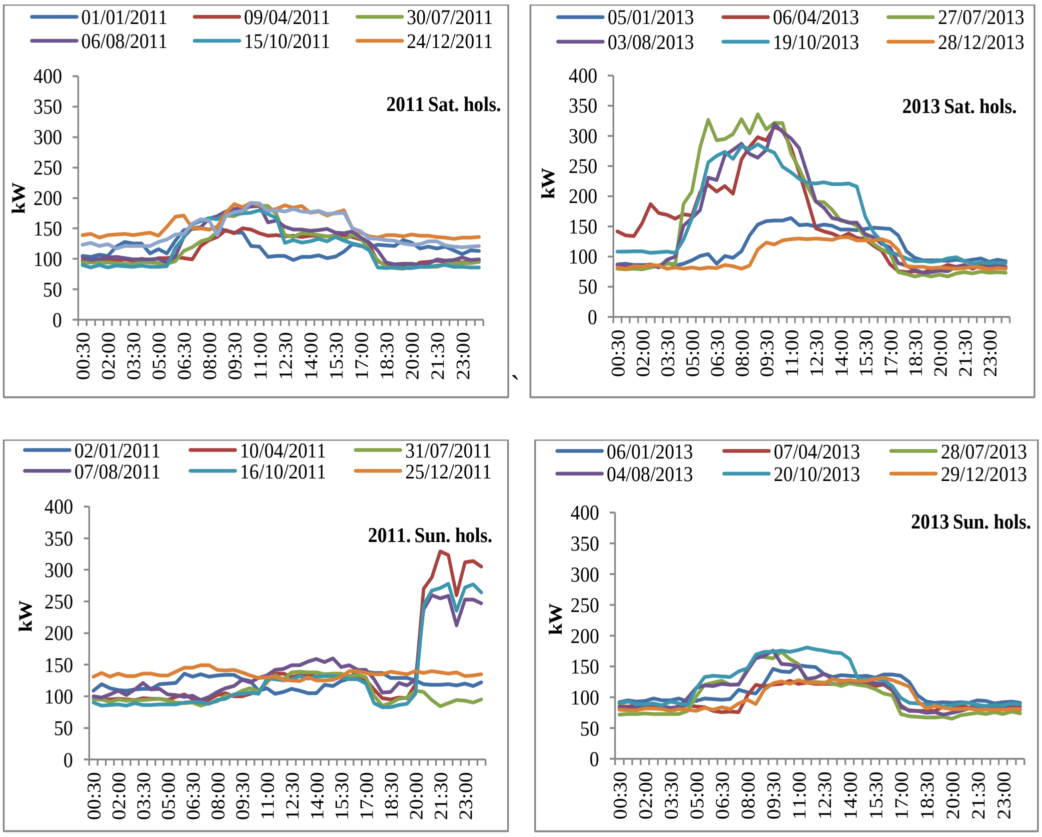


Figure 115 - 2011 and 2013 holiday weekends demand comparison

Hols.= holidays

In complicated manufacturing systems, such as this one, every day has a different energy signature this is what we can deduce from the analysis above. The observed variations indicate energy demand unpredictability controlled by various factors—some of these are discussed above. Explaining these factors is only possible through keen and extended site-specific knowledge and observations. The lessons learnt could be adapted to implement a range of energy efficiency measures, but requires a level of detail that is impossible through low-resolution data analysis.

6.3.1.3 Energy trends and patterns for electricity

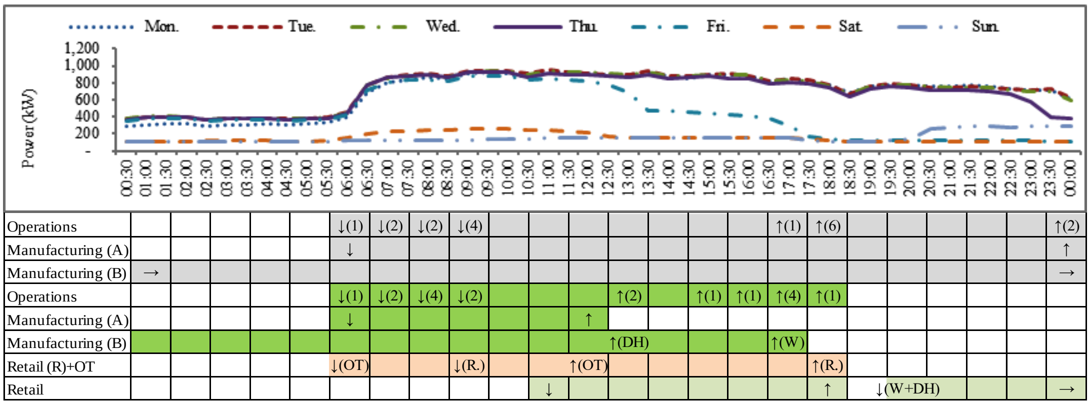
Averaged year-long H-H daily energy data is calculated against daily activity to develop a relationship with demand. The assessment uses total average, peak- and off-peak, and summer and winter demands for 2011 and 2014 and compares within and between them. Defined in Chapters 4 and 5, the legend (Table 69) and the terms for the Figures and the activity table used in this and in the next Section (6.3.2) are explained further here. Manufacturing (A) includes Finishing (Fin) and Yarn production (YP), and the remaining sections of Operations finish an hour earlier before midnight on Thursday. Manufacturing (B) includes Dyehouse (DH) and Weaving (W). R and OT symbolise Retail and overtime respectively. Numbers in the boxes/brackets indicate the number of small sections of offices and other areas opening/closing.

Table 69- Legend

→	Continued
↓	Starting
↑	Finishing
▨	Mon-Thursday
🟩	Friday
🟧	Saturday
🟩	Sunday

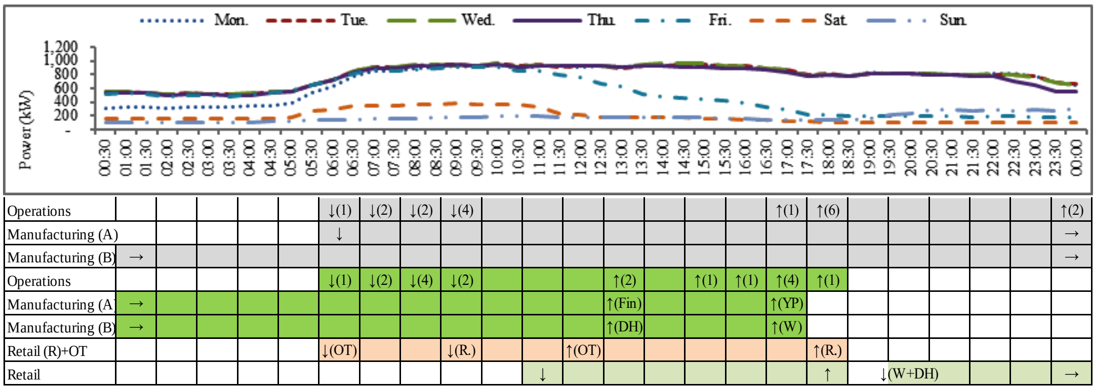
For 2011, Monday–Thursday peak-time average demand remains relatively constant (800–900kW) (see Figure 116). The reduced off-peak (00:00–06:00) demand for Monday is already discussed above. Early demand falls for Thursday at around 23:00 is also known. Continuing through to midnight Figure 117 indicates 2014 average peak-time demand between 800–900kW, which enters a slight fall due to reduced activity at night-time until 06:00. The quite low early Monday's demand until 06:00 (as observed above) is due to some departments/sections starting at this time instead. Weekends for 2014 (ignoring overtimes) show demand less than in 2011, as already established. Weekday (Monday–Thursday) demand characteristics for both years are similar (expected when averaging). To help visualise and understand demand variations in details weekday characteristics have already been discussed, in Section 6.3.1.2.

Figure 116 and Figure 117, however, help to visualise a generalised impact of shift pattern on demand variation. This for 2011 is greatly responsive to starting times (06:00), peaking from 400kW to 900kW, and finishing times (00:00) reducing to 400kW due to manufacturing (B). Due to the change in shift patterns 2014 peak- and off-peak times demands (950kW and 600kW respectively) difference is less. The contribution of the other departments/sections (numbered in brackets) is trivial (as in Table 67) as compared to the manufacturing. It is less visible at the starting and more at the finishing time (a slight dip between 17:30–18:00). The graph for Fridays (gradual fall) and weekends (Saturday overtime) are similarly depending on the manufacturing activity for both years. Moreover, the figures obtained through this analysis are comparable with the figures in Table 67. The reason for the greater night-time deviation of these values is reduced intensity of the activity (shift is on but reduced in terms of the number of workers). This point applies to both before and after the change in shift patterns. This technique has helped to understand such a complicated activity and production process and its impact on energy in a visible way.



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		↑
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)						↓						↑												
Manufacturing (B)													↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

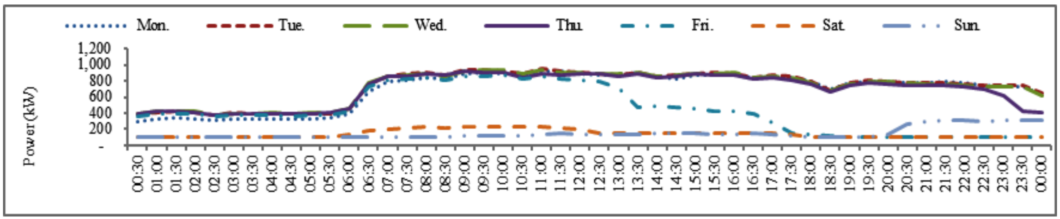
Figure 116 - 2011 average weekday



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

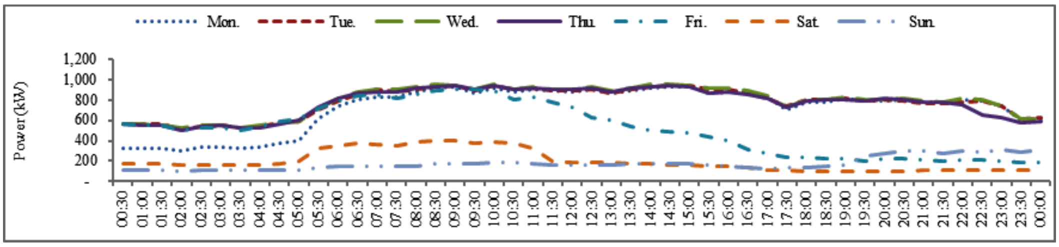
Figure 117 - 2014 average weekday

Figure 118 and Figure 119 indicate 2011 and 2014 average peak production demands. Years 2011 and 2014 show demand difference (around 400kW and 600kW respectively). A sudden demand rise at 06:00 (to around 900kW) is visible for 2011 which starting from 05:00 gradually peaks at 06:00 for 2014. Different contributing factors, such as workers starting to arrive, bigger handover loads by night-shift workers, and overtimes starting an hour earlier, maybe involved. For both years the 900–950kW load continues until around 14:00 followed by a shift change-related slight dip. The next slight dip between 17:30–18:00 relates to Operations sections finishing followed by the fall, steeper for 2011 at mid night. The less steepness for 2014 is already known. Saturday production between 00:00–06:00 is non-active for 2011 (around 100kW demand) and is relatively active for 2014 (around 170kW demand). This rises further (to around 450kW), between 06:00–midday, as compared to 2011 (around 200kW). The Sunday's raised demand (between 08:00–18:00) is attributable to the retail shop, although some occasional 2014 Sunday overtime has been recorded (not significantly visible).



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		↑
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)						↓						↑												
Manufacturing (B)													↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑		↓(W+DH)				→

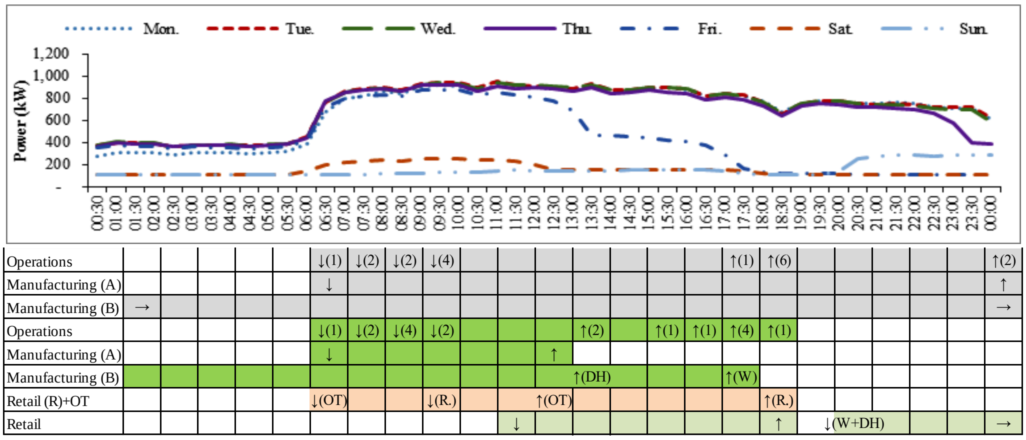
Figure 118 - 2011 peak production average



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑		↓(W+DH)				→

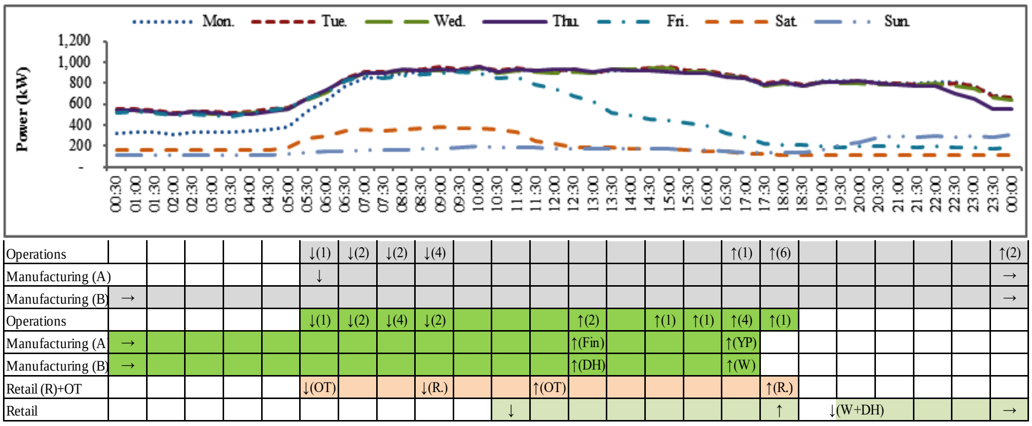
Figure 119 - 2014 peak production average

Off-peak production seasons demands in Figure 120 and Figure 121 for both years, compared to peak-production seasons, are quite similar. Reduced demand for Monday 2014 (between 00:00–06:00) is explained earlier. The lines for other weekdays and times do not indicate significant difference implying that these years have been busy even during off-peak seasons. Additionally, the contributing factors towards these profiles' shapes, such as the persistent baseload demand without any reduction, cannot be ignored. Another issue is that most of the off-peak season months fall in winter which naturally has an increase in building heating demand. The factor of air conditioning-related increase in demand, as discussed in Section 4.3.1, in summer is also noteworthy.



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		↑
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)						↓						↑												
Manufacturing (B)													↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑		↓(W+DH)				→

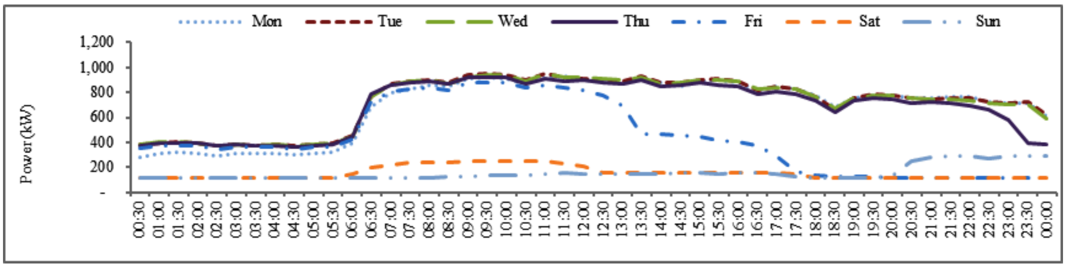
Figure 120 - 2011 off-peak production average



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑		↓(W+DH)				→

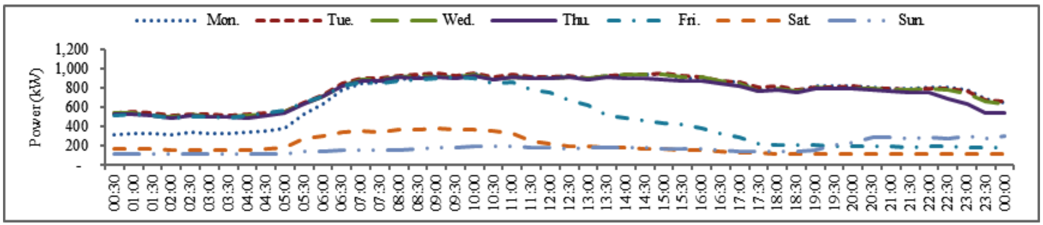
Figure 121 - 2014 off-peak production average

Figure 122 and Figure 123 show average winter demand, which falls in the off-peak season, indicating significantly higher demands as discussed above. Figure 122 shows a reduced Monday (morning) and Thursday demand during peak time through until midnight. This can be attributed to 2011’s four-week (October─November) holiday which reduced activity in Yarn production, as mentioned in 6.3.1.2. Figure 123, however, does not indicate any difference throughout the week except for Monday early hours which correlates with reduced production activity as discussed above. Saturday overtime is clearly visible.



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		↑
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)						↓						↑												
Manufacturing (B)													↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

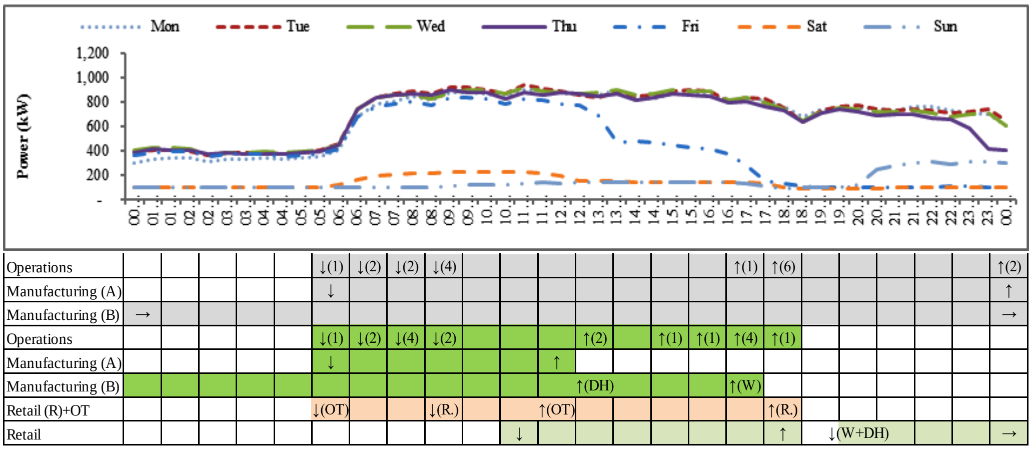
Figure 122 - 2011 winter average



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

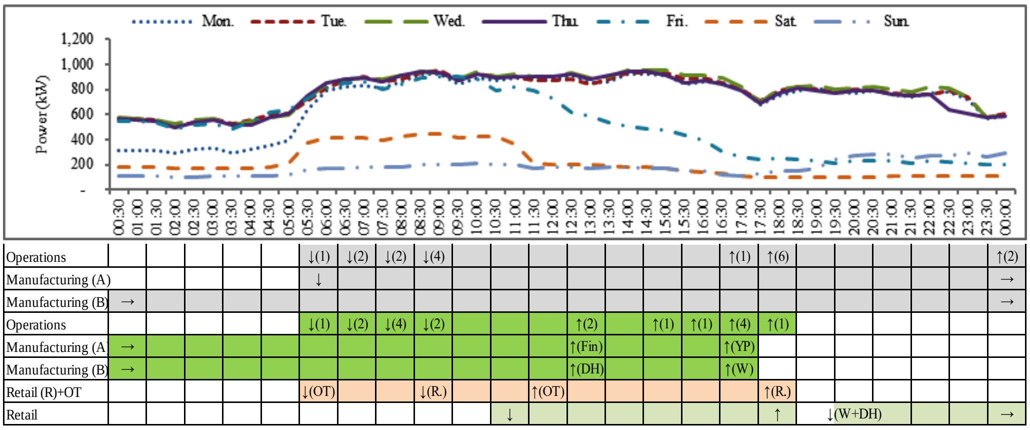
Figure 123 - 2014 winter average

The average demand for summer in Figure 124 and Figure 125 is higher due to standing mostly in peak-season and these are comparable to peak-season profiles. The dip at 23:00 followed by the rise at 00:00 on Thursday 2014 indicates intensity reduction (change of shift) of Finishing and Yarn production departments during these hours and regaining the full production intensity at midnight through until Friday evening. 2014 Saturday indicates some overtime-related demand even between 00:00–06:00, which is higher during the 06:00–midday period.



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		↑
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)						↓						↑												
Manufacturing (B)													↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 124 - 2011 summer average



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 125 - 2014 summer average

In addition to indicating the impact of 24-hour activity of individual years, these graphs when analysed for a single year across seasons also indicate important demand characteristics. For example, peak- and off-peak seasons for 2011 specifically between Mondays (between 00:30–06:00), Fridays (between 13:00–18:00), Saturdays (between 06:00–midday), and Sundays (between 20:00–00:00) show similar trends are observable for winter and summer. Similar differential attributes are identifiable for 2014 for such inter-seasonal comparisons. The time periods identified through this analysis are key points of Table 65, Table 66, and Table 67 putting the analysis of Section 6.3.1.1 into context. Cross-checking figures obtained through both methods gives confidence in generating numerical figures through both graphical and numerical methods. Additionally, departmental demand segregation is a key benefit of such methods specifically in the absence of metering/monitoring provisions.

6.3.2 Gas

In this section, high-resolution gas data is utilised to demonstrate a robust H-H data-based gas assessment method, as suggested in Chapter 5. Due to operational differences with electricity, timeslots designed for gas data are slightly different. This also indicates the creativity and practicality of the method designed according to the activity/operations in question. Unfortunately, the change in weekly shift patterns does not allow segregating demands at the department level as in Section 6.3.1.1.

6.3.2.1 Available data

Complete 2015 data was divided into two: holiday and non-holiday sets and analysed accordingly. Activity hours and the total consumption is comparable to 2014 and is similar to the focus years. This indicates that the identified saving strategies are still ongoing. Therefore, it can be assumed that the demand trends and patterns are similar to the historical ones.

6.3.2.2 Establishing the baseline consumption

Indicating total daily demands, Figure 126 reveals Monday to Thursday demands, remaining between 60,000–80,000kWh/day, patterns are quite similar throughout the year. The lower demand represents peak-production/summer and the higher is mainly for winter. Holidays' higher demands remain around 10,000kWh specifically for winter and reach to a minimum for summer (August and October). Friday's demand follows its own pattern (7hours reduced) and Saturday's indicates overtime whereas Sunday increased demand is mainly due to the shift starting at 20:00. However, some Sunday overtime (mainly 06:00–12:00) has also been observed.

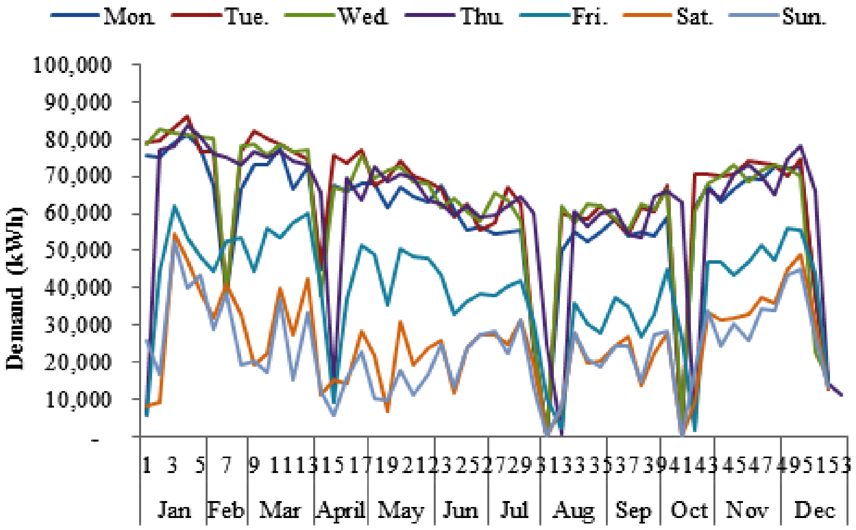


Figure 126 - 2015 daily weekday demand

Unlike in Section 6.3.1.1, demand averages from Monday to Friday are taken together as the operations in 2015 are 24hrs/day 5 days/week. The cumulative demand after 17:30 Friday has been slightly compromised, for the sake of brevity, shown in Table 70. Average peak, off-peak, and winter seasons' demands, when compared, did not show much difference in winter, but were notably different in summer. The average highest and the lowest demand time periods are 06:30–08:30 and 00:30–06:30 respectively.

Table 70 - Weekday average gas loads (kW)

Time	Departments/Sections working	Avg. 2015	Avg. load Mon-Fri peak-season	Avg. load Mon-Fri off-peak season	Avg. load Mon-Fri winter	Avg. load Mon-Fri summer
00:30-06:00	All production departments	1,968	1,909	1,968	1,968	1,898
06:30-08:30	All Production and most of the Operations	3,263	3,171	3,263	3,263	2,914
09:00-12:30	All the Production and the Operations	3,136	2,967	3,136	3,136	2,716
13:00-15:00	All the Production and the Operations	3,203	2,726	2,835	2,835	2,512
15:30-17:30	All the Production and the Operations	2,736	2,597	2,736	2,736	2,393
18:00-00:00	All production departments	2,526	2,406	2,526	2,526	2,220

Table 71 shows significantly less weekend load. Saturday average nighttime baseload is higher than Sunday, which is due to lower overtime on this day. Sunday's are higher than Saturday's evening average baseload due to the 20:00'Oclock shift start. In addition to establishing baseload demands, it helps assuming this demand being less than in 2011 due to weekend boiler operation management established in 2013 (as in Sections 6.2.2.2/6.4.2.2).

Table 71 - Weekend average gas loads (kW)

Time	Departments/ Sections working	Average Saturday	Avg. load peak-season Saturday	Avg. load Off-peak season Saturday	Avg. load Summer Saturday	Avg. load Winter Saturday	Avg. Sunday	Avg. load peak-season Sunday	Avg. load Off-peak season Sunday	Avg. load Summer Sunday	Avg. load Winter Sunday
00:30-06:00	Base load	875	855	941	694	941	891	719	891	764	891
06:30-12:00	Retail shops+Sat O-T	1,591	1,497	1,706	1,434	1,706	1,167	945	1,167	1,004	1,167
12:30-18:00	O-T induced	991	865	1,064	895	1,064	1,031	865	1,031	826	1,031
18:30-20:00	Base load	820	713	885	735	885	1,001	847	1,001	764	1,001
20:30-00:00	Dye house and Weaving for Sunday	818	708	881	737	881	1,120	1,002	1,120	956	1,120

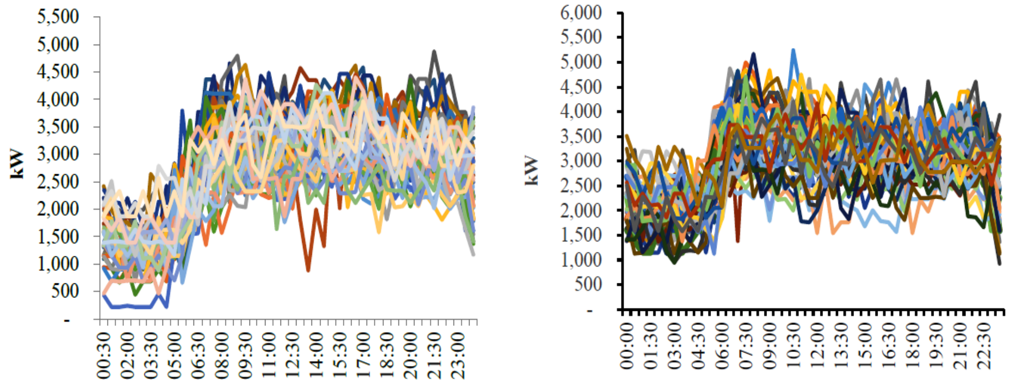
6.3.2.3 Daily peak- and off-peak demands

Figure 127 shows 2015 Monday–Saturday gas profiles. Reduced night-time demand for Monday (800kW–2,400kW) again reflects the reduced activity. The profiles from 06:30 until midnight show similar trends. The higher values, crossing 3,500kW threshold, again are attributable to winter/peak production and the lower to summer/peak season. The stenter's demand in peak- and off-peak production seasons also changes in response to the intensity and load of activity (although it runs continuously through this period). The unusual demand reduction (the red line between 13:00–15:00) indicates February 23, which is believed to be a faulty reading.

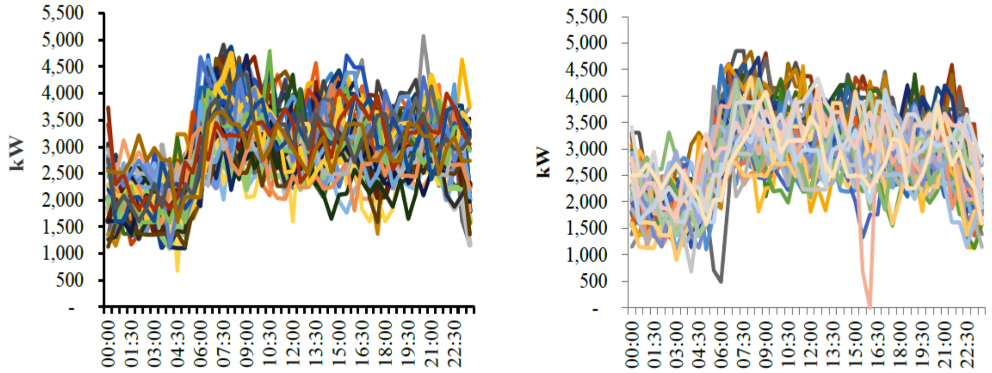
Tuesday has a relatively higher night-time (1,000kW–3,300kW) and daytime (2,500kW–5,000kW) demands than Monday. The intensity and load of activity peaked on Tuesday and Wednesday, shown in Figure 127, are the highest demand days (for electricity as well). Thursday is quite similar to Tuesday and Wednesday. A considerable number of peak-demand lines fall below the 3,500kW region, as observed in the Monday–Wednesday profiles. This can be attributed to summer as there is highest production demand except for building heating. The data lying just beneath can be attributed to low demand days during peak seasons. Approaching midnight, on Thursday the demand enters a sharper off-peak dip. The unusual orange dip on Thursday is October 22 and could be attributed to a misread. Such data errors were intentionally not rectified to reflect the system's natural error frequency.

Friday is notably different than the other weekdays as most of the peak- and off-peak time profiles lie within the medium demand region. This can be due to a gradual closing of different sections and departments before the weekend. As can be seen in the Figure, the starting demand is similar to other weekdays. However, after mid-day, things start to change and most of the times the demand is baseload only (when no overtime). As Friday night enters Saturday, the demand is relatively low, but could rise up to 3,500kW indicating overtime. The demand increase at (06:30) indicates some overtime in production departments. In case of no overtime, the consumption can only be associated with baseloads (in summer) and factory's buildings heating in winter. Some constant demand is also incurred by the onsite café. The occasional zero demands, at the bottom of Friday (after 15:00) and Saturday, show when the boilers use the least gas (which is below the AMR's readability limit). This can be in response to saving measures, such as boilers on timers, or completely isolated. As the factory runs until 17:00 on Friday, these patterns are unusual. However, these can be attributed to the last Fridays before holidays as there is mostly reduced activity on this day. Such readings are more common on Sunday (between 00:00–14:00) until the afternoon when boilers will be turned on properly to get the whole system ready to start work in the evening.

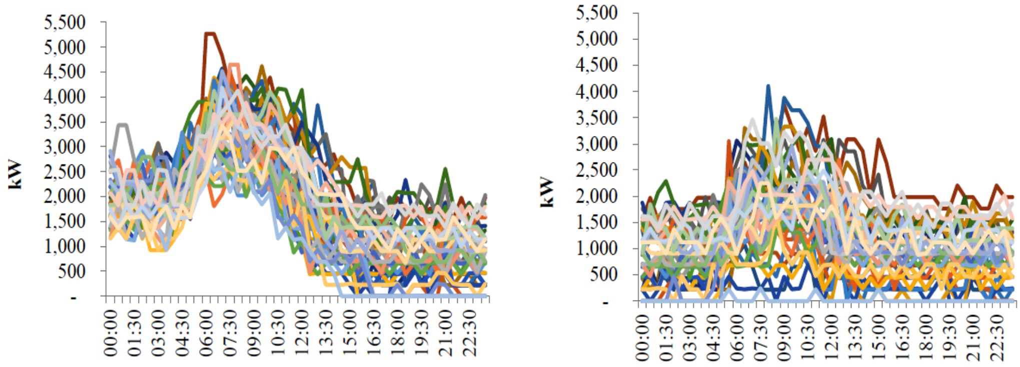
Sunday demand, shown in Figure 128, is mainly to keep the boilers running with some of this associated with the café. The lines at the base of the profile indicate the baseload in summer, in the middle can be associated with baseload in winter, whereas the ones lying above all suggests some overtime. Understanding gas demands in such details was not possible without such data analysis. Had data before the change in operation times been available it would have been possible to compare and estimate the impact of new timings as well as its relationship with electricity.



Monday Tuesday



Wednesday Thursday



Friday Saturday

Figure 127 - 2015 Monday to Saturday gas profiles

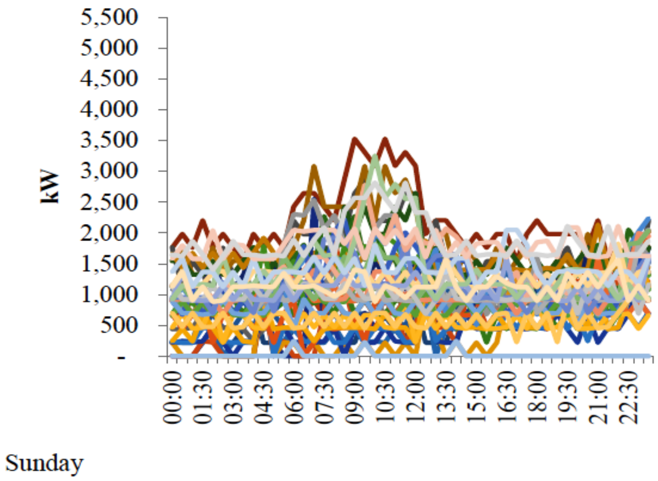
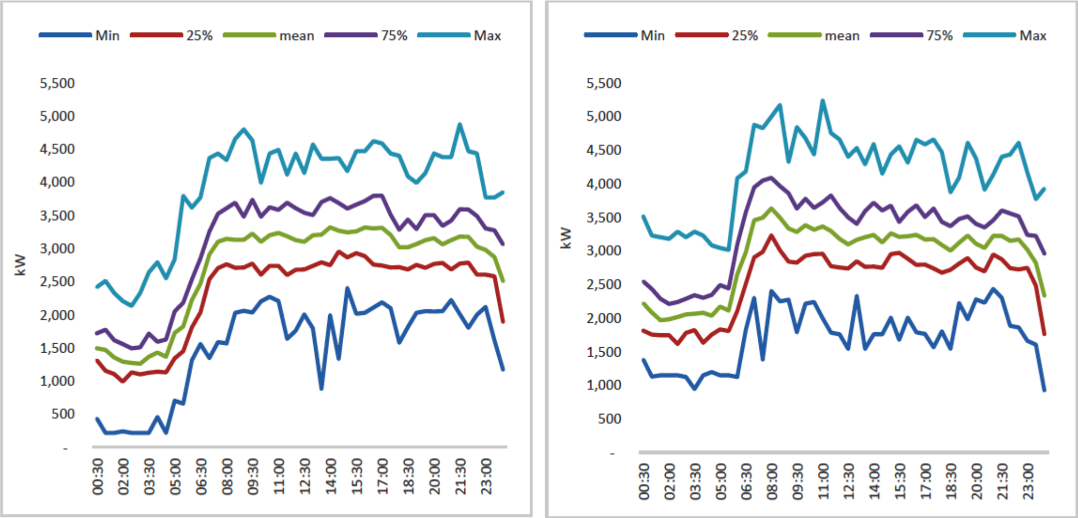


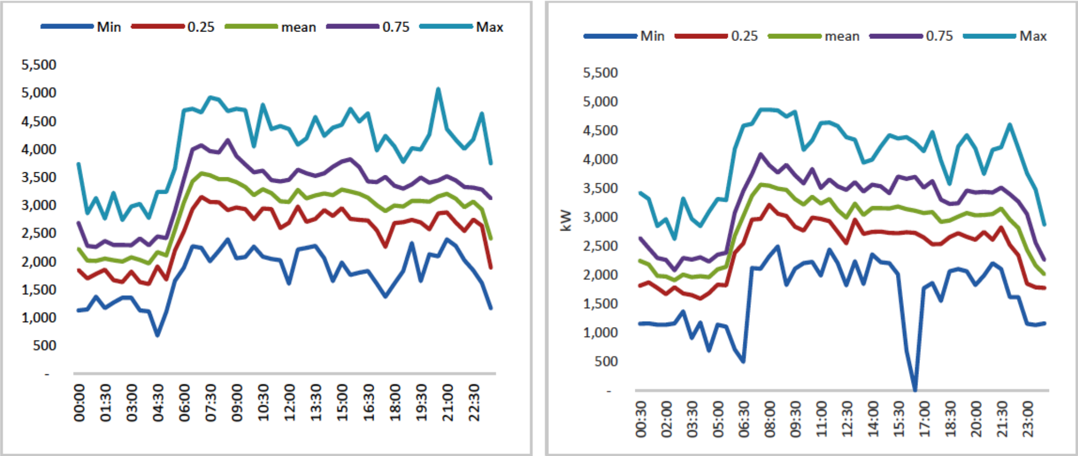
Figure 128 - 2015 gas Sunday profile

Individual weekday average gas percentiles are analysed in Figure 129. Minimum demand, shown in the dark blue line, can be associated with least thermal activity and load days (such as long-hour dyeing batches, reduced washing in scouring, and minimal demand from the stenter). Such factors are possible in any seasons and reflect that they were equally affecting the electric intensive departments. This once again indicates the manufacturing processes' environmental, management, and activity complexity. The red line (below 25%) can be associated with the off-peak season that lies in summer. The green line (mean) represents average peak-production and off-peak winter season. The purple line (below 75%) represents top peak-production and peak winter season. The blue (max) line represents peak winter at low-temperature conditions. The demand characteristics of each day tell a distinctive story for that specific day. Note, the fall to zero from 15:00 onwards on Friday could be due to faulty zero reading or a point of no demand.



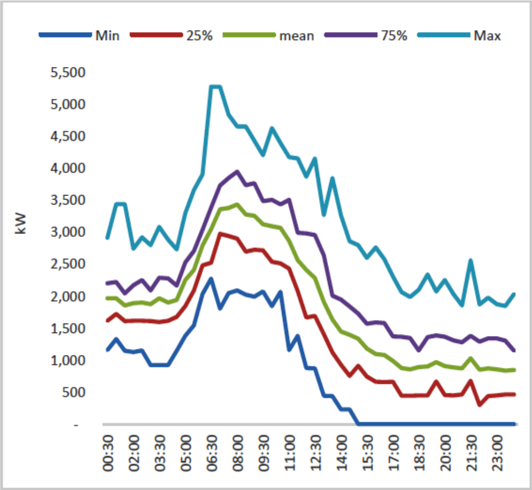
. 2015 Monday

2015 Tuesday



. 2015 Wednesday

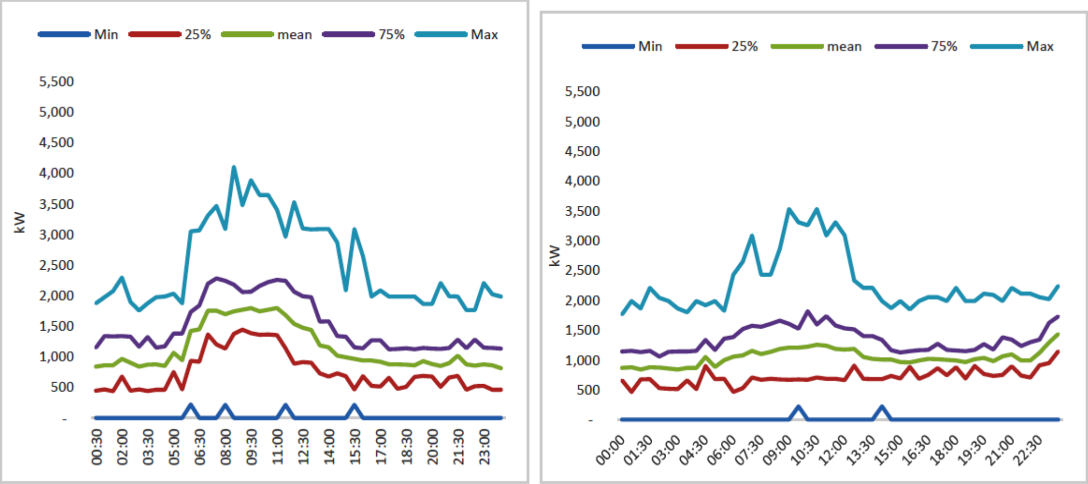
2015 Thursday



2015 Friday

Figure 129 - Monday to Friday average gas

Similarly, Saturdays and Sundays (Figure 130) show multiple zero points for the minimum, which can be attributed to the reasons above for Friday, summer, and or saving measures. The red, green, purple, and the sky-blue lines represent the same story for the attributes associated above. The rise between 06:00–12:00 is due to overtime (based on season and intensity of activity). The raised demand (sky-blue and purple lines) on Sunday indicate some overtime (which, although rare, did occur on occasion) whereas the other red and green lines indicate winter.

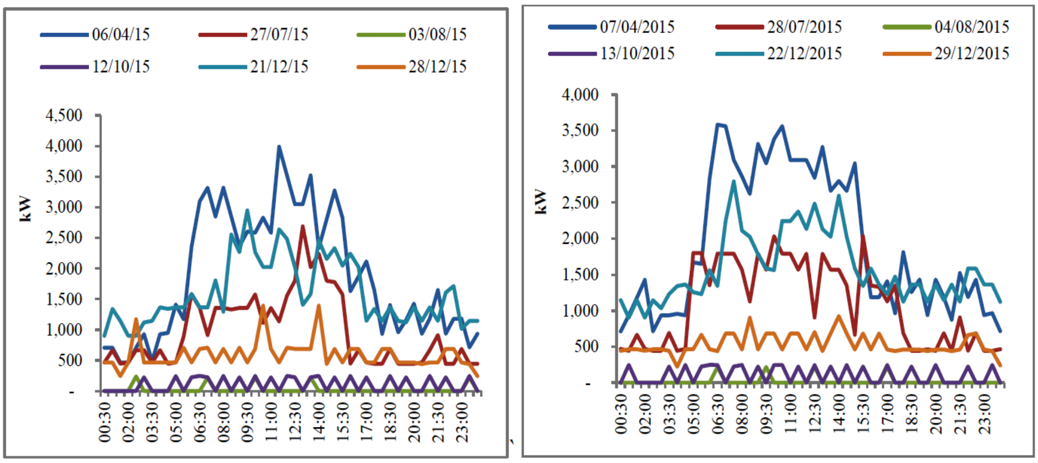


2015 Saturday

2015 Sunday

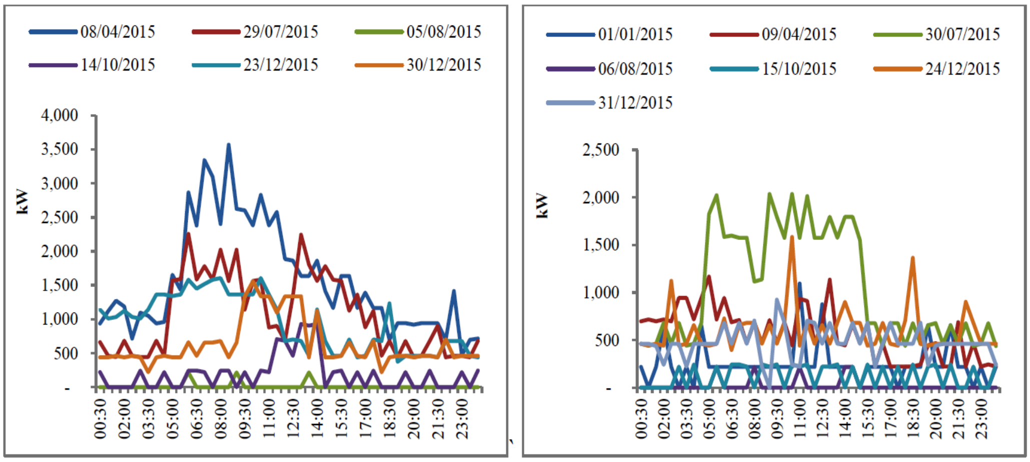
Figure 130 - Saturday and Sunday average gas

To understand the further reduction in demand, weekday holiday profiles are presented in (Figure 131 and Figure 132). The base of the graph at x-axis indicates the demand without overtime. This is suggestive of avoiding weekend overtimes when a significantly higher quantity of energy is used towards boilers' baseload. The overtime also prevents implementing weekend saving measures (switching-off) on Friday. Thus, relatively less quantity of products is produced (six-hour at relatively reduced activity/intensity) at higher energy use. The lines at the top of the Figure (Monday-Wednesday) indicate overtimes even during the holidays. These generally represent first few days (Monday–Wednesday) of the first holiday week utilised to cover the pending work. When overtime during holiday goes beyond the first week it maybe indicative of production management improvement. This also suggests that despite increasing the factory's working hours, overtime is still required.



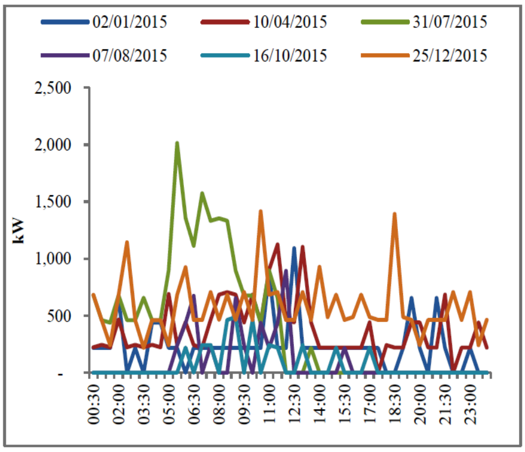
2015 Monday holiday

2015 Tuesday holiday



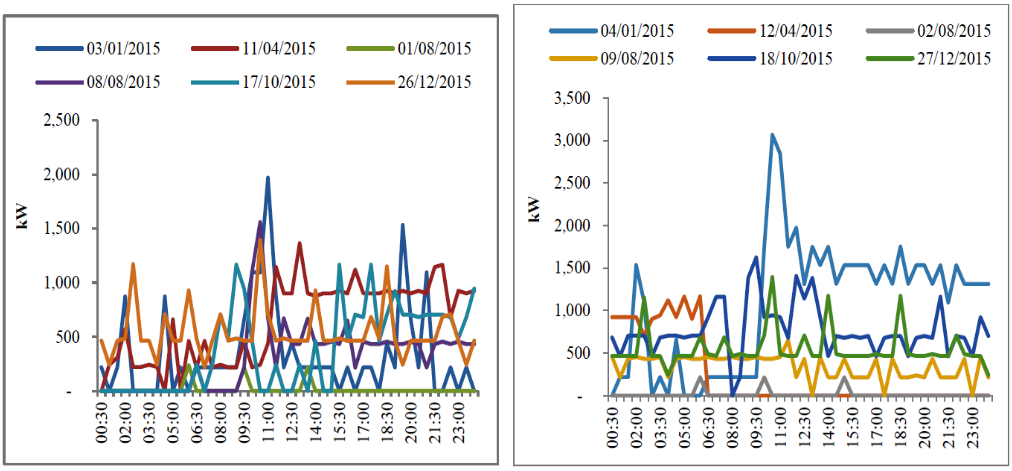
2015 Wednesday holiday

2015 Thursday holiday



2015 Friday holiday

Figure 131 - Monday to Friday holiday gas



2015 Saturday holiday

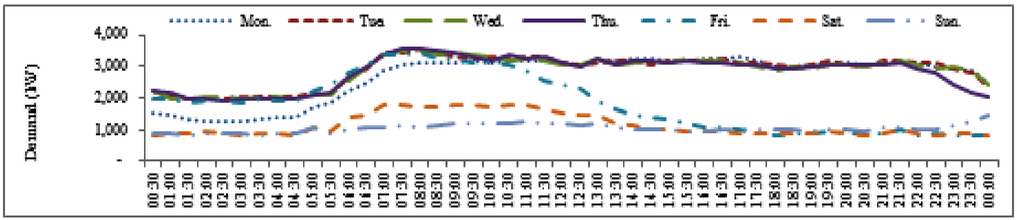
2015 Sunday holiday

Figure 132 - Saturday and Sunday holiday gas

The profiles from Thursday onwards have different characteristics. The highest profiles for Thursday and Friday represent the first week of the July holiday. It is possible that some departments/sections still needed to work before going on holiday in the second week. The other demands (from Thursday to Sunday) lying in between highest and the lowest can be attributed to holidays in winter when some building heating is still required to prevent condensation (or pipe-freezing). The lines at the base across x-axis of the graph represent holiday in summer (July and August).

6.3.2.4 Energy trends and patterns for gas

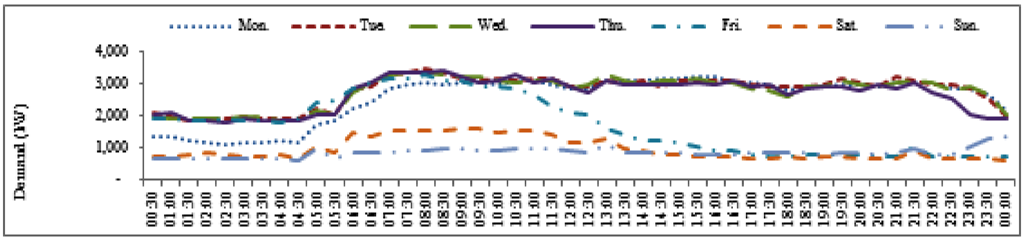
To capture these energy characteristics and patterns, average weekday, on- and off-production, and winter and summer seasons' profiles are presented against the activity. Figure 133 shows changes in the intensity of the activity having a visible impact on demand. Monday's lower demand during early hours is already discussed however during peak times the Monday–Friday demand is almost the same. A fall for Thursday at 23:00 and mid-day Friday is already known. Saturday and Sunday show demand deviation with activity (overtime, retail shop). The shape of the profile is quite similar to the average 2011 electricity profile and is mainly influenced by the intensity of the manufacturing activity. This is negligibly affected by the Operations sections having little thermal energy dependence (winter only). The demands visualised in Figure 133 through the day are comparable to Table 70 and Table 71. Slight dips for break time and change of shift (at 18:00 (Operations) and 00:00) can be seen. The less impact of the afternoon change of shift (14:00) can be due to thermal processes mostly programmed for longer (1–several hours) requiring minimal human attention.



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

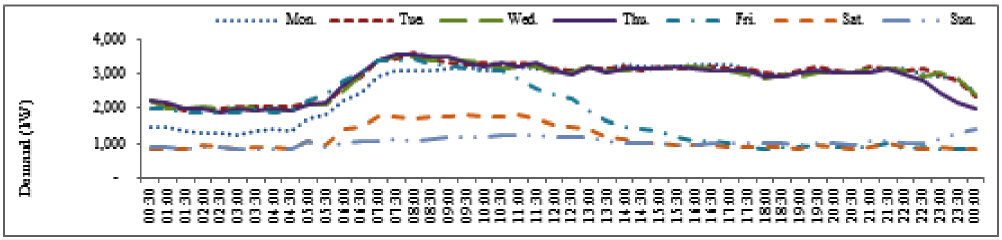
Figure 133 - 2015 average weekdays

The shape and the factor affecting the average peak-production profile (Figure 134) is quite similar to Figure 133. However, the average off-peak profile (Figure 135) shows increased demand for both weekday averages (mainly during peak-time) as well as at the weekends, as all three boilers are running during this period (mostly winter). This is also comparable with Table 70 and Table 71, as shown in Figure 136. The reduction in demand, despite mostly belonging to peak-production-season, in summer can be seen in Figure 137 as discussed in the above section.



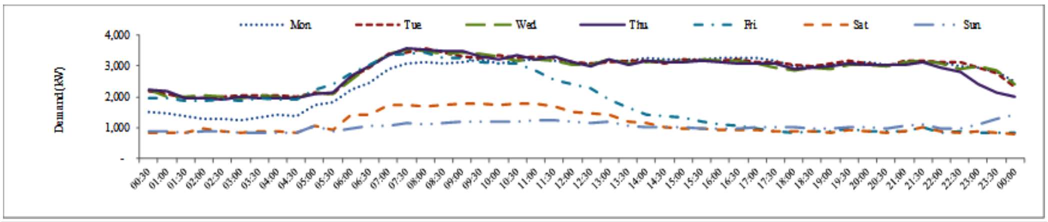
Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 134 - 2015 average peak weekdays



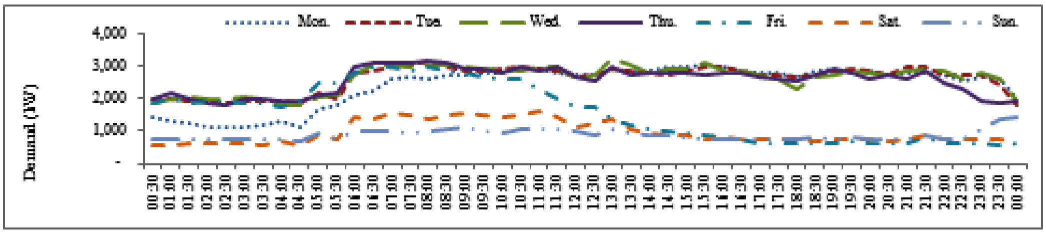
Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 135 - 2015 average off-peak weekdays



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 136 - 2015 average winter



Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
Manufacturing (A)						↓																		→
Manufacturing (B)	→																							→
Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
Manufacturing (A)	→												↑(Fin)				↑(YP)							
Manufacturing (B)	→												↑(DH)				↑(W)							
Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
Retail											↓							↑	↓(W+DH)					→

Figure 137 - 2015 average summer

The analysis, though based on average demands, indicates the impact of changing activity throughout the day. It is helpful to visualise seasonality-based impacts too. The generalised day demands for various seasons, though having a little difference between each other, are still comparable. The clarity of activity and process identified through the analysis allows for the possibility of analysing the importance of intensity of shift and load.

6.4 Analysis of energy savings

Knowing and associating a manufacturing activity's consumption, cost, and carbon emission, at various levels, ensures the whole energy audit process is well informed. The next step would be to identify energy saving recommendations, evaluating cost-benefit and carbon savings, thus making energy efficiency a business case. The identified measures include no- to medium-cost investment (indicated where possible) with the highest being £80k. Detailed reports on technical energy efficiency of the key technology were produced, briefly summarised in Appendix 1 (sections b, c, e, g, j, and l), for the company. However, due to limitations such as funding restraints and the other investment commitments the factory picked up only few. Heat recovery systems in the boiler house (as in section k) were installed. In response to other key recommendations technology manufacturing and installing companies were invited for weighty investigations. However, site-specific designing related increase in cost seriously affected the payback periods specifically for heat recovery system in the dyehouse, BMS system upgrade, and economiser in the boiler house.

For consistency Defra's 2012 carbon emissions factors are utilised for both fuels. Each sub-section presents key attributes tables as to make sense of auditing procedures/processes, and the methods learnt.

6.4.1 Electricity

6.4.1.1 Air compressors

A few good housekeeping and wasteful behaviour related energy-saving measures can be implemented on these reasonably energy-efficient CA systems (i.e. sparging, agitation, and handheld guns), as in Table 72.

Table 72 - Saving measures for CA systems

No.	Measure/ recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment/quote year	Payback (y)	Risks
1	Repair leaks	-	Air leaks can cost upto 50% of total energy cost	Lack of a leak prevention programme	Walk around/ O&M, and detailed energy audit	Energy measuring and monitoring	Engineering principles	165	16,472	76	low-cost. Maintenance staff can be utilised to fix it	Soon after the installation	None
2	Weekend running schedule change				Walk around/ O&M, and detailed energy audit	Energy measuring and monitoring	Engineering principles/ use of control feature	See * below	See * below	See * below	no-cost	Soon after the installation	Condensation in winter. Attentive scheduling for unusual OT
3	Recover waste heat	various	Units are packaged heat recovery easier	Systems operate all year round	Standard energy audit	Expert observation	Engineering principles	See **below	See **below	See **below	-	-	-
	i)	recover waste heat for hot water	-	The kWh emitted are higher than required. Running cost will be incurred.	-	-	-	63	6,317	29	Bespoke nature of installation	unknown	Optimum space management for heat recovery system installation

	ii)	recover waste heat for heating in Warping	-	Space heating only needed for winter. The kWh of heat is higher than required.	-	-	-	12	3,917	22	Bespoke nature of installation	unknown	Space issues may be faced for system installation
4	Reduce system header pressure	-	High header pressures are high for the varying demand. It is a wasteful practice and savings can be made.	Observations showed the pressure lowering possibility. To benefit from at least of 0.5bars a storage tank may be needed.	Walk around/O&M	Energy measuring and monitoring	Engineering principle	1.6	1,648	8	Cost associated with installing a new storage vessel in the Yarn production area is unknown	unknown	Risk of machinery stoppage exists. Installation of storage vessel advised.
Total								241.6	28,354	135			

**See Table 74*

***See Table 75*

Air leaks cost, estimated through weekends (no work (mostly on Sundays)), controlling have saving potential. On the other hand, the generally ignored leak prevention practice causes constant 24 × 7 days leaks, equating to £49/day as in Table 73.

Table 73 - Weekday/Weekend energy and cost saving through controlling air leaks

Daily leak related consumption (kWh)	Daily leak related cost(£)	Weekday kWh savings	Weekend kWh savings	Weekday cost saving (£)	Weekend cost saving (£)	Total CO_2 savings (tonnes)
493	49	113,432	51,291	11,343	5,129	76

Values are derived from Table 47 and Table 48

The system's control could be utilised to use varied on/off and other modes for weekend operations (including periodic running for condensation prevention). Extending the servicing time (cost-saving) and system longevity this will also save some energy (as in Table 74).

Table 74 - Suggested CA system's weekend operations

	Friday	Saturday	Sunday	Hours saved	Avg. hourly cost (£)	Cost saving (£)	CO_2 saving /annum (tonne)
No weekend overtime							
Swtich-off	17:30						
Swtich-on			19:30				
Total				50	2.10	105	22
One of the sections working throughout Friday night till 12:00 Saturday							
Swtich-off		12:30					
Swtich-on			19:30				
Total				31	2.10	65	14
There is overtime betwee 06:00-12:00 on Saturday							
Swtich-off	17:30						
Swtich-on		05:30		12			
Swtich-off		12:30					
Swtich-on			19:30	31			
Total				43	2.10	90	14

The efficiency for these systems may be generalised (90% electricity is transformed into heat of which 80% can be recovered) as described by the Carbon Trust (The Carbon Trust, 2012b), and indicated in Table 75. The recovered heat used to save electricity and gas (as indicated in Table 76 and Table 77). However, the measure is based on typical guidelines, requiring thorough evaluation.

Table 75 - Theoretical electrical and gas savings potential

Avg. annual consumption (kWh)	Energy converted in to heat (90%)	Heat recovery (kWh) @80%	Electric cost equivalent (£)	Gas equivalent (£)	Electric equivalent CO_2 (tonne)	Gas equivalent CO_2 (tonne)
285,398	256,858	205,487	20,549	5,137	95	38

Table 76 - Different ways of cost saving (electric)

Appliance	Rated power (kW)	Period (wk)	Hours	Total (kWh)	Cost saving (£)	Carbon savings (tonne)
Utility hot water	3	46	7,728	23,184	2,318	11
Hot water dispenser	3	46	7,728	23,184	2,318	11
Heaters in the canteen	4	25	4,200	16,800	1,680	8
Total				63,168	6,317	29

Note: none of these items run constantly, therefore, cost and saving is indicative only

Table 77 - Savings towards building heating (gas)

Energy required to produce 205,487 kWh (thermal) @82% boiler efficiency	Fuel saved in winters (kWh)	Fuel cost for winters (£)	True steam cost(£)	Carbon savings in winter (tonne)
250,694	120,526	3,013	3,917	22

Base values are derived from Sections (6.2.2.2 Boilers and 6.4.2.2 Boilers)

Pressure optimisation as in Table 78 is another measure with some relevant implications further explained in Section (a) of Appendix 1 (c).

Table 78 - Pressure optimisation related savings

Consumption at 7bar (kWh)	Consumption at 6.5bar (kWh)	Units saved (kWh)	Cost savings (£)	CO_2 savings (tonnes)
296,283	279,537	16,746	1,675	8

kWh are derived from monitored values

6.4.1.2 Gas user technologies for electric

Electric components (motors) of some gas using technologies can save energy when installed with VSDs, as indicated in Table 79.

The stenter's electric motors do not have VSDs. This, theoretically, can be reduced through the measure, as indicated in Table 79 below and calculated in Table 80.

Table 79 - Electricity saving measures for gas using technology

No.	Measure /recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment/ quote year	Payback (y)	Risks/Caution
1	Install VSDs on blower motors of stenter	-	A VSD, e.g., by reducing 20% rotating equipment speed, can reduce input power requirements by 50% approx	No VSD on the blower motors	Standard energy audit	Nameplate rating and hours used	Engineering principles	81	8,073	37	18,000 (2014)	1.2	An expert textile engineer may be required to assess the feasibility on this machine
2	Install VSDs on combustion air fans on boilers		Boilers have electricity efficiency potential through VSDs	The boilers electronically operate dampers with forced draught fans. It is unclear if the air dampers shut fully when the boilers are not operating.	Walk around/ O&M, detailed energy audit	Nameplate rating and hours used	Engineering principles	118	11,826	54	unknown	unknown	It is essential to enquire this first as this measure will only be useful if the air dampers do not shut fully when not operating

Table 80 - Calculations for VSD installation on stenter

Before the measure	Consumption			
	hourly	weekly	annual	CO_2 (tonne)
Demand (kWh)	45*	3,510	161,460	
Cost (£)	5	351	16,146	
				74
After the measure**				
Demand saving (kWh)	23	1,755	80,730	
Cost saving (£)	2	176	8,073	
				37

- **estimated*
- ***(U.S. DoE, 2012a)*

Payback	
Cost of 6 units* (£)	15,000
Labour for 6 units* (£)	3,000
Total cost	18,000
Pay back (years)	2.23

**rough estimation*

The boilers' forced-draught combustion fans are fixed-speed requiring air damper to throttle to control flow. For the boilers' top and bottom range outputs, such a simpler mechanism is reported to have poor control. The reduction in power consumption, with varying boiler loads, is reported to be minimal (Ozdemir, 2004). This consistent-speed of motors is suggested to be controlled through installing VSDs on the burner (Ozdemir, 2004). Depending on the operational requirements, the electric savings are in excess of 60% in some applications (Action Energy, 2004a) or more with the boilers mostly running below the maximum rating at low fires. The greater production variability at the factory makes boilers frequently going on high/low fires. Therefore, these are excellent candidate for VSDs as calculated Table 81.

Table 81 - Installing VSD on boilers

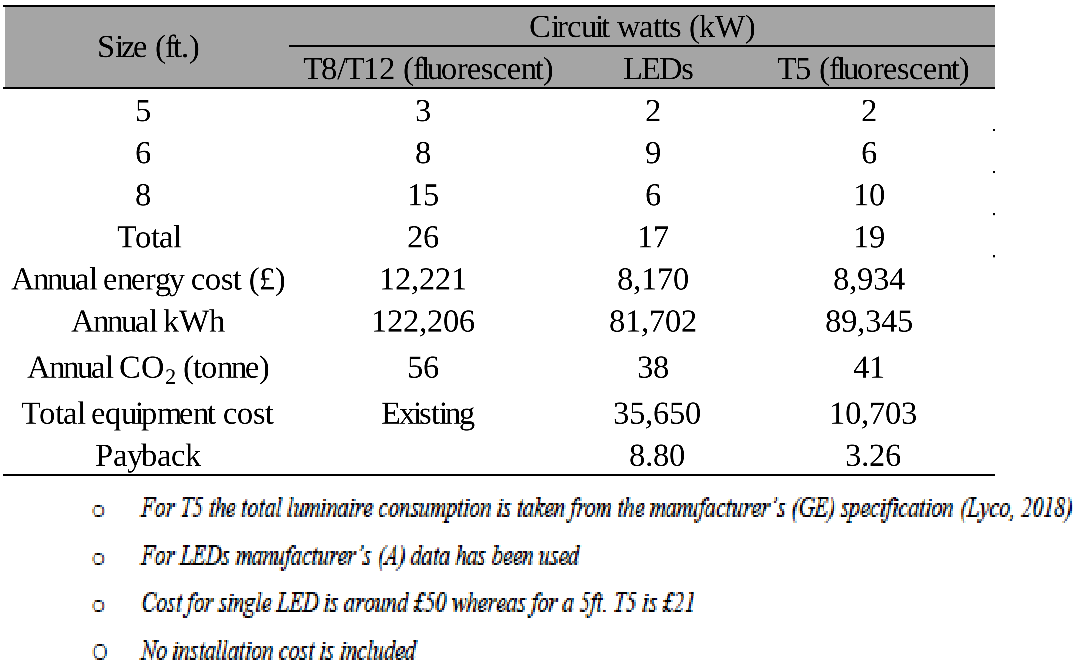
Boiler	Burner motor power (kW)	Annual energy consumption (kWh)	Annual cost savings (£)	Energy savings at 60% (kWh)*	Cost savings at 60% (£)	Carbon savings (tonne)
2	7.5	65,700	6,570	39,420	3,942	18
3	7.5	65,700	6,570	39,420	3,942	18
4	7.5	65,700	6,570	39,420	3,942	18
Total	23	197,100	19,710	118,260	11,826	54

- *Assumed operations* 24 × 7 × 365
- *60% energy saving assumed*

6.4.1.3 Lighting evaluation of a case-study building

The efficiency recommendations for Section 6.2.1.3 are given in Table 49 and T5 triphosphorous and LED lighting technologies are compared (Section 5.3.2.4). The total circuit watts, cost, and savings for both technologies are calculated in Table 82. T5 shows the highest energy efficiency and quicker payback but with slightly higher CO_2 footprint. With lower operational energy and CO_2 emissions, the payback for LEDs nears to its life expectancy. In that, it is likely that targets around capital cost become the deciding factor for the chosen technology.

Table 82 - Total circuit watts and annual cost with alternative technologies



Size (ft.)	Circuit watts (kW)		
	T8/T12 (fluorescent)	LEDs	T5 (fluorescent)
5	3	2	2
6	8	9	6
8	15	6	10
Total	26	17	19
Annual energy cost (£)	12,221	8,170	8,934
Annual kWh	122,206	81,702	89,345
Annual CO_2 (tonne)	56	38	41
Total equipment cost	Existing	35,650	10,703
Payback		8.80	3.26

- *For T5 the total luminaire consumption is taken from the manufacturer's (GE) specification (Lyco, 2018)*
- *For LEDs manufacturer's (A) data has been used*
- *Cost for single LED is around £50 whereas for a 5ft. T5 is £21*
- *No installation cost is included*

Second year MF and life expectancy were determined (e.g. 70% output for fluorescent T12, 96% for triphosphour T8 (The Carbon Trust, 2006a; Myer, Paget and Lingard, 2009) and 98% for LEDs (by manufacturer "A")), as shown in Figure 138. Out casting the T12's, T8/T5 maintains a better lumen output with very little difference from LEDs.

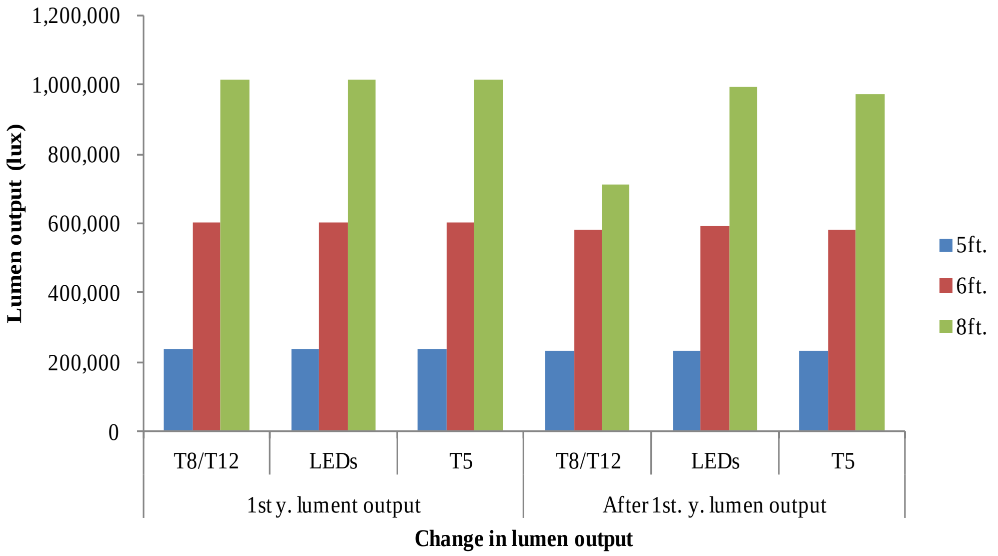


Figure 138 - Lighting technology's first and second year lumen output

- *Depreciation after 6,000hrs*

LEDs and 5ft. T5s, manufacturers data life expectancy showed 50,000hours and 30,000hours, respectively. LEDs perform well compared to the T5 competitor, particularly in terms of cost (three times less). The suggested old tube fittings and ballasts for LEDs are short in number and would not last 50,000hours, thus incurring replacement costs. For T5s, the tube rods might last for 30,000hours (or 24,000hour bulk-change) but the normal life expectancy for the control gear and the fixture is 50,000hours (NSW Government Australia, 2014). This means it can last at least two T5s (costs £4). Retrofitting the existing fittings for T5 has a capital cost associated with it, though installation can be carried out by the in-house maintenance team.

The additional measures below, in general, can add to cost savings around the factory;

- To avoid 30% lighting level reduction, within 2–3 years, regular maintenance is required (The Carbon Trust, 2010b)
- Replace T12 with suitable alternatives (T8/T5) without compromising the incident lux
- Replace the old fittings with new energy-efficient fittings (electronic ballasts)
- Roof-lights in many buildings has been not efficiently used, automatic modulating light-level controlling sensors can be considered
- A large number of faulty (parasitic) fluorescent tube lights need replacing/removing

- Review individual building's lighting intensity against SLL's lighting benchmarks
- Simple measures, such as two-way switch banks, additional switches, occupancy sensors, pull/timer switches, and or simply by using on as-needed basis, should be applied where practical

6.4.2 Gas user technologies

A different approach of utility, technology, general building heating, and heat recovery measures was considered on chosen gas technologies.

6.4.2.1 Stenter

The savings estimation suggested mainly address behaviour change, as indicated in Table 83.

To avoid hot air blow on the operator's face (with a broken extractor fan noted), a higher air exhaust rate (55%) is permanently set. This results in quicker exhaust rates of hot air that is less saturated with water vapour, which can cause energy wastage. Reducing the damper valve opening limit can save energy. Measuring the quantity of wasted air is advisable. However, the savings are assumed to be that a 45% opening will result in a 5% kWh saving, as shown in Table 84.

Table 83 - Saving recommendations for stenter

No.	Measure /recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment /quote year	Payback (y)	Risks/Caution
1	Reduce down the exhaust air flow rate from 55% to at least 45%	-	As mentioned section on stenter in Chapter 3	The exhaust air damper is set fixed at 55% opened to avoid hot air leaking into the operator's face	Standard energy audit	Nameplate rating and hours used	Engineering principles	97	2,106	18	Fixing cost of the fan is within £1,000		Complaints of face burning if the extractor fan on this side is not fixed
2	Completely shut down the gas and exhaust dampers during tea/cigarette breaks	-	The practice is recommended for short breaks	Observed revealed that the machine is running during short breaks	Walk around/ O&M	Nameplate rating and hours used	Engineering principles	138	4,485	29	None	0-months	Increased frequency of turning on/off may result in increased fatigue of the machine

Table 84 - Savings for damper valve closing

	Savings			
	hourly	weekly	annual	CO_2 T/yr.
Units 5%(kWh)	27	2,106	96,876	
Cost (£)	0.68	53	2,422	
				17.94

- *Gas cost £0.025/kWh*
- *refer to Appendix 1(h)*

For many short-breaks, either the machine or the damper valve is not shut resulting in energy wastage, as noticed in Section 6.2.2.1. The measure can save some significant energy (e.g. 1-hour) energy, as shown in Table 85.

Table 85 - Savings for gas shutdown

Gas	Savings			
	hourly	weekly	annual	CO_2 (tonne)
Cost (£)	14	68	3,105	
Unit (kWh)	540	2,700	124,200	
				23
Electric				
Cost (£)	6	30	1,380	
Unit (kWh)	60	300	13,800	
				6
Total cost			4,485	
Total unit			138,000	
Total CO_2				29

- *Refer to Appendix 1(i)*

6.4.2.2 Boilers

Any saving measure implemented on boilers can have unintended consequences on related energy aspects (i.e. turburators impacting on the economisers' recovery potential). Measures suggested in Table 86 are discrete and do not regard each other's impacts on savings.

Table 86 - Boilers energy saving recommendations

No.	Measure/ recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment/ quote year	Payback (y)	Risks/Caution
1	Operate two boilers instead of three during off-peak times in winter.	-	At night time the production and building heating demand is low	Maintenance staff can easily manage such a boiler running operation	Walk around/ O&M leading to standardard energy audit	Energy measuring and monitoring	Engineering principles/ direct and indirect metering	480	12,000	89	none	0-months	What if one of the two running boilers locks out
2	Install economisers to recover heat from the flu gas	various	Economisers are cheaper and well trusted choice for the job	Heat in the flue gas is being wasted	Standard energy audit	As recommended in technology specific reports	Engineering principles	-	-	-	-	-	The building structure of the boiler house, due to little room above the boilers might need changing requiring additional cost
	i)	Install conventional economisers	-	-	-	-	-	467	11,687	86	30,000 (2012)	30,000/ 11,687=2.5	-
	ii)	Install condensing economisers	-	-	-	-	-	1,124	28,104	206	Unknown	Unknown	-
3	Install combustion air preheater system	-	The installation of the system is mostly less complicated and easy	The top of the boiler house has warm air accumulated all the time which could be harnessed	Standard energy audit	As recommended in technology specific reports	Engineering principles	313	7,813	57	Bespoke nature of installation	-	Some alterations might be needed for air ducting. Also, the nature of draught fan and the dampers might not allow the intake of warm air requiring alterations

4	Install boiler and burner management systems, digital combustion controls and oxygen trim system.	-	Proven efficiency of these systems [18]. Boilers do not have such systems built in	A burner-related inefficiency has been identified in boiler 4 in the past. Boilers at the factory are non-modulating hence are less efficient	Standard energy audit	As recommended in technology specific reports	Engineering principles	744	18,606	138	Bespoke nature of installation	-	More alterations might be needed and new burners may be required
5	Install automatic TDS blowdown control system	-	Controlled TDS level improve boiler performance and life. Improved boiler efficiency saves cost	Numerous TDS related issues have been reported, scaling being the major one. Practices adapted to avoid these have caused waste of energy	Standard energy audit	As recommended in specialist guideline reports	Engineering principles	259	6,472	48	The company's steam survey audit report (2012) reports £5,000 equipement cost	Less than a year	None
6	Install blowdown heat recovery system	-	Installing such a system is a cost effective measure to avoid waste of energy	Numerous TDS related issues have been reported, scaling being the major one. Practices adapted to avoid these have caused waste of energy	Standard energy audit	As recommended in specialist guideline reports	Engineering principles	518	12,944	96	The company's steam survey audit report (2012) reports £16,500 equipement cost	Just over a year	None
7	Install turbulators to improve efficiency	-	These are simple and can be easily installed. Once installed they last for the lifetime	Onsite boilers have three passes and are ideal candidate for turbulators	Standard energy audit	As recommended in specialist guideline reports	Engineering principles	156	3,901	29	Bespoke nature of installation	-	None

8	Install flue gas shut off dampers	-	Flue gas shut off dampers prevent convection losses taking place inside the boilers	The boilers, have forced draught fans with electronically operated air dampers. It is unclear if the air dampers shut fully when the boilers are not operating. Therefore, it is essential to enquire this firs to ensure saving	Standard energy audit	As recommended in technology specific specialist reports	Engineering principles	156	**3,901**	29	Bespoke nature of installation	-	Finding out the nature of the air damper mechanism is required

The weekend operation management practice as discussed in Section 6.2.2.2 can be further extended to, such as at night-time in winter, without needing such an expensive system. The possible savings are estimated in Table 87.

Table 87 - Savings for off-peak winter boiler shutting

Total daily average consumption (kWh)*	Average consumption per boiler (kWh)	Hourly conumption per boiler (kWh)	Savings for 6 hours (kWh)	Energy savings/annum (kWh)	Cost savings/annum (£)	Carbon savings/annum (tonne)
32,000	10,667	444	2,667	480,000	12,000	89

- **Total annual gas consumption divided by total number of days (including weekends)*
- *Excluding electric savings*
- *The savings is only possible in winter*

Economisers are HEs used to recover heat from the flue gas to raise feedwater temperature. Every 5°C reduction in the gas can increase 1% boiler efficiency or every 1°C increase in boiler feedwater temperature results in approximately 4°C drop in flue gas temperature (Action Energy, 2004a). A conventional economiser can increase up to 5% boiler efficiency (The Carbon Trust, 2012d) as calculated in Table 88. Whereas a condensing economiser recovers heat more efficiently, therefore, can raise the system's efficiency by 10% (U.S. DoE, 2004b), as calculated in Table 88. Thus the efficiency can exceed 90% as shown in Table 89.

Table 88 - Install economizer

Boilers	Gas (m^3) required after 5% reduction in fuel	Gas (m3) required after 10% reduction in fuel	Energy (MWh) saved on achieving 5% reduction in fuel	Energy (MWh) saved on achieving 10% reduction in fuel	Cost (£) saved on achieving 5% fuel reduction	Cost (£) saved on achieving 10% fuel reduction	Carbon saved (tonne) on achieving 5% fuel reduction	Carbon saved (tonne) on achieving 10% fuel reduction
Boiler 2	329,773	312,416	96	289	2,410	7,232	18	53
Boiler 3	219,077	207,547	102	231	2,562	5,765	19	42
Boiler 4	574,074	543,860	269	604	6,714	15,107	49	111
Total			467	1,124	11,687	28,104	86	206

Table 89 - Comparison of conventional and condensing economisers, *(U.S. DoE, 2012c)*

System	Combustion efficiency @ 4% excess O$_2$ (%)	Stack gas temperature (°C)
Boiler	78 to 83%	165 to 285
-with feed water (FW) economiser	84 to 86%	120 to 150
-with FW and condensing economiser	92 to 95%	25-65

Combustion air preheating is economical. The assumed temperature of the air drawn is 20°C which can be raised by either ducting-in the hot air accumulated at the top, or drawing combustion air over or through the boiler casings. This can increase the overall efficiency by up to 2% (Steam and high temperature hot water boilers: Introducing energy saving opportunities for business (CTV052), n.d.; The Carbon Trust, 2012d; Action Energy, 2004a). The efficiency improvement is suggested in Energy calculation vi and Table 90.

Energy calculation vi)

$$If701kWh\ required\ to\ produce\ 1\ tonne\ of\ steam\ with\ 100\%\ efficiency\ then$$
$$855kWh\ are\ required\ to\ produce\ steam\ at\ 82\%\ efficiency$$
$$(as\ in\ Energy\ calculation\ i)$$
$$At\ 84\%\ (82+2)\ efficiency\ it\ will\ require\ 701\times\frac{1}{0.84}=835kWh$$

$$Therefore, total\ kWh\ saved = 855-835=20kWh$$
$Using\ consumption\ and\ steam\ production\ values\ from\ the$ Table 56, $we\ ge$t as show in the Table below

Table 90 - Savings for hot ambient air harnessing

Boilers	Energy saved (MWh)	Cost saved (£)	Carbon saved (tonne)
2	90	2,239	17
3	60	1,511	11
4	158	3,958	29
Total	308	7,708	57

Combustion efficiency determines how effectively the heat content of the fuel is transferred to the usable heat. Optimised through automatically controlled systems in modern boilers, optimum excess air supply ensures reduced heat loss through exhaust and minimum soot, smoke, and CO_2 formation. The burners on onsite boilers however were incorrectly adjusted when identified in boiler 4 and was rectified promptly. An often-stated rule-of-thumb is that boiler efficiency can be increased by 1% for each 15% reduction in excess air (U.S. DoE, 2012f). Boiler and burner management systems are available to control it. Oxygen trim systems are used to adjust the oxygen concentration. Reported to increase 1% boiler efficiency (U.S. EPA, 2010) these systems can be installed on a conventional combustion control system or can form an integral part of a digital control system. In combination with digital combustion control, and boiler and burner management system these can improve up to 5% efficiency (Action Energy, 2004a; The Carbon Trust, 2012d). The cost-saving calculations are indicated in Energy calculation vii and Table 91.

Energy calculation vii)

$$If\ 701\ kWh\ are\ required\ to\ produce\ 1tonne\ steam\ with\ 100\%\ efficiency\ then$$
$$855kWh\ \ are\ required\ to\ produce\ steam\ at\ 82\%\ efficiency\ \ (as\ shown\ in$$

$$Energy\ \ calcuation\ i)$$

$$At\ 87\%\ (82+5)\ efficiency\ it\ will\ require\ 701 \times \frac{1}{0.87} = 806kWh$$

$$Therfore, total\ kWh\ saved = 855 - 806 = 49kWh$$

$$Using\ gas\ consumption\ and\ steam\ production\ values\ from\ \text{Table 56}, we\ get\ as\ shown\ in\ \text{Table 91}$$

Table 91- Savings for installing oxygen trim systems

Boilers	Energy saved (MWh)	Cost saved (£)	Carbon saved (tonne)
2	216	5,405	40
3	146	3,646	27
4	382	9,555	71
Total	744	18,606	138

Automatic blowdown system can control TDS and support boilers' health reducing (manual/labour) cost. Better water softener and TDS control chemical regime facilitates 2% cost savings (The Carbon Trust, 2012d). The TDS system installation identified potential savings, calculations (assuming energy saving=cost saving) are shown in Table 92 as further explained in Section (a) of Appendix 1 (k).

Table 92 - Energy saving through blow down system management

Technology	Total consumption (MWh)	2% saving (kWh)*	4% saving (kWh)*	Cost saving for 2%(£)**	Cost saving for 4%(£)**	CO_2 saving for 2% (tonne)	CO_2 saving for 4% (tonne)
Boiler 2	3,761	75,211	150,422	1,880	3,761	14	28
Boiler 3	2,537	50,734	101,467	1,268	2,537	9	19
Boiler 4	6,647	132,943	265,887	3,324	6,647	25	49
Total	12,944	258,888	517,777	6,472	12,944	48	96

- *Derived from Table 56*
- **gas= £0.025/kWh*
- **(The Carbon Trust, 2012d)

From the blowdown steam heat can be recovered, the related energy saving can be up to 50% or 4% of the total energy cost (The Carbon Trust, 2012d) as shown in Table 92 and explained in Section (b) of Appendix 1 (k).

To maintain the turbulent regime, various shapes of turbulators (e.g. small metal baffles, spiral blades or coiled wire) are inserted normally in the last part into the fire tubes. As indicated in energy calculation viii and Table 93, they can increase efficiency by 1% (U.S. EPA, 2010). These are easy to install, with the supervision of a qualified installer, and maintain (Brock, n.d.). These are ideal for onsite, that have three tube passages, boilers.

Energy calculation viii)

$$If\ 701kWh\ required\ to\ produce\ 1tonne\ of\ steam\ \ with\ 100\%\ efficinecy\ then\ 85$$
$$required\ to\ produce\ steam\ at\ 82\%\ efficency\ (as\ shown\ in\ Energy\ calculation\ i)$$

$$At\ 83\%\ (82+1)\ \text{efficiency it will require}\ 701\times 1/0.83 =\ 845\text{kWh}$$
$$Therefore, total\ kWh\ saved\ = 855-845 =\ 10\text{kWh}$$

Table 93 - Savings for installing turbulators

Boilers	Energy saved (MWh)	Cost saved (£)	Carbon saved (tonne)
2	45	1,133	8
3	31	764	6
4	80	2,003	15
Total	156	3,901	29

Due to natural convection, a continuous heat transfer through the water and the boiler to the air infiltrating to the refractory happens. This escaping through the chimney is continuous regardless of whether the boiler is running or on stand-by. Flue gas shut-off dampers, which automatically operate in accordance with the boiler cycle, restrict such air escaping and can save up to 1% energy cost (The Carbon Trust, 2012d). These are easy to install/retrofit at the flue-gas exit or at the burner combustion-air fan inlet and are ideal for onsite boilers. Due to unavailability of exact total gas costs the savings are being indicated in terms of 1% energy savings, estimations are indicated in Table 93 with further discussions in Section (a) of Appendix 1 (j).

6.4.3 Steam using technologies

Requiring extensive steam/gas, the delicate and sensitive woolen products are susceptible to contaminants, needing extra care in wet finishing processes. The major steam users are building heating systems, dye pots (dye house), washing machines (wet finishing), and drying machines in the dry finishing area e.g. Decatiser and press machines. The washing machines use hot water at 40˚C. Considering the same temperature of the effluent, this energy can be recovered for reusing for the next fabric rinsing. The process control programmes on these machines, which can be from one hour to several hours long, are preset for individual product lines. In the case-study site, these have never been revised for many years for energy-saving purposes due to concerns towards the product quality. A thorough review of these programmes and test studies, if carried out, can at least justify the reason for carrying on the same practice, in case, if could not be made more energy-efficient. Some suggested saving measures are discussed below.

6.4.3.1 Operation and resource-saving

Steam persistently loses thermal energy to the materials and the mediums (like distribution pipes and valves). These losses (conduction, convection, and radiation) are a state of the function of the outside environment. The system is also subject to other challenges (like leaks, insulation, proper pressure and condensate return, traps functioning, pressure control valves, and pumps, etc). Each of these topics needs individual attention and evaluation to pinpoint sound measures, some site-specific measures are indicated in Table 94.

Table 94 - Operation and resource related steam saving recommendations

No.	Measure/ recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment/ quote year	Payback (y)	Risks/Caution
1	Improve steam distribution system's maintenance and insulation	-	Opportunities for insulation and maintenance still exist	Reactive maintenance	Walk around/ O&M, detailed energy audit	As recommended in technology specific reports	Engineering principles	47	11,426	85	No general benchmarks available	unknown	none
2	Revise heating system operations and temperature settings e.g by 1˚C	-	8% heating costs can be reduced for each 1°C reduction	Heating is mostly managed through through BMS system. It can electronically be controlled	Walk around/ O&M, detailed energy audit	As recommended in technology specific reports	Engineering principles	179	5,362	33	None	0-months	Complaints of discomfort may be reported which can easily be addressed to
3	Consider revising dyeing programme e.g. reduce 10% use of hot water	-	Reducing the hot water use for the processes has been suggested in literature for energy and affluent charges	Dyeing programmes in the dye house are not revised. More advanced methods need to be identified	Walk around/ O&M, detailed energy audit	As recommended in technology specific reports	Engineering principles	20	588	4	Zero, if this is managed by the on-site staff	none	Dyeing process speicialist expert opinion may be needed to minimise risks
4	Consider, at least, 10% reduction in hot water use in the wet finishing processes	-	Reducing the hot water use for the processes has been suggested in literature for energy and affluent charges	The washing process mostly is based on the unrealistic operator's intuition. An informed revision of the programme is required	Walk around/ O&M, detailed energy audit	As recommended in technology specific reports	Engineering principles	100	3,002	19	Zero, if this is managed by the on-site staff	none	The products are sensitive and care must be taken to maintain the quality

Steam distribution system performance improvement is a convincing measure as, for example, controlling distribution system losses can reduce waste by 3%, shown in Energy calculation ix and Table 95 for the site.

Energy calculation ix)

$$If\ 701kWh\ required\ to\ proudce\ 1tonne\ of\ steam\ with\ 100\%\ efficiency\ then$$
$$855kWh\ are\ required\ to\ produce\ steam\ at\ 82\%\ efficnecy$$
$$\left(\begin{matrix} as\ shown\ in\ Energy \\ calculation\ i \end{matrix}\right)$$

$$At\ 85\%\ (82+3)\ efficiency\ it\ will\ require\ 701\times\frac{1}{0.85}=825kWh$$
$$Therefore, total\ kWh\ saved=855-825=30kWh$$
$$Using\ gas\ consumtpoin\ and\ steam\ production\ values\ from\ the\ \text{Table 56}, we\ get$$
$$as\ shown\ in\ \text{Table 95}$$

Table 95 - Savings for steam distribution system insulation

Boilers	Energy saved (MWh)	Cost saved (£)	Carbon saved (tonne)
2	133	3,320	25
3	90	2,239	17
4	235	5,868	43
Total	457	11,426	85

Building temperatures are generally set at higher/lower than standardised (like at the factory) values, resulting in compromising the user comfort or energy wastage. The suggested temperature, in general, is 16˚C–19˚C for light manual work and from 19˚C–21˚C for sedentary (CIBSE Guide B, 2005) or 18˚C in production and 21˚C in design areas. This can be reviewed for both energy saving and user comfort enhancements, as suggested in Energy calculation x.

Energy calculation x)

$$As\ cacluated\ in\ Section\ 6.2.2.4\ that\ total\ building\ heating\ thermal\ demand$$
$$(based\ on\ 7month\ winter\ period) is\ \frac{234{,}169kWh}{annum}$$
$$As\ 1^{\circ}\text{C reduction in thermostat can save upto 8\% energy,}$$
$$Therefore,\qquad saving\ will\ be=2{,}234{,}169\ (kWh)\times\frac{8}{100}=178{,}733(kWh)$$
$$Or\ £5{,}362\ (based\ on\ gas\ cost\ of\ \frac{£0.03}{kWh})$$

The dyeing technology and the recipes are over 15 years old therefore may require revising towards new efficient methods and materials. In fact, the periods such as dye-fixing for 6-hours, and the use of water may be reduced through experimenting. Such process and quality management and resource efficiency provisions can offer no-cost savings as estimated in Energy Calculation xi for dyeing house and in Energy Calculation xii for Wet finishing.

Energy Calculation xi)

$$\begin{gathered} Values\ for\ calculations\ are\ derived\ from\ \text{Table 59}\ and\ energy\ calculation\ ii\ it \\ is\ suggested\ to\ reduce \\ 10\%\ hot\ water\ use\ in\ the\ dyehouse \\ 10\%\ reduction\ in\ energy\ use\ equates\ to \\ Energy\ (kWh) = 19{,}603 \\ Cost\ (£) = {}^{588}/_{annum} \\ CO_2 = {}^{4\ tonne}/_{annum} \end{gathered}$$

A similar exercise could be applied on Wet finishing as well as shown below.

Energy Calculation xii)

$$\begin{gathered} Calcuations\ are\ based\ on\ the\ values\ established\ in\ \text{Table 60}\ and \\ energy\ caclualtion\ iii \\ It\ is\ suggested\ to\ reduce\ 10\%\ hot\ water\ use\ in\ Wet\ finishing \\ 10\%\ savings\ equates\ to \\ Energy\ (kWh) = 100{,}057 \\ Cost\ (£) = {}^{3{,}002}/_{annum} \\ CO_2 = 19 tonne/annum \end{gathered}$$

Additional actions, consisting of revising the dyeing programme and measures based on water use, can help to reduce costs in both departments.

- Steam pressure reduction can prevent a breakthrough, which improves the heat transfer efficiency in direct steam heating applications
- Temperature control sensors on these machines may be tested and calibrated to see if they are working correctly
- To save energy less number of hot washes or mixing two small batches has been recommended (U.S. DoE, 2012g). A trial and test method may be carried out
- Requiring a thorough assessment, insulating the dye pots is another (longer-term payback) measure.

6.4.3.2 Heat recovery opportunities

There may be many ways to realise heat recovery on site, as reported through an internal report to the factory (indicated in Appendix 1 (l)). Some of such measures shown in Table 96 are discussed.

Table 96 - Proposed heat recovery opportunities

No.	Measure/ recommendation	Scopes	Rationale	Onsite experience	Key audit type	Audit approach	Estimation basis	Energy saving (MWh)	Cost saving (£)	Carbon saving (T)	Investment/ quote year	Payback (y)	Risks/Caution
1	Install air-to-water waste heat recovery system		Hot air is emitted through the stack with a reduced dwell time in the chambers. The heat can be recovered with a heat recovery system	The stenter has a system installed for exhaust humidity level control. The system is not used for some reason				581	10,453	108	54,000 (2014)	5	Poor designing can result in very long payback
2	Install new heat recovery system for the wet finishing		Plate HE are efficient and robust for water/water installations in textile effluents	No WHR system exists in the area				1,000	30,017	185	Bespoke nature of installation	-	Poor designing can increase payback time. HE unit is subject to clogging thus a system that can be dismantled is requried
3	Install new waste heat recovery system for the dyeing pots only		Plate HE are efficient and robust for water/water installations in textile effluents	Existing HE unit is a welded tubular HE and is found to be clogged. The proposed heat exchanger can be dismantled, serviced, and cleaned				196	5,881	36	80,000 (2014)	14	According to the HE supplier company only one HE will be installed which may pose a risk of long down-times in the event of breakdown or servicing

Installing air-to-water heat recovery system on the stenter, as shown in Table 97, is further discussed in Section a) of Appendix 1 (g). Electricity cost saving is also calculated.

Table 97 - Savings for installing heat recovery system on the stenter

System capacity (kW)	Cost (£)*	Annual kWh saving (supplier)*	Annual kWh (theoretical saving =30%)**	Payback supplier	Annual saving (£)(theoretical)	Payback (theoretical)	CO_2 (theoretical (tonne))
270	53,571	968,760	581,256	3	10,413	5	108

**as claimed by the supplier*

*** in theory*

Where

Electricity	Annual maintenance
2,512	1,607

Additional annual cost(£)

Wet finishing as in Table 60 and energy calculation iii, offers promising heat recovery. The figures in Table 96 are from Table 60 (assuming that all process heat is available to recover and the maximum energy can be saved). Due to constraints such as design novelty for heat sources below 60°C, and the second law of thermodynamic-related heat losses, the savings will be less. Although substantial recovery is possible, more work will be required for pertinent decision making. Costs for pipe network for hot effluent separation, and probable disruptions in the production process must be included in payback evaluation criteria.

Installing a new (water-to-water) heat recovery system on the dyeing house effluent (from dyeing pots only, as they would not be consistent with the faulty, existing effluent heat recovery system) is also suggested. Utilising the same facility and the pipework for the hot effluent (new with relatively lower-cost) waste heat recovery unit was proposed, as calculated in Table 62.

6.5 Carbon assessment

The scopes 1, 2, and 3 for CO_2 accounting, (as in Figure 31), have been considered with limitations as discussed in Chapter 5. The data problems, where possible, were avoided by using secondary sources as indicated in Table 37. Some of them, estimated in Table 38 are further discussed in Table 98. Due to the constraints and data limitations, the CO_2 analysis was somewhat approximated to take an accounting snapshot. The carbon emissions for the total and associated emissions with a specifically selected product are discussed in sections below. The CO_2 factors (taken from Defra's annual publications) were utilised for corresponding years. The factors in some cases were applied to the data generated outside the UK. The whole exercise, however, calculates unit level (for both cumulative and specific-product related) CO_2 emissions based on annual (low-resolution) data. This portrays how energy audits can be helpful to identify, calculate, and improve on organisational performance indicators such as carbon accounting.

Table 98 - Footprint calculations limitations for the case-study site

Data availability and limitations	Sources
—Transportation (such as wool from various countries condensed in to China to be exported to the factories around the world, routes used, quantity of the wool purchased/sent to various buyers around the world, wool sent to the UK ports, transportation of the wool from UK ports to the storage warehouses, modes, methods, and quantities of wool sent from the storage spots to the end users).	Not practical due to data constraints.
—Sheep rearing emissions	Secondary data used.
—Waste of material during wool to yarn manufacturing.	No waste was assumed to take place.
—Wastewater.	Energy used and emissions associated to treat wastewater was utilised (secondary data).
—Freshwater.	Borehole water was extracted through electric pump onsite, utility water could not be included due to negligible amount as well as lack of data.
—Degreasing.	Secondary data used.
—Company cars.	Data for 2014 was made available.
—Company fleet.	Data for 2014 was made available.
—Liquid fuels.	Data for 2014 was made available.
—Raw materials for finishing (i.e. for scouring, buttons, and tags etc).	Not practical due to data constraints.
—Raw materials for Dye house (i.e. dyes, dye fixing agents, dye removing agents etc.)	Not practical due to data constraints.
—Wool.	The kilograms of yarn is considered to be the kg of wool/cashmere used.
—Goods processed internally and externally cannot be taken in to account.	Too complicated process.
—Total amount of the yarn used is utilised to avoid complication.	As yarn used in the factory is assumed to represent consumption for the year.
—It is difficult to comment on meters produced externally used their own yarn or were supplied by the factory as both or one could have happened. Therefore, materials used or energy used regarding this is a grey area.	As yarn used in the factory is assumed to represent consumption for the year.

6.5.1 Total footprint

In Table 99, scope 1 of natural gas-related carbon emissions shows a declining trend from 2011 to 2014. This is mainly due to the reduction in gas use over the years.

This may also be related to slight variations in the annual emission factors. The other data available for scope 1 was for LPG for forklifts and diesel for transit vans used on site. However, the retrieval of this data was only possible for 2014 (including most of scope 3, company cars, as well). The increased electricity emission in 2014 is in response to increased consumption in response to higher weekly working hours, as discussed above. It can also be slightly affected by the change in emission factors. Scope 3 mainly uses figures taken from the secondary data except for company cars. However, the factors used to calculate product/energy input/output are mainly derived from UK studies except for sheep rearing related CO_2 emissions. The total CO_2 emissions for 2014 takes account of various scopes but the value obtained is still lower than in 2011. This is due to multiple factors such as considerably reduced gas emissions, total production, the quantity of yarn used, and the factors included having trivial CO_2 contributions. The data collected for the footprint calculation could have been utilised to calculate the detailed SEC. However, fractional conversion to kWh for company cars could not be undertaken as the available data was in miles. Also, the kWh values for sheep rearing could not be established on solid grounds basis, hence no significant difference between pre-established SECs could be expected (as indicated in Table 44). However, the availability of annual wool used and the associated CO_2 emission estimations helped to take some of the upstream emission on board as well (limitations are discussed in 5.3.5.1). It also helped to quantify the specific article related to CO_2 emissions at unit levels, as discussed in the next section.

Table 99 - CO_2 emission trends over the years

Scopes	Type/acitvity	Tonne of CO_2			
		2011	2012	2013	2014
1	Natural gas on site	3,148	3,120	2,844	2,892
	LPG (liquified petroleum gas) on site	–	–	–	0.3
	Transit vans	–	–	–	3.2
2	Electricity	1,875	1,895	1,855	2,244
3	Company cars for executives	–	–	–	9.1
	Sheep rearing for wool 28.7 kg of CO_2/kg of wool	11,527	9,654	10,485	11,208
	Wool degreasing process (electricity)	45.4	38.7	40.7	48.3
	Wool degreasing process (gas)	59.5	49.8	53.8	57.8
	Wastewater treatment for wool degreasing (electricity)	0.5	0.4	0.4	0.5
	Wastewater treatment for wool degreasing (gas)	0.2	0.2	0.2	0.2
Total CO_2		16,655	14,759	15,279	16,463

6.5.2 Specific product CO_2 assessment

Based on the total specific product (WA000608) metres produced, as described in Section 5.3.5.2, data for the associated CO_2 footprint of the product is indicated in Table 100. Distinguishing between the cumulative and individual type of CO_2 units the

Table also calculates the CO_2 emissions for per unit invoiced for the specific article. The reduced total emission for WA000608 in 2014 is in response to reduced production of the article. It can be seen that despite higher production in 2014 (compared to 2012 and 2013) the average CO_2 emissions/metre for the article is lesser than 2011 and 2012. This is in response to the factors as discussed above. This could have been even less had the hours/production for the electricity-intensive departments not been increased for this year.

Table 100 - Specific product CO_2 footprint

Emission category	2011	2012	2013	2014
Total metres excluding WA000608 type	1,023,889	879,457	967,798	991,623
Total WA000608 metres	186,774	74,119	154,742	146,514
CO2 emitted (tonne) for total metres excluding WA000608	12,916	13,230	12,274	13,543
CO2 emitted (tonne) for total WA000608 metres	3,739	1,529	3,005	2,921
Cumulative CO2 emitted (kg) per metre of cloth	13.76	15.48	13.61	14.47
CO2 emitted (kg) per metre of cloth (excluding WA000608)	12.61	15.04	12.68	13.66
CO2 emitted (kg) per metre of cloth (WA000608 only)	20.02	20.63	19.42	19.93
*CO2 emitted (kg) per unit (scarf) of WA000608	5.00	5.16	4.85	4.98

**3-5 scarves are produced from 1metre of WA000608, averaging to 4/metre*

The slight increase in emission for the year (2014) would have been caused by more scope 3 data availability (as in Table 99). When we look at the quantity of wool/yarn used to produce these metres, as shown in Figure 96, the quantity used is less than in 2011 and 2013. It can be clearly seen that when we compare CO_2 emissions/metre (for both excluding WA000608 and cumulative metres) the emissions for WA000608 production are considerably higher. This can be associated with the quantity of wool used, apparently more, (as wool production in Table 43 have larger emissions) to produce one metre of the product. However, more electricity being used in 2014 had a notable impact on CO_2 emission increase. Some of this would have been cancelled out by the reduction in gas consumption and electricity savings through saving measures. The emissions, however, reduce considerably when the article is quantified in terms of units invoiced. It can be seen that CO_2 emission inventory is as complicated as the supply chain, as discussed in Chapters 4 and 5, in relation to data availability, emission reduction measures, and product-specific footprint. Also, some of the wool prepared for the article WA000608 is also used in other items as well.

It can be seen that these CO_2 emissions are significantly higher than the CO_2 emissions figures resulting from the SEC figures only, as indicated in Table 43. The key contributor to this emission uplift is the CO_2-e/kg wool production, as indicated in Section 2.3.2. These CO_2-e/kg wool figures, however, are based on the dominance of wool production over meat.

6.6 Conclusion

This chapter analysed various types of data mainly energy, cost, production/consumption, activity, and weather to understand energy consumption characteristics. Using this data at both low- and high-resolution provided results such as cost, the complexity of production processes and supply chain, the impact of key variables (such as weather, production, activity, and work load), and administration and management were derived. The key impact on daily energy use and possible measures to reduce this, mainly no-cost, were identified for cost and carbon saving.

Various energy analyses, based on energy efficiency and management techniques, showing the possibility of numerous energy-saving opportunities on site were reviewed. No-cost operations and technology management measures showed tangible savings when compared with the total baseline (21GWh) demand. Specifically, over the four years period, over 1GWh/annum gas reduction (from 17GWh to below 16GWh/annum, as in Table 43) was observed despite notable variations in onsite variables. Electricity demand reduction, for these measures however, was not significant and was only observable at the weekend graphs. Total electric demand, when compared with baseline (4.2GWh), was actually seen to rise. Key factors affecting this included weather and production seasonality, operations, and change in shift patterns. However, the demand remained between 4.2-4.5GWh.

Inter- and intra-system energy efficiency improvement suggestions considered various aspects of behaviour- and technology-change. Measured and or rated power baseline for specific system/technologies were used to determine the energy, cost, and carbon savings. A generalised estimation of the key suggested measures is indicated in Table 101. The 33% reduction on the total energy is promising to the possible savings in such environments.

Table 101 - Efficiency opportunities and saving benefits

Technology/end-use	Specific saving measure	Energy saving (MWh)	Cost saving (£)	CO_2 savings (tonne)
Air compressors	Repair air leaks	165	16,472	76
	Waste heat recovery	75	10,234	51
	Reduce system header pressure	2	1,648	8
Lighting	Exsiting flourescent tube replacment with T5 in yarn production	33	3,287	15
Electricity measures for gas using technologies	VSD on stenter blowers	81	8,073	37
	VSD on boilers cobumstion air fan	118	11,826	54
Gas user technologies	Stenter	235	6,591	47
	Boilers	4,217	105,428	778
Steam user technologies	Operations and resource saving	346	20,378	141
	Heat recovery opportunities	1,777	46,351	329
	Total	7,048	230,288	1,536
Savings % against base year		33	28	28

Red text indicates cumulative of all the possible measures for boilers

The whole exercise practically demonstrated that these behaviour- and technology-change measures were achievable, tailored to the site, and economically feasible with beneficial outcomes. Furthermore, the use of the described energy assessment approach in highlighting these measures has been comprehensively demonstrated. A review of performance indicators such as SEC and CO_2 footprint for the whole organisation and a specific product was also taken. This was to understand energy practice within the organisation and what could be achieved after implementing the recommended measures. The limitations associated with available data, scope, and the methodologies were clearly identified and suggestions to control them in the future were highlighted. Further details of the findings are discussed in the next chapter.

Chapter 7 − Discussion

In this study, an energy assessment procedure has been developed for a complicated manufacturing environment (leading to energy use, cost, and CO_2 emissions reduction). The coexisting impacts between various operational and administrative areas have been investigated through a series of different metrics (as discussed in Chapters 4, 5, and 6) for simplicity. Various energy measuring and monitoring tools and sources have been used to collate energy, operation, consumption, and production data. Within the scope of the thesis, results have been obtained through practical data analysis techniques as discussed in Chapter 2, 3, and 5 and demonstrated in Chapter 6. Having real-time energy consumption and analysing it against variables such as weather and production is one of the key outcomes in this thesis. This results in pinpointing more detailed energy efficiency areas and opportunities. However, as discussed in Section 2.2.5 each procedure (including survey, utility cost analysis, standard, detailed, and or macro/micro audits) has a specific scope and leads to particular findings. For example, the identified data within Section 6.1 (spanning up to the interface between utility cost analysis and standard audit analysis) offers utility and baseline energy analysis and highlights saving opportunities. However, the procedure/s have intrinsic limitations, such as only covering monthly to daily consumption, lacking consumption accountability of individual days and at the weekend, and does not reflect daily peak- and off-peak demands. To address some of these issues and carry out analysis in response to activity, an enhanced energy analysis (a detailed energy audit that is key to this thesis) based on high-resolution data analysis is suggested (Section 6.3). The H-H data has been used against key variables (such as production, activity, and weather as discussed in Sections 6.3 and 7.2.2) to establish and understand energy trends and patterns comprehensively. The method has been historically practical for energy enquiries (mainly electricity) in non-domestic buildings but has not been used for manufacturing environments in such a way. The thesis also suggests another novel analysis method, similar to that used for electricity, for the gas as well. The enhanced analysis helped to identify consumption aspects that were poorly defined/understood by the methods commonly used for standard energy analyses. Methods used for measuring/monitoring, for both demand and savings estimations, have been discussed in Sections 2.2.3.2, 2.5.1. The real-life example of assessing the practicality of such topics is demonstrated in this thesis. This is carried out by analysing the data (energy, activity, production, and weather) from the case-study site and by comprising the outcome (as in Section 7.2.1). The detailed energy analysis along with detailed efficiency opportunities at the technology level, can enhance the scope of the whole energy audit and hence the assessment process. Energy monitoring and data collection of key individual technology micro-audit process have also been carried out (as discussed in Section 6.2 and 6.4). The procedure, in addition to fortifying the idea of a detailed energy audit, also broadens the scope of the thesis. This is how energy saving opportunities that are not highlighted through other audit processes can be identified. Thus the exercise, utilising both top-down and bottom-up approaches, identifies energy use and saving opportunities at both whole system (case-study site) and technologies within that system. The key energy assessment determinations through this thesis are highlighted below:

- Total energy use
- Departmental electricity demand disaggregation
- Disaggregation of production and weather related thermal load at key end-use levels
- SEC kWh/unit and CO_2/unit of production
- Top-down and bottom-up energy and carbon consumption and savings estimation
- Low- and high-resolution data analysis for total and end-use demand estimation to compare contrasting and similar results to identify more suitable methods
- Indication of behaviour- and technology-change related measures
- Indication for savings investment, where possible, with payback periods
- Evaluation of textile upstream CO_2 emissions of the composite textile manufacturing site that is adaptable to similar sites

Limited assessment of movements of goods and materials outside the whole system boundaries was also carried out (for CO_2 evaluations only). However, it also suffered from some constraints, limiting the scope of the analyses, such as steady-state nameplate ratings, a limited number of intervals in a day, and spot and short-term monitoring discussed in Section 7.3 in detail. Other restraints and directions for future work are discussed in Section 7.3. Indicating the purpose, flow, and type of the analyses through various audit procedures carried out in Chapter 6, Table 102 contextualises the whole exercise. Following Table 102, Table 103, and Table 104 and the suggested methods and analyses an improved energy assessment program could be designed for complex manufacturing sites.

Table 102 - Audit procedure adapted for the case-study site

Top-down approach. Macro-audit (Walk-through/O&M and utility cost analysis leading to detailed energy audit, Sections 6.1, 6.3, and 6.5)				
Audit approach	No.	Energy/consumption measurement	Data approach/source obtained/generated	Identified key saving areas
Total energy	1	Monthly utility invoices	Actual/estimate/peak demands, CV values, and utility cost analysis	The need for actual/AMR readings, cost effective tariffs,low-resolution profiling, and actual gas historical profiling
	2	Main meter readings	Daily readings for gas, water, and effluent main- and sub-meters	
Demand disaggregation	3	Nameplate based	Inventory and rated power accounting of the whole system, technologies, and system categories	Identified high- and low-demand of departments, equipment, systems, and system categories
	4	H-H metered load based on peak- and off-peak times energy profiles	Using high-resolution data to estimate peak- and off-peak times and seasons loads	Energy profiling of weekday and weekend base and normal/abnormal loads. Behavioural and management changes to avoid waste
	5	H-H metered load based disaggregation in response to activities	Numerical demand figures based on increased/decreased activity points in 24 hours	Numerical estimation of peak, off-peak, production and weather related impact on energy demand and related saving possibilities. Departmental demand break-up enabling costing and comparability
	6	Observation based	Managers' estimation on total departmental water consumption	Heat recovery from wastewater. The importance of appropriate metering/calibration for certain energy management measures such as wet thermal processes
Total energy for SEC and CO_2 accounting	7	Monthly utility invoices based annual consumption	Actual invoices/daily readings	Savings measures identified through macro- and micro-audit
	8	Annual fuel consumption data	Actual invoices	Impact of such fuels on total consumption and emissions, the need to understand and implement efficiency measures through behavioural and technology change
	9	Annual raw materials consumption and metre production data	Production/consumption data produced on-site	Accounting procedure related steps. Evaluation of SEC and CO_2 emissions leading to appraising and appreciating measures that can help to reduce them
	10	Secondary production, consumption, waste, and other data sources and emission factors	Related data produced elsewhere for calculation estimations	Accounting procedure related steps. Realisation of up-stream steps and energy involved in generation of raw materials and the need to use them sparingly
Audit outcome	11	Housekeeping (maintenance department)	Identified leaks, insulation, and building fabric issues. Energy saving communication, scrutiny, and leadership and technology maintenance procedures reviewed/instigated	Improvement methods suggested and implemented. Saving estimations were made using demand disaggregation methods, as above
	12	Housekeeping (production departments involvement)	Usage of small power and IT equipment, draught prevention, building temperataures revising, energy saving communication, scrutiny, and leadership	Improvement methods suggested and implemented. Saving estimations were made using demand disaggregation methods, as above
	13	Organisational initiatives	Funding for efficient IT equipment, lighting, considering to buy efficient new/replacement technology, energy ideas gift scheme, rolling out of energy efficiency awareness, evaluation, appreciation, and support to the audit process and the outcome	All of the improvements identified and suggested periodically inspected, appreciated, and backed-up for continuous improvement

Audit outcome	14	CO_2 reduction evaluation through renewable resources	Reviewing of energy mix and possibility of low-carbon and RE generation through various technology installations suitable for the site	Solar photovoltaics, wind turbines, CHP in relation to wood fuel, and small hydro-power were (some of which were superficially)evaluated (some through micro-audit). Solar PV were suggested to reduce electricity related CO_2 emissions
Bottom-up approach. Micro-audit (standard- and detailed-energy audit using macro-audit as foundational, Sections 6.2 and 6.4)				
Measurement based	15	Compressed air	Hourly monitoring/clamp-on meter/short-term (cross-checked with nameplate ratings)	Management through maintenance department, electronic control management, system pressure reduction, house-keeping at the end-use, heat recovery)
	16	Yarn production tech	Intrusive digital electrical meter/spot measuring (cross-checked with nameplate ratings)	Component change/installation
	17	Weaving technology	Non-intrusive digital electrical meter/spot measuring	Not fully evaluted however helped to estimate the department's key technology's total load
Meter based	18	Boilers	Sub-meters/long-term/low-resolution (cross- checked with main meter)	Operations management through maintenance department, electronic control management, house-keeping at the end-use, component change/installation, heat recovery, reduce heat loss such as blow down and insulation, energy used for HVAC
	19	Indirect metering for boilers with no meters	Using data from sub-meters (cross-checked with main meter)	
Engineering principles and rules of thumb based	20	Thermodynamic principles for heat loss/gain/phase change. Rule of thumb based leaks/losses	Borehole water used/steam produced/ steam used for building heating, waste hot effluents (water & gas), heat loss, air leaks, (thermodynamic equations used)	Heat recovery, heat waste/insulation control, air leaks control, house-keeping at the end-use, and reduction in fresh water usage
Nameplate based	21	Stenter gas	Thermodynamic equations used (cross-checked with main gas meter)	Operations management through maintenance department, electronic control management, behaviour at the end-use, component change/installation, heat recovery, reduce heat loss
	22	Motors on stenter and boilers	Nameplate ratings with simple maths calculations	Component change/installation
	23	Lighting		Operations management through maintenance department, electronic control management, house-keeping at the end-use, component change/installation
	24	IT		Phase-based replacemenet of old less efficient devices with new more efficient ones
Audit outcome	25	Organisational initiatives	Funding and support for behavioural measures, departments, sections, and individuals. Provided funding for low-cost projects. Funding for various high-cost energy recovery technologies granted (such as heat recovery in boiler house and dye house)	Various behavioural and no- to low-cost measures were implemented. Some suggestions were postponed till the funding becomes available in future
	26	Individual technology	Saving measures and investment proposed for various technologies	Discussed in details in sections 6.2-6.4
	27	Others	Technology/component quotes, specific types of audits/surveys by external organisations, manufacturers' demand and saving estimations	Cost and payback realisation, technology/component efficiency understanding, contribution towards audits/assessments

7.1 Site-specific findings

Analysing various technologies/areas/systems Chapter 6 estimates numerical demand and savings through no- low- and medium- to high-cost measures along with the payback indications (where possible). The exercise results in energy and carbon emission evaluation of both textile-specific and crosscutting industrial technologies. Table 103 (as defined in Section 2.2.2) discusses the technical and O&M (behaviour/good housekeeping) related energy efficiency following the organisational energy format structured in Chapter 3. The Table indicates key points/audit scopes used in Table 102 to recognise the importance of their use and interdependency, in the whole assessment. Due to issues of data availability (and time), it was not possible to include all the technologies/areas (as described in Section 4.3.1 and Chapter 5) or cover all the aspects of several chosen technologies/areas (as discussed below in Section 7.3). However, the approach described and demonstrated could be applied to other specific technologies in other sites (in part or full) with improved and informed choice. It can be seen that despite a complicated manufacturing process and supply chain, a flexible and effective auditing process can be designed. This also showed that a range of likely efficiency (behavior-change and technology-change) opportunities (from no-, low- and medium- to high-cost measures) for the textile or any such industry exist, some discussed below and in Section 7.2.2.

Table 103 - Key audits types and onsite energy consumption areas

Action area	no.	Equipment/topic	Key direct and indirect contributing audit assessments
Equipment	i	Stenter	20−24
	ii	Boilers	20—22,24, and 29
	iii	Heat exchangers	6, 22, 29
Utility	iv	Compressed air	3, 17
	v	Steam distribution and end-use demand	20—22, and 29
	vi	HVAC	21—22, and 29
	vii	Lighting	14, 15, 25, and 29
	viii	IT	14, 15, 26, and 29
	ix	Other building services	3, 13, 14, 15, and 22
Enablers	x	Motors and pumps	3, 13, and 24
Behaviour change	xi	Management and staff	14, 15, 27, and 28
	xii	Maintenance	supervising and implementing 1-29
Performance indicators	xiii	CO_2	9—12
	xiv	SEC	9—11
Miscellaneous	xv	General	1—6, 13—16, 19, 27—29
Energy and carbon assessment	xvi	Energy profiling and saving	1—29

Key direct and indirect assessments are derived from Table 102

Roman numerals refer to individual technologies and their limitations as discussed in Table 104 below

Behaviour change options included:

- O&M (production side): material used/produced, batches/loads, shift patterns, overtime (not fully explored)
- O&M (technology side): weekend boilers and CA use, other appliances and machines running at the weekends, and pressure reduction in air compressors
- Energy behaviour change, management, and awareness-raising: switch-off when not needed, energy efficiency delivery at leadership levels, saving actions and expectations from the organisation-wide various levels of the staff, responsibility and interaction of maintenance staff to communicate and deliver actions and saving strategies, staff satisfaction, uniformity, and agreement on built environment conditions such as temperature and lighting levels
- Maintenance and repair: responding to energy waste events, air leaks, air and liquid filter changing, lubricating oil replenishment/changing, etc.

Technology change options included:

- Component/feature optimisation: exhaust air flow reduction on stenter, electronically time-controlled air compressors at the weekends
- Component replacement: oxygen trimming system enabled burners in boilers, and assessing and enabling features of existing exhaust air humidity sensing and controlling software
- New component installation: turbulators in boilers, automatic blow-down system, and blowdown heat recovery system
- New system/technology installation: LED lighting, T5 trip-hosphor lighting systems to replace T12
- Recovering waste energy (heat): heat exchangers for heat recovery in the dye house, economiser in the boiler house

7.2 Project-specific findings

7.2.1 Comparison of different auditing routes

The possibility to compare/crosscheck results obtained through different audit approaches helped to support the proposed saving measures and improved energy investment decision-making. Based on existing auditing methods and approaches, the exercise allows multiple aspects described and compared to highlight contrasts. It provides a more robust basis for auditors, energy assessors, and energy managers to choose energy-saving options in complex manufacturing environments. Errors, cautions, and strengths and weaknesses of each step are highlighted in a meaningful way. For example, the estimation of total electric load based on nameplate rating is 1,472kW (from Figure 97). When individual departmental loads (excluding miscellaneous) were multiplied with activity hours (in Table 67) the total annual consumption is significantly higher (4,905MWh) than the actual consumption (4,147MWh). However, the nameplate based gas calculations for the stenter matched with indirect metering method based estimate. This does not mean that this method is good for gas or bad for electricity but depends on various factors, particularly the extent to which equipment is run at part-load. Accuracy of activity intensity and hours, and batch-load variation (for example motor efficiency significantly varies with load change), and the presence of energy-saving components such as VSD on the technologies all contribute to such disagreements in energy use. Another factor is that the electricity estimation concludes a large number and variety of types of machines and systems (hence the error is intensified) compared to the stenter only. For example a large number of technologies, having enablers (air compressors, weaving and spinning machines), have inbuilt VSDs for load savings whereas the lighting systems would have a constant demand. Some technologies with inbuilt VSDs, when monitored and spot-checked, had loads that were significantly less than the rated power (as indicated in Table 54). These problems can be more intense and pronounced in a complicated manufacturing industry. Therefore, the requirement of more detailed and robust audits (unlike quick-fix or general standard audits in Chapter 5) like this is convincing for a rational assessment approach, if true savings justification is the criteria.

The analysis of measured data (as in Table 67) estimates the total annual consumption (4,317MWh) quite close to the actual (4,148MWh). However, for the departmental loads disaggregation (in Table 67) this is significantly different (specifically for Yarn production and Finishing) than the nameplate ratings (Figure 97). This could be mainly due to factors affecting as discussed in the paragraph above. The similar baseload in both cases can be due to reduced variation in activity and load, and total hours. For the nameplate rating based cumulative demand estimation of individual equipment category (Figure 98 (A)), the total becomes more than twice the actual. Despite the calculation considering the utilsation factor of individual machine/system/component, the error is even higher. The importance of measuring/monitoring loads of machines/systems/departments for the error reduction is clear (however upholding suitable load and utilisation factors). Relying on the nameplate rating is, however, inevitable and suitable in the absence of measured data. The measurement-based method reduced the error significantly, but the exercise has clearly indicated the need to have a good understanding of the duration and intensity of activity.

7.2.2 Assessment framework

In Chapter 2, defining borderlines between audit types, some experts suggest that a standard energy audit encompasses walkthrough (O&M) and utility cost analysis, whereas others propose detailed energy audits come even after this. Another distinction is the physical extent of the survey, specifically the macro- versus the micro-audit. This thesis utilised both types to contextualise the whole exercise. The audit procedure, building upon walkthrough survey and cost-benefit analysis, was transformed into a standard energy audit. This, for example, utilises nameplate ratings and generalised activity hours to determine the demand/savings. The standard energy audit in terms of physical extent is equivalent to a macro-audit. The audit then led to micro-audit, which helped to delineate project borderlines, identifying key technologies/systems for enhanced individual studies through available resources time constraints (as in Table 102). The micro-audit approach involved monitoring and using photo and intrusive meters. This enabled the comparison of measured data with the other types such as monitored (H-H), and nameplate ratings (as in Section 7.2.1). This approach enhanced the project scope to a level that the standard energy audit may not cover. Additionally, the creative use of H-H data against the activity (as in Section 7.2.4) is another such scope-enhancing aspect leading towards the detailed energy audit. Hence, in terms of audit types, the project is suggested to be defined as a detailed energy audit.

O&M and technological change measures, depending on the nature of the business, can significantly help to increase energy efficiency (as discussed in Section 2.2.2). These strategies mostly inherit a mixture of qualitative and quantitative aspects. Behavioural change strategies, for example, can consist of equipment maintenance, and state of quality of the user experience such as a change in building illuminance/temperature levels. The saving impact of these measures, though difficult to measure at individual action/s or measurement level, is a well-examined approach towards energy saving. Often, the savings made are collectively (difference in total utility invoices) traceable. The measures also account for the quantity of devices needed, such as using two boilers instead of three, or using reduced/induced number of luminaires to control luminosity/energy use. Unlike the qualitative measures, the tested empirical efficacy indications of the technological strategies are available in the form of various energy efficiency studies/principles/manufacturer guides. Many of these provide estimates of savings (e.g. percentage reduction) for explicit technology/measure/component measures. Compared to qualitative behavioural measures, these can be more helpful for energy investment decision making. In reality however, it is observed that these estimates for technological changes are not always accurate. This is due to several reasons, such as lack of understanding of the activity, operations schedules, working environment, and the way machines operate (mainly housekeeping) as established in Section 7.2.1. This has practically been observed on site through an external audit, as discussed in Chapter 5. Another contributing factor is the lack of knowledge about the technology-specific energy efficiency. There are many such occurrences in the textile industry and therefore, this study has been designed with the help of a particularly relevant case study.

It is known that behavioural measures are very much related to the energy environment (such as housekeeping) of the organisation. In reality, qualitative measures can significantly dictate the quantitative measures in many ways. For example, running equipment (such as a motor) that undertook a component change (VSD installed) as usual will still save some energy, compared to a pre-retrofit. However shutting it down, by making justified arrangements, will be an even more appropriate measure for both pre- and post-retrofit scenarios. Implementing (one or both) these measure/s appropriately is only possible by studying and analysing the individual systems' inputs and outputs and service/delivery requirements. Estimating the benefit of different scenarios of each measure is crucial for organisations pursuing energy efficiency at proven cost-effectiveness. This underlines the importance of the whole exercise of energy audits/surveys for the project. Only such assessments can result in conclusive site/system-specific energy savings and efficiency improvements. This understanding is now clearly demonstrated through the analysis of the case-study site and components in Chapter 6 and through pre-established findings as in Chapters 2 and 3. Therefore, it can be suggested that the study encompassed a complete energy investigatory assessment for textile and associated manufacturing industry.

7.2.3 Performance indicators

The importance of establishing and communicating performance indicators for specific activities such as textile manufacturing is equally important for the regulators and the industry stakeholders. The established indicators are recycled by the researchers and regulators for reasonable compliance setups/goals/suggestions keeping green-conscious stakeholders informed towards their business activities. Having various forms of performance indicators and benchmarks for a textile encourages energy efficiency in the sector. General performance benchmarks for the UK textile manufacturing buildings for lighting intensity, and heating temperatures in industrial buildings as discussed above have been published. These, however, are more about the improvement of the buildings users' experience and environment. Availability of UK textile fabric manufacturing-related benchmarks at various levels of textile classification in terms of type (natural/artificial fibre), nature of use (upholstery/knitwear/footwear/clothing), unit of production (per kg/metre/unit of production such as scarf/shawl/throw), and process (weaving/finishing/dyeing) is valuable. This makes the scope of performance assessment for the auditors and the manufacturers clearer and easier to carry out, when the auditing guidelines are available. The performance indicators such as SEC and carbon emissions are widely accepted and assessed. Both benchmarks for the UK (mainly per metre) for any type of textile (specifically for woolen/metre) fabric have not been recently established/suggested in current research. Producing some UK-based SEC and CO_2 indicative figures for woolen textile with appropriately-defined reservations (as mentioned in Chapter 5 and Section 6.5) is essential. This work is informing, convincing, and contributing to these communities to produce such industrial benchmarks. In addition to contributing to the research community, this study designs an appropriate CO_2 calculation method for textile fabric manufacturing industry. This is followed by the guidelines specified by the specialist government and industrial organisations. The SEC evaluation is based on a well-established method for specific energy investigation. However, some challenges such as SEC and CO_2 estimations for individual processes are desirable for future works.

In addition to that, composite textile general end-use energy from an international perspective was available (Figure 17) and could have been compared for an idea. Unfortunately, the percentage available for both gas and electric fuels were different in end-use format. In addition to that, large discrepancies such as no building thermal/cooling load, detail of technology, production format and other factors were existed for comparison and discussion.

Annual energy use per unit area (m^{-2}) of the factory was compared with CIBSE's textile energy benchmarks. Although, the comparison was interesting with comparable discrepancies but whole exercise once again indicated the need of clear identification of the scope and boundary of energy studies. This, as discussed in Section 6.1, would have been a great opportunity for a true comparison had unclear shift patterns been defined clearly.

7.2.4 Approach to energy data analysis

It can be seen that the assessment approaches (discussed in Sections 7.1, and 7.2.1 and 2) generated and analysed data, and pinpointed various aspects of further data analyses (as carried out in Chapter 6 and section 7.2.1). The analyses, enquiries, and approaches (discussed in Chapters 5 and 6, and Sections 7.2.1 and 2) are based on and developed from well-established methods (as discussed in Chapter 2), though the thesis-specific queries and the way they are used are unique to this study. Using real-time energy consumption and analysing it against variables such as activity, weather, and production is one of the key outcomes in this thesis, using this information to highlight energy efficiency opportunities. The method is reliable as historically it has been used for various energy enquires (in buildings such as schools, offices, local governments, and supermarkets) by researchers, though this study adapts it for shift patterns that will be particularly useful for manufacturing industries. It can be utilised for both electricity and gas H-H data (as long as the activity can be distinguished). Previous examples of similar applications elsewhere generally include energy profiling and seasonal separation for trends and patterns, and demand variation in response to 24-hour occupancy for energy saving. The contributing investigations based on H-H data analysis in this thesis have various aspects as described below:

I. Identify energy waste/saving measures
II. Understanding demand variation in response to 24-hour production activity
III. Disaggregation of baseload and departmental demand (depending upon the distinction between time and nature of activity) at various seasons levels
IV. Based on (iii), estimating annual/periodic baseload and departmental demands

V. Estimating savings and comparing (pre- and post- measure/retrofit) them specifically in response to behavioural and qualitative measures in an industrial setting

The method is low-cost to carry out as does not require expensive software subscription and is easy to adapt to (as almost little or no training is required, for example, on MS Excel). This is important as such assessments should be part of long-term energy management within an organisation (rather than via external consultants) to maximise their effectiveness. The method is therefore highly suitable for SMEs due to intrinsic weaknesses and barriers towards energy studies and efficiency as discussed in Chapter 2.

7.2.5 Manufacturing industry assessments

The whole energy assessment process has been used over a vertically integrated and composite textile industry (a rare occurrence in complicated textile supply chain globally). The project design, application, and analysis have remained focused on site, but the investigation has identified clear energy estimation gaps across the complicated supply chain. These involved gaps from the suppliers of various manufacturing processes and services (such as weaving, dyeing, finishing, and sub-processes) as in Section 6.2.4. Estimating UK specific energy for each of these unit processes can be helpful in many ways and can lead to assessing the SEC and CO_2 indicators for discrete processes. The transportation involving the movements of semi-manufactured and semi-finished materials is also an area of concern, as identified in Sections 5.4.3 and 6.5. These are suggested as areas for future study in Section 7.3.

Looking at the production processes and the technology used, the assessment carried out through the project is specifically beneficial to the textile and associated manufacturing industry. The energy assessment approach applied using varied auditing tools such as nameplate ratings and micro-audits can be applied to all types (mainly non-domestic) of buildings. The individual technology/system assessment and specific energy saving measures observed (as in Chapters 3, and 6) can be utilised by industries/buildings using such equipment (for example air compressors, boilers) as indicated in Table 102 and Table 103.

7.3 Limitations and future work

The broad limitations related to time and resource (metering, equipment-hire, intrusive monitoring) availability have already been discussed in Chapter 5. Key limitations for demand-side assessment in general were nameplate ratings, inability to indicate the average number of staff per shift, number of process technology in use (activity), production units active at a certain time-period, utilisation factor, and assumed steady-state conditions for loads, and departmental hours. Ideally, these could have been improved with real-time load, activity, and hours' data. These limitations equally impacted the saving-side calculations and improved results could have been produced if the recommended measures had been implemented and monitored. The individual-technology assessment-related methods and procedures adapted and the limitations in the thesis are discussed in Table 104 below. However, some of these limitations are merely a consequence of using a real, in-use, case-study.

Specific technology metering, measuring, and monitoring related reservations are discussed in Table 104 in detail. This is designed to suggest more detailed investigations of similar technology/project works in the future. In terms of the process, the project proposes a further investigation into embedded energy at various manufacturing processes (i.e. dyeing, weaving) and services (i.e. transportation, storage) levels. In addition to nameplate ratings reservations (as in Table 104**)** the methods chosen for energy data analysis also suffered from other shortfalls, for example, the H-H data analysis. Due to unavailability of high-resolution (weekly/daily) production data (both total and individual process level), it was not possible to develop production and consumption relationship at daily/weekly periods. This would have helped to understand the in-depth relationship between production and energy, along with energy-saving avenues informed by that. The number of hours worked were indicative, though the detail on the magnitude of work and variation in workload was not known. In terms of project-related limitations, these included options used for standard (such as engineering and observations based methods instead of measuring/monitoring) and detailed energy audit (such as spot and short-term monitoring compared to long-term ones) as discussed in Table 102. End-use of steam technologies could not be addressed. The project scope also meant that areas like resource efficiency and production management (such as batch sizes for various processes, and process design options) were not included. These, if fully accounted for, could have given a different insight to the project. Due to the site being the manufacturing industry, it was not possible to use improved methods to clearly distinguish between building heating and thermal processes' energy demand. This was due to the project scope being more focused towards process energy. The project also had some investigatory limitations such as availability of upstream secondary energy/carbon data, (such as external dyeing and finishing). This consequently affected the overall SEC and CO_2 results.

Of note, having most of the end-use and production rates metered at a detailed level is potentially beneficial. However, one should not ignore the emerging challenges of designing new analytical techniques for tasks overloaded with such data; large datasets require more processing before any clear message can be delivered to an end-user of that data. In addition to that, meter and sub-meter installation should be carefully designed. This can be learnt through an example from the case-study site. Onsite temperature measurement can be even more useful for building cooling/heating load evaluations. Although the case-study factory had a thermostat centrally installed at the factory, unfortunately it was too close to the boiler house to provide reliable temperature data.

The suggested method did exhibit some limitations such as inability to indicate the average number of staff per shift, number of process technology in use, production units active at a certain time period, and utilisation factor. Having details available of such metrics and analysing each of the metrics individually can make the analyses even better (Chapter 5).

These documented limitations addressed above also act as things to consider for the research community and auditors when carrying out similar energy audit/assessment projects in the future.

Table 104 - Demand and savings side limitations/improvement opportunities (future work)

no.	Equipment name	A	B	C	D
		Demand-side energy assessment, presumptions, and limitations	Ideal/suggestive assessment	Saving assessment presumptions and limitations	Ideal/suggestive assessment
i	Stenter	1) auxiliary equipment and burner performance is not assessed. 2) nameplate rating is used. 3) air flow rate method is very basic.	1 and 2) auxiliary equipment be individually assessed. serviced regularly, testing for burner efficiency unknown. 3) metering and measuring for certainity.	1) nameplate demand cross checked with indirect metering. 2) VSD saving as in A of xi. 3) heat recovery assessment by maker using hours and nameplate rating.	1 & 2) using transient state analysis, assessing indiviudal equipment. 3) as suggested in B and row i in point 3.
ii	Boilers	1) only two boilers monitored. 2) water usage used to estimate gas usage. 3) steam estimated through engineering principles. 4) seasonal load variation based on metering. 5) suggestions for operation and burner automisation based on measured and estimated data.	long-term monitoring of boilers, fuel and water use, steam production, with high-resolution data for gas and water use and steam production.	1) steady-state demands & engineering principles. 2) all the seasons as the same for the year. 3) rules of thumb and engineering principles were used.	1) as referred in B of ii. Apply suggestions in C-D of xi.
iii	Heat exchangers	1) waste thermal energy disaggregation based on estimations and observations backed with some measured data at various end uses.	measured quantity of effluents (gas and water) is required first.	1) engineering principles and steady-state conditions were used to calculate heat recovery potential.	1) measured quantity of effluents (gas and water) is desirable.
iv	Compressed air	1) short-term monitoring. 2) auxiliary equipment assessment. 3) evolutionary distribution related pressure loss. 4) poor zonal/departmental supply control. 5) changing header pressure. 6) waste heat recovery poorly understood.	1) long-term monitoring. 2) storage vessels and dehumidification assessment required. 3) distribution system assessment will help to adjust end-use pressure. 4 and 5) need departmental controlling and zoning. 6) see row iii and v.	1) points 1 and 3 of column C and row ii. 2) weekend shutdown not possible to avoid condensation.	1) accurate measurements or engineering principles will increase saving certainty. 2) periodic running at weekends suggested.
v	Steam distribution and end-use demand	1) steam production estimated through gas used. a rough disaggregation made through observations. 2) revising wet thermal programmes and water use and system insulation was based on engineering principles and knowledgebase.	1) steam metering required. steam pressure and flow rates can be used for a very rought estimation but the end-use estimation of individual technology will require a detailed energy modelling/metering.	1) points 1 and 3 of column C and row ii. 2) it is not possible to estimate behavioural measures related savings.	1) measuring at least at departmental level before and after the saving measures are implemented.
vi	HVAC	1) engineering principles used for heating load. 2) balancing heat in buildings subject to over-heating. 3) building cooling load in summer was not assessed.	1, and 2) assessing detailed heating loads is helpful. measured data reduces using engineering principles with improved estimation. 3) cooling load evaluation is helpful where air-conditioning systems are used.	1) engineering principles and the available knowledgebase used for heating associated savings.	1) measuring steam for building heating, pre- and post-implementation of saving measures.
vii	Lighting	1) a case-study building used for example. 2) energy demand was based on nameplate rating. 3) lighting distribution software assessment could not be used.	1, 2, and 3) assessment based on nameplate rating is relatively straightforward. the use of software can reduce uncertainty and ambiguity.	1) savings were based on nameplate rating.	1) savings based on illuminance improvement evaluated through lighting software.

viii	IT	1) generalised nameplate rating was used. 2) steady-state conditions assumed despite most of the equipment was energy star enabled.	1 and 2) such assessment is easier way to handle IT energy demand in a complicated site. monitored data will reduce uncertainty.	1) old inefficient equipment are periodically being phased out. this is based on nameplate ratings.	1) transient state analysis is more powerful for correct estimation.
ix	Other building services	1) fridges, hot water dispensers, cookers, and vending machines were ignored.	1) observable in the weekend baseload demand however is overridden by others such as motors on boilers.	1) savings through switching off has been observed during factory holidays.	1) classifying categorical demand through metering and monitoring clarify things.
x	Motors and pumps	0.8% efficiency was assumed for calculations. 2) only identified motors in technologies were addressed.	2) some technologies that were ignored might have more savings to offer.	1) motors efficiency was assumed generally improve with VSD.	1) VSD measure have many factors thus individual technology assessment is needed.
xi	Management and staff	1) awareness raising, departmental representatives, gift schemes, and involvement of company's higher hierarchy. energy saving action schemes like checklists, and energy loss/waste communication/reporting.	1) need consistency in communicating and feedback. auditable central system. require person/s responsible for recording and mending leaks and generate saving reports.	1) savings based on communal actions and shutdowns, cannot be measured.	1) point 1 of D and viii.
xii	Maintenance	1) equipment operations management and operations control 2) energy saving/loss communication/reporting 3) repairing leaks and losses promptly.	1) automation of operations control. 2 and 3) auditable central system with person/s responsible for recording and mending leaks and generate saving reports.	1) being responsible for maintenance assumes all the points of column C for every technology.	1) being responsible for maintenance assumes all the points of D for every technology.
xiii	CO_2	1) annual figures were produced, product specific emissions generated. 2) suppliers were assumed to be equally carbon intensive. 3) transport of the materials could not be accounted for.	1,2, and3) detailed input of the energy contributors desired for on- and off-site processes, transportation emissions, raw material production figures at least at the sourcing levels could have been made.	1) identified that all the energy saving measures can help to reduce emissions/intensity. activity and rate of production can significantly affect.	1) indicated savings/reduction in intensity after energy saving measures were implemented.
xiv	SEC	1) organisational and 2014 extra organisational SEC was calculated to see the impacts of operations outside of the factory.	1) SEC at individual process completion/semi-finished product-level such as dyed wool, yarn, woven meter.	1) n C of xv.	1) D of xv.
xv	Energy profiling	1) h-h data for gas and electricity but not for activity and production. 2) h-h data for boiler and stenter and for the steam was not available.	1) h-h data for energy, activity, and production facilitates detailed analysis. 2) individual equipment h-h gas data can make analysis more sensible.	1) helped to identify consumption before saving measures implemented.	1) helped to estimate savings after the saving measures were implemented.

Columns A-D are denoted as letters only for brevity

Rows i-xv are denoted as numbers only for brevity

Chapter – 8 CONCLUSION

This thesis demonstrates a comprehensive energy and carbon assessment procedure which is developed by combining various energy assessment methods. The procedure has been validated through implementation on a complicated manufacturing case-study site. Energy demand assessment and saving strategies, designed at various levels, utilise detailed energy audit and survey tools. The theoretical and practical methods used are replicable and semi-empirical and are based on data (measured/assumed), engineering principles, rules of thumb, and observations and assumptions. This is combined with more powerful evaluation methods such as analysing high-resolution energy data to demonstrate demand pre- and post-savings for sites with poor metering. In addition to pre-retrofitting total organisational CO_2 footprint accounting, individual technology-level post-retrofitting energy and CO_2 savings were also estimated. The methodology adapted to calculate scopes 1, 2, and 3 was derived from Defra, PAS-2050 and -2395, and GHG protocol methods.

The robust auditing method presented is adaptable to various manufacturing SMEs, specifically for textile and similar industries. Discussing in detail, Chapter 2 indicated the global and regional energy use with specific relation to industrial sectors. It further discussed the complexity of types and methods used for performance-based energy assessments. Chapter 3 reviewed energy efficiency promoting behaviour- and key technology-change related measures and strategies. The literature review Chapters also signified the current practices and measures used for energy quantification and performance indicators like carbon emissions and SEC. Introduction to the case-study site was presented in Chapter 4. In light of current and established practices, Chapter 5 presented the designed methodology that was suitable to address the challenges and the scope of the case-study site. In the later Chapters various aspects of the identified measures were applied onsite to interrogate and design strategies for possible cost, energy, and carbon savings.

8.1 Research outcome

- The study clearly demonstrates that energy savings in the manufacturing industry (large-size SME in this case) can be maximised through appropriately designed energy assessment programmes. Barriers to achieving this include reduced sectoral initiative and attention (from policy and industry), small number of similar energy studies, lack of awareness and relevant expertise, and sites being more production orientated. A better energy audit scoping with specifically designed methods helped to identify various (technology-change) saving opportunities from utilities, energy delivery network, end-use technologies, and wasteful practices (behaviour-change). Only key technologies were selected, for example, boilers and CA systems, showing no- to medium-cost saving opportunities as calculated in Section 6.4. Thus, as such design and scoping of these audits can help make the groundwork for a range of enquiries, as discussed in points I and IV in Section 1.3. For example, the energy audit carried out onsite was also used to assist in implementations of the ISO-140001 environmental management standard and ESOS-2014 energy efficiency scheme

- Quick and non-exhaustive H-H data-based energy assessments are possible even for manufacturing, as raised in point II in section 1.3. Using this data along with information relating to weather, activity, and production seasons identifying energy trends and patterns along with numerical weekday demands, daily demands at peak and off-peak periods, departmental demand disaggregation, impact of production and weather seasons, and future demand prediction, can facilitate detailed energy assessments even for sites with poor energy metering practices. However, site-specific approaches need tailoring which are fundamentally based on empirical data. This is to establish and distinguish various demand sub-categories for a comprehensive energy analysis and understanding.
- The study clearly demonstrates that textile energy is site-specific, as discussed in point II in Section 1.3 which is further discussed in the next paragraph. Therefore, individual sites need to be individually assessed for tailored energy saving advice. The case study site, alongside these intrinsic SME manufacturing issues discussed above, also had a heterogeneous and complicated supply chain. For example, multiple sub-stage processes carried out on- and off-site some involving consecutive transportation energy accountability. In addition to that, the case study showed complications for CO_2 footprint accounting for both logistics as well as for upstream scoping
- The energy site-specificity for manufacturing becomes even more important by realising that the inter-system (i.e. within the factory and individual technology) energy assessment is significant as mentioned in point I in Section 1.3. This case-study investigation attempted to assess this level of detail to generate performance indicators such as SEC and CO_2 as mentioned in point III in Section 1.3. The more detailed energy auditing method results in a clearer

baseline performance indication and transparency in any improvement results. Both the performance indicator assessments, based on low-resolution data, were carried out at the case study site. The SEC was based on unit of production (metre) whereas CO_2 was provided in terms of organisation total and product-specific footprint in metre as well as for a specific product (as an item). The carbon accounting, as compared to SEC, also incorporated upstream emissions (where possible). This indicated two— energy and wool production as the main CO_2 contributors

- Strongly influenced by the nature of the data, every auditing approach can lead to different results. These investigations (e.g. estimating individual system/sub-system, technology appraisal, whole site demands) therefore have the potential to disagree with each other, such as differences in the outcomes of nameplate measurement and monitored estimations. Good quality data in either case (substantiated with suitable load factor, rated efficiency, and working hours) can help to minimise the gap. However, for each of these, time and equipment (sub-/monitoring-meters) may be required. Bypassing some of these limitations H-H data, if available, can meaningfully illustrate such enquiries as designed in this study. However, the in-depth onsite observations happened to be equally important for both inter and intra-system auditing types (of any levels), as raised in points I,II, III, and IV in section 1.3
- Quick fix audits can still play a role in achieving energy-efficient practices, but the savings may be overly exaggerated or associated with misrepresentative calculations. This risk can be reduced by improving the scope through more use of reality-based information such as onsite observations and measured energy and other relevant data. For quality assessments, one should not ignore key demand contributing technologies for demand/disaggregation estimations, use appropriate engineering principles and rules of thumb, and imply scientific grounds. This research learnt through in-situ experience and demonstrated improvement through utilising and comparing various routes towards a detailed energy audit
- Thermal energy such as gas is a significant contributor towards energy demand in manufacturing such as textile. Identifying savings related to this, however, is quite different to other non-domestic sectors where space heating may play the dominant role in gas usage. For more varied use of gas in manufacturing,

the study demonstrates the importance of gas- related savings, actual invoicing, AMR metering, and the influence of efficiency improvement on cost and carbon

8.2 Research Originality

Assessing demand, identifying efficiency improvements and waste periods, and recommending saving strategies, this research project is specifically designed for the chosen sector (composite textile). Specific methods of energy analyses, as summarised below, have been designed for such a complex manufacturing environment.

1. H-H energy data (electricity and gas) visualisation techniques have been developed against activity (as discussed in II in Section 1.3 and in 8.3.1.3)
2. Based on 24-hour activity, a technique is designed to numerically asses the demand variation (electricity and gas) which can further be translated into departmental load disaggregation and annual load prediction (discussed in II of Section 1.3 and in Section 8.3.1.2)
3. The data analysis methods, informed by existing methods and principles, can simply be carried out on MS excel. The platform and the method is adaptable to various energy investigations
4. A CO_2 footprint assessment method for the total organisation and a selected product, (as discussed in point III in Section 1.3 and in 8.3.2.1) has been designed. The proposed method is adaptable for similar manufacturing activities

8.3 Overall conclusion

8.3.1 General building assessment

8.3.1.1 Improved quality of audit and surveys for industrial buildings

Various types of energy auditing approaches, with differing levels of information, may be used; however, clarity and distinction of individual types and their inter-relationship is crucial. Energy investigations in industrial buildings depending on the audit scope may lack depth, resources, and observation. Sometimes, this can be exacerbated by the dearth of data, accuracy, and suitable application of scientific principles, observations, and method/approach as discussed above. Addressing this through detailed auditing in this study has clearly shown features, drawbacks, and differences between audit approaches.

Building heating and process thermal demand disaggregation in manufacturing is usually if deemed necessary, relied upon basic observations and rules of thumb. Such basic, and sometimes misrepresentative, assumptions could be replaced with more logical and scientifically proven approaches. This is possible even on sites with poor metering provisions, such as the case-study site. The simple method demonstrated and suggested can be easily adapted for data-poor sites. The method, based on onsite observations and available energy data, produced results comparable to reality when compared with other methods. Utilising daily gas meter reading data to assess weekend gas demand and the saving potential assessment for the boiler operation is another proven example of such approach. Some of the identified measures supporting better auditing are indicated below.

Project assessment/scoping

- Better energy knowledge at both advisor (technology installer/energy consultant) side and the receiving company side (director/manager/energy decision-maker) is required for better-justified savings. This translates into more technical knowledge/expertise on the advisor side and more energy awareness, observation, and training on receiving side

Data collection/handling

- Aim for in-situ measuring and monitoring methods, utilising generic data if sub-metering is not available

Investigatory methods

- Investigate improved methods for disaggregating production and building heating components of thermal demand, and related efficiency measures at end-use level
- It can be seen that crosscutting technologies such as boilers may share a variety of technology- and behaviour-change measures with general energy efficiency guidelines but site-specificity always remains important. Therefore, energy-saving measures for these technologies should not be purely based on general guidelines but with tailor-made estimates realised from site investigation
- Textile process-specific technology is diverse and some technologies, specifically used in thermal processes, require in-depth assessments for enhanced end-use energy efficiency. Therefore, more individually tailored methods should be sought

8.3.1.2 Utilisation of H-H data for consumption analysis

The increasing availability of H-H energy data has brought improved manufacturing industry energy analysis to the fore. The forms of visualising such data, making use of attributes i.e. average such as peak/off-peak times, production seasons, and seasons of weather, is important. The high-resolution data may also be analysed using other statistical methods such as percentile analysis. These various exercises based on different methods help to establish the impact of independent variables (holiday, weekends, and production and weather seasonality) on dependent variables (energy use) to analyse and compare. Realising the benefits and limitations of each of these approaches, such forms of investigations have been applied in this project. This helped to thoroughly establish and understand various aspects of energy use and causations at a higher resolution (when and where possible). The H-H data is also arranged in a standardised way, based on a 24-hour change in intensity of activity, to numerically establish demand variations, as discussed in 5.3.3.1.

8.3.1.3 A new H-H data-based method for manufacturing activity

The proprietary based H-H data analysis tools have various associated limitations (subscription, reduced analysis skills of the relevant staff, or absence of energy efficiency programmes onsite). No-cost and easy to understand analytical tools can benefit organisational energy management capability and capacity. The method, based on simple spreadsheet packages, has been conveniently designed to analyse manufacturing energy data for various objectives. Moreover, the usage of H-H data in the past consists of electric demand, waste, and efficiency assessments for various types of non-domestic buildings. The data for manufacturing energy is rarely used specifically against the daily activity. Various reasons, as established in Chapter 2, such as lack of energy studies in SME, most of the energy assessments using traditional audit methods (low resolution data, nameplate rating based demand estimations, and the use of pre-prescribed saving measures,), and dearth of methods dealing with such data can be attributed to it. This thesis demonstrated that using such detailed activity against 24-hours daily energy use can help establishing trend and patterns and, ultimately, energy saving opportunities. These continuously changing demand profiles not only correlate with activity but also indicate changing load factor as a result of variation in intensity (speed, batch load, process intensity) of the activity. The average profiles have been presented in the form of various seasons based on general and peak- and off-peak weather and production seasons. Anomalies exist among seasons such as peak-production season falls in summer and off-peak production in winter. However, the shapes of the profiles representing each season indicated slight differences. This is further understandable through year-long individual day profiles as indicated in the analyses, as discussed in Section 5.3.3.3.

The H-H data for gas is becoming frequently available for manufacturing sites and thus requires similar analytical methods to fulfil site energy and audit scopes. In order to understand buildings' thermal energy, individual demands such as steam/hydroponic boilers were studied. Building fabric, supply system efficiency, energy recovery, and the user behavior is generally focused on. Despite varied thermal end-uses in manufacturing, similar methods have been applied due to reasons such as lack of tailored methods, over-generalisation of non-domestic energy usage, and availability of resources. Moreover, thermal energy improvement in manufacturing sites is generally ignored due to cheap fuel, affordability, and production being the highest priority. Appropriately designed analysis for H-H gas data, as demonstrated onsite, can present consumption behaviour and useful saving tips. The study also suggests various demand categories based on varying activities during numerous annual seasons and activities in 24-hours pinpointing areas of improvement.

8.3.2 Textile manufacturing

8.3.2.1 A method for carbon footprint assessment for textile manufacturing

Carbon footprint is a desired indicator towards a business' sustainability, however, the evaluation can be complicated due to various processes related boundaries, and calculative hurdles. Although new procedures and methods are being developed, for example PAS2395 for textile industry, to create a variety of more precise and informed indicators, matrices, and procedures, further research and development is required. The textile industry, for example, uses a variety of synthetic and natural fibres each having specific production process-related energy. In addition to that supply chain-related logistics can further complicate this picture. This study designs an embedded energy/carbon evaluation method for woolen fabric manufacturing. Despite limitations such as using secondary and low-resolution data, and missing data, the study partially demonstrates a CO_2 assessment method. Indicating the key elements involved in such evaluations, the method confirms the significance of availability of missing data. The data plays a key role in completing a true representation of carbon footprint for textile manufacturing.

8.3.2.2 The need for assessing individual textile process/building energy

The case-study site influenced the scope and the results of the study in terms of the type and the nature of the building (Chapter 2), the technology used (Chapter 3), processes carried out (Chapter 4), and energy data and analyses (Chapters 5 and 6). This helped to confirm important factors from an energy perspective such as textile manufacturing being a complicated supply chain and each sub-manufacturing process having specific (and recognisable) energy demand characteristics. The technologies may vary among the individual processes and units but are likely to be similar to that used in composite textile factory. Although the case study is relatively uncommon, studying the specific, non-homogeneous practices was of great benefit to this research. Firstly, due to relatively few such formats around the world, more energy assessments are needed. Secondly, this single study has covered all the four textile technology and energy aspects in one project instead of many as;

- Technology change measures suggested in this study are equally useful for both types of individual units and composite textile manufacturing formats
- Large numbers of energy culture and signature related saving strategies will be the same for all types of formats in textile manufacturing
- Many production management approaches (limited number in this project) can also be useful for both individual units and composite manufacturers

Due to the differences in individual and composite textile manufacturing formats the SEC for individual processes will be different. Knowing such difference and the reasons can be interesting and encouraging to enhance energy efficiency in the sector. It has been established in Chapters 6 and 7 that understanding energy use for individual processes is essential. The study also identified the need for establishing energy benchmarks for these individual process units. Filling the energy data gaps within the case study site, or similar sites, is only possible when such indicative values become available.

8.3.2.3 Textile industry in the UK

The UK textile industry, despite having a declining trend, needs manufacturing-specific energy performance indicators and guidelines. Established guidelines mainly, as discussed in Section 7.2.3, focus on buildings users comfort. The lack of other forms of indicators available is arguably linked to the fall in the country’s overall industrial activity. Having such benchmarks available can be helpful for local manufacturers in many ways, particularly aiding the route to achieving energy and carbon compliance. The available detailed benchmarks can also be helpful to textile importers in the country, for example, to engage stakeholders to achieve UK requirements for local CO_2 targets. Thus the study is helpful in designing a standardised auditing method, generating global energy indicators and UK specific performance indicators for a non-homogeneous sector.

8.4 Recommendations

The studies discussed and demonstrated the fundamental methods for clearer energy auditing for complicated manufacturing industries. Despite the limitations (as discussed in Table 104 the work could be adopted as a detailed energy audit for enhanced scopes and objectives onsite and other similar sites, and can be extended for improved findings such as:

- To help and support individual units and composite manufacturing, individual energy/CO_2 investigations are required to complete the energy performance and efficiency picture. Assessing organisational (unit-level) energy for individual processes (such as dyeing, washing, and weaving) is one area that could be developed. This will be useful to estimate and compare energy/carbon-related drawbacks/benefits. The studies can also help identify embedded energy/carbon indicators for the upstream supply chain. For example, Australia, New Zealand, and China are the biggest producers and exporters of luxury wool such as cashmere and angora. However, a significant quantity of these types is also produced in other countries of Asia, which is then exported to China. Investigating energy/carbon involved in wool production, processing, and complex transportation/supply chain (from producers, middle-men, sellers, and end-users) can be useful in many ways. Studies involving such investigations can help to create upstream energy/carbon indicators for the products, useful to suppliers, buyers, and sellers. Furthermore, for performance indicators such as SEC it will be useful to compare performance characteristics and adjust them to standard conditions (such as weather, activity, processes intensity and their energy intensity (internal & external), unit of production (length, weight, colour, material, etc).
- An even more in-depth method consisting of H-H data from the main meter and (at least) at the departmental level for such a site can be designed. The

departmental load data then can be utilised in two ways; firstly comparing its contribution towards the main meter, and secondly assessing the impact of contributing technologies within the department by using load and activity factors. The energy signature and in-depth energy efficiency of each machine could, therefore, be determined. This type of micro-audit can play a key role in understanding the energy profiles of individual technologies of textile/SME sector. In the presence of high-resolution individual departmental and overall production data (daily/weekly, monthly) the variation in daily SEC/CO_2 of the individual process can be understood. This is also true for building heating technologies, particularly where multiple units are run in a centrally controlled operation. More detailed sub-measuring is also helpful to compare the nameplate based total demands for individual departments.

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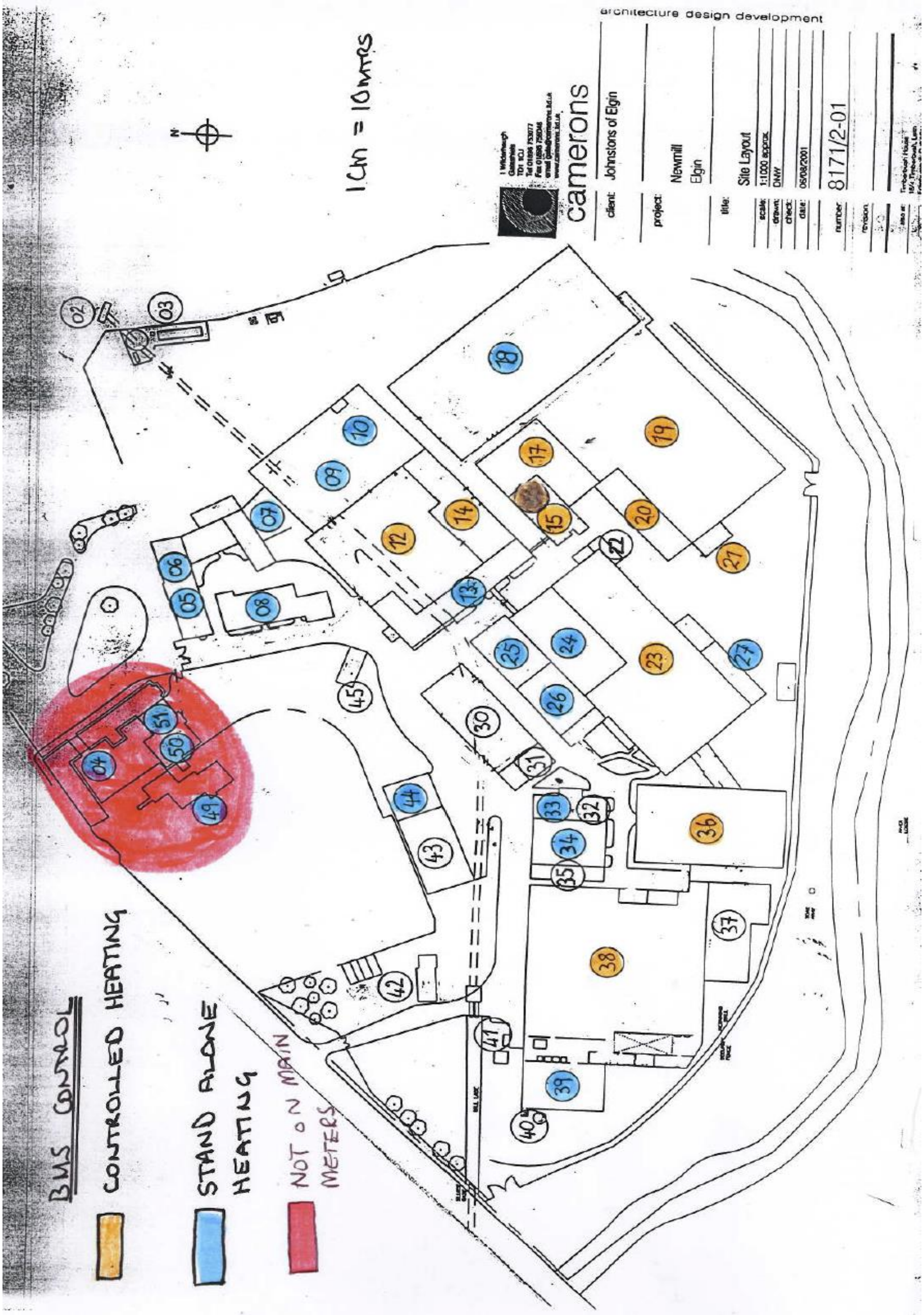
Appendix 1

(a)

Factory Map. Factory map indicating BMS enabled buildings



Controlled means controlled through the BMS system

Additionally, in Finishing and some admin buildings heating (09, 10, and 12,14) is provided by five boilers

Table 105- Sample embroidery nameplate rating data collection sheet

Section	No.	Equipment details	Weekly hours	Quantity	rpm	Volts	Amperes	Power
Computers	1	Tower computers of different makes	24X7	1				250W*
	2	LCD monitor	24X7	1		240		34W*
	3	HP laserjet printer CP2025dn (office)	Sun-Frid	1		240		
	4	1 old style panasonic printer	occasional	1		240	1.6	
	5	1 Zebra printer	24X7	1		20	2.5	50W
Equipment	6	2 Emboirdery machines 15 head		1		415	3.2	1.6kW
	7	Emboirdery machine 4 head		1		1	9	
	8	2 kettle		1				2.2kW±
	9	I irong						2.2kW±
	10	I small fridge						
	11	1 microwave`						800W
HVAC	12	Electric heater	seasonal	1				2kW
	13	Steam heater	seasonal	2				0.37±
		Heat						steam
	13	3 pedestal fan	seasonal	1				60W
Lighting	14	10X2 5ft fittings double	on as needed	20				58W
Miscellaneous	21	1 radio						

Key	
Not known	⊝
Approx/est	±
P=IV	¤
Red is yet to confirm	
Estimated	*

Appendix 1 (b)

Overall energy management options (at low/zero cost) to reduce unnecessary onsite energy consumption

This initial report onsite presented mainly standard energy audit based general energy saving measures. The report used various auditing routes to suggest low-cost measures (based on staff, behaviour, operation, and process management). The technology evaluated included small power and IT, HVAC, and hot water dispensers as well as boilers, CA units, and some steam and electric technologies. The report also emphasised on the importance of communication and staff involvement in EM. The report played a pivotal role towards setting up the whole auditing process at the factory.

Appendix 1 (c)

Air compressors

This report consisted of two parts, the first part (comprising improvement opportunities in the factory with payback periods and the implementation suggestions) and the second part (consisted of technical knowledge backing-up the validity of the recommendations made). In addition to identifying the baseline costs and running of the onsite CA systems the first part evaluated both the CA and distribution system. These saving measures consisted of good housekeeping, technical (such as installing a heat recovery system). Key identified measures are discussed above in Chapter 6.

Discussing the background knowledge the second part highlight identified measures as to put their significance in to context as discussed in Chapter 3. Several saving suggestions were made in the report, one of the examples is shown below in Section a).

a) Pressure minimisation

Reducing the header pressure is a simple no-cost saving measure, however required care to avoide malfunctioning. A daily gradual pressure reduction (0.1bar) monitoring study was carried out. The system coped until reaching 6.6bar. At 6.4bars Schlafrhost winding machine in the Yarn production stopped working. It was assumed due to a large number of leask around that the system can cope well at reduced pressures if these are repaired. Another suggestion was pressure regulating where more than desired pressure was supplied. A saving of £1,700/annum has been calculated based on this study. The savings equalled to around 5% of the total CA energy cost for lowering the pressure by ½bar. This is slightly higher than estimated by most studies (The Carbon Trust, 2012b) (between 3-4%) for lowering the pressure by 0.5–1bar. The confidence of analysis and savings could be improved by increasing the quality and accuracy of data e.g. from data acquired by a data logger. A survey was carried out to see individual technology set pressures, it has been noted that some regulators were out of order. It is advised that the company should review these pressures in line with the technology manuals. This practice will help to increase machinery's as well as the CA system's efficiency. A pilot study on effects of air pressure reduction on the performance of weaving machines has been suggested for the future. Pressure reduction in the air blow guns is also recommended, as some of the blow guns are supplying air at the system pressure. It is against the health and safety provisions if an air gun is being operated over 2.2 bars (The Carbon Trust, 2012b).

Appendix 1 (d)

Lighting load (circuit watt) in different buildings

Building number	Building name	Total circuit watt (kW)	Building number	Building name	Total circuit watt (kW)
1	No data available		26	Drying house	1.01
2	No data available		27	Main office	1.27
3	No data available			Canteen	0.72
4	Courtyard (down lights)		28	Spare	
4	Courtyard(fluorescent)		29	Spare	
5&6	Shop (down lights)	19.86	30	Dye kitchen	0.17
5&6	Shop (fluorescent)	1.5		Dye house 1	1.44
7	Offices	1.48		Dye house 2	0.56
7	Coffee shop	3.11		Lab	1.04
8	Main offices	6.85	31	Spare	
9	Dry finishing fluorescent	8.54	32	Yarn store C	2.77
	Dry finishing metal halide	3.74	33	Training room	2.54
10	Retail warehouse	7.51		Knitting	0.92
11	Spare		34	Yarn breaking	0.81
12	Cropping	1.56		Hank winding	0.63
12	Mozer and Stenter area	18.12	35	Yarn store cage	0.21
12	Canteen	0.42	36	Lab and office	1.75
13	No data available		36	Main office	0.84
14	Wet finishing	6.05	36	Yarn store (A)	10.97
15	Show room	2.91	37	Yarn store (B)	3.54
16	BOM	1.55	38	Twisting	5.16
	Design	2.47		Canteen	0.67
17	Sales	5.28		Toilets	0.19
18	Warehouse	12.65		Spinning	7.24
	Embroidery	1.39		Fettling	3.89
	Despatch	4.2		Carding	13.69
	Goods in/out	0.91	39	Teasing	2.94
	Sewing	3.97	40	No data available	
	Stockroom	2.7	41	No data available	
	Canteen	1.24	42	No data available	
19	Main stockroom	21.17	43	Wool store	2.16
20	Workshop	4.1	44	Store	3.05
21	No data available				
22	Water extraction	0.21	**Total**		**247.83**
23	Weaving	17.3			
23	Weaving (toilets)	0.52			
23	Warping	5.95			
23	Canteen	0.36			
24	Purling	2.71			
	Pattern cutting	4.12			
25	Boiler house	3.21			

Red text indicates that some lighting installations/luminaires are broken

Appendix 1 (e)

Lighting efficiency using a case-study building

Micro-auditing for such a large number of buildings was not possible. Therefore a case-study building, as discussed above was selected. Taking a general technical review of the state of the art of lighting, the report took a quick account of the prevailing lighting status at the factory. The report then explained the case-study building and assessed the demand and efficiency prospects in it along with the payback and carbon emissions.

Appendix 1 (f)

Lighting load density in Yarn production

Carding

Type	Number	Total circuit load (kW)	First year lm density	Total lm density depreciation after first year	lux/m^2
5ft. (T8)					
6ft. (T8)	33	3	221,760	212,890	
8ft. (T12)	91	11	728,000	509,600	
Total		14	949,760	722,490	628

Spinning

Type	Number	Total circuit load (kW)	First year lm density	Total lm density depreciation after first year	lux/m^2
5ft. (T8)	33	2	183,744	176,394	
6ft. (T8)	12	1	80,640	77,414	
8ft. (T12)	30	4	240,000	168,000	
Total		7	504,384	421,809	1,141

Twisting/Winding

Type	Number	Total circuit load (kW)	First year lm density	Total lm density depreciation after first year	lux/m2
5ft. (T8)	10	1	55,680	53,453	
6ft. (T8)	45	4	302,400	290,304	
8ft. (T12)	6	1	48,000	33,600	
Total		5	406,080	284,256	822

Yarn production

Type	Number	Total circuit watt	Total first year lumen density	Total lm density depreciation after first year
5ft. (T8)	43	3	239,424	229,847
6ft. (T8)	90	8	604,800	580,608
8ft. (T12)	127	15	1,016,000	711,200
Total	260	26	1,860,224	1,521,655

Appendix 1 (g)

Stenter

The report technically defined and discussed the functionality of different parts of the machine their efficiency possibilities. Reviewing the onsite stenter machine, the report evaluated behaviour- and component-change related suitable energy saving opportunities. The saving estimations were instructed through both monitored data and theoretical values.

a)

Air-to-water heat recovery system was found to be a suitable measure compared to air-to-air recovery system. This was refused by the system manufacturer due to smaller size of the stenter. The Mahlo system's non-functioning was investigated and the installers were contacted which suggested to re-evaluating it for a fee. The question arose that why the evaluation was not carried out upon installation. Experiences like this (where the installer company/consultant is more interested in selling a system and less in checking the product suitability and optimum performance) are good enough to warn the organisations' decision makers. It encourages organisations to have technically sound personals to question about the appropriateness of the technology before installation. Another matter that may arise in the installation of a heat recovery system is the need of the utilisation of the hot water generated through the heat recovery. The water has a potential utilisation in the nearby wet finishing section. However, the optimisation for the storage and utilisation system can be a costly challenge significantly increasing the project cost. This increase in the payback period may not be suitable for industries that are not interested in investing in measures with over five year's payback.

Appendix 1 (h)

Energy consumption calculations

As assumed in the study (Mehta, n.d.) natural gas consumption of a stenter machine can be calculated by the following forumula;

$$\frac{\text{maximum capacity}\,\frac{\frac{\text{kcal}}{\text{h}}}{\text{chamber}}\ X\ no.of\ chambers}{calories\ produced\ per\ unit\ fuel\ x\ efficiency\ of\ the\ machine}$$

Or

$$\frac{200{,}000\,\frac{kcal}{h}/chamber \times 3}{8905\ kcal/m3 \times 0.95^{1}\ (efficiency)}$$

$$= \quad 64\ \text{m}^3/\text{h}$$

Considering the machine is running at 80% of its full capacity (as lower temperature are required for drying processes)

We get $64*0.8= 51\ \text{m}^3/\text{h}$ (0.8 load factor)

Or 51 *10.60[2]=540kWh (as 1m^3 of gas=10.6kWh)

Based on these figures, the weekly gas use (78 hours) of the stenter is 3,978 m^3 or 42,166 kWh which costs £1,054 or £14/h. Theoratically, as mentioned in (Defraeye, 2014), 2,400kJ energy is required to evaporate 1kg of water at room tempeature

2400*0.000277[3]=0.67kWh

Therefore the theoratical hourly evapoeration rate will be

540/0.67=806kg

The per hour electricity cost for the machine is 60kWhX0.1[4]=£6.

So simply the total running per hour cost of the stenter will be 14+6=£20

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[1] 0.95 is generally used efficiency factor

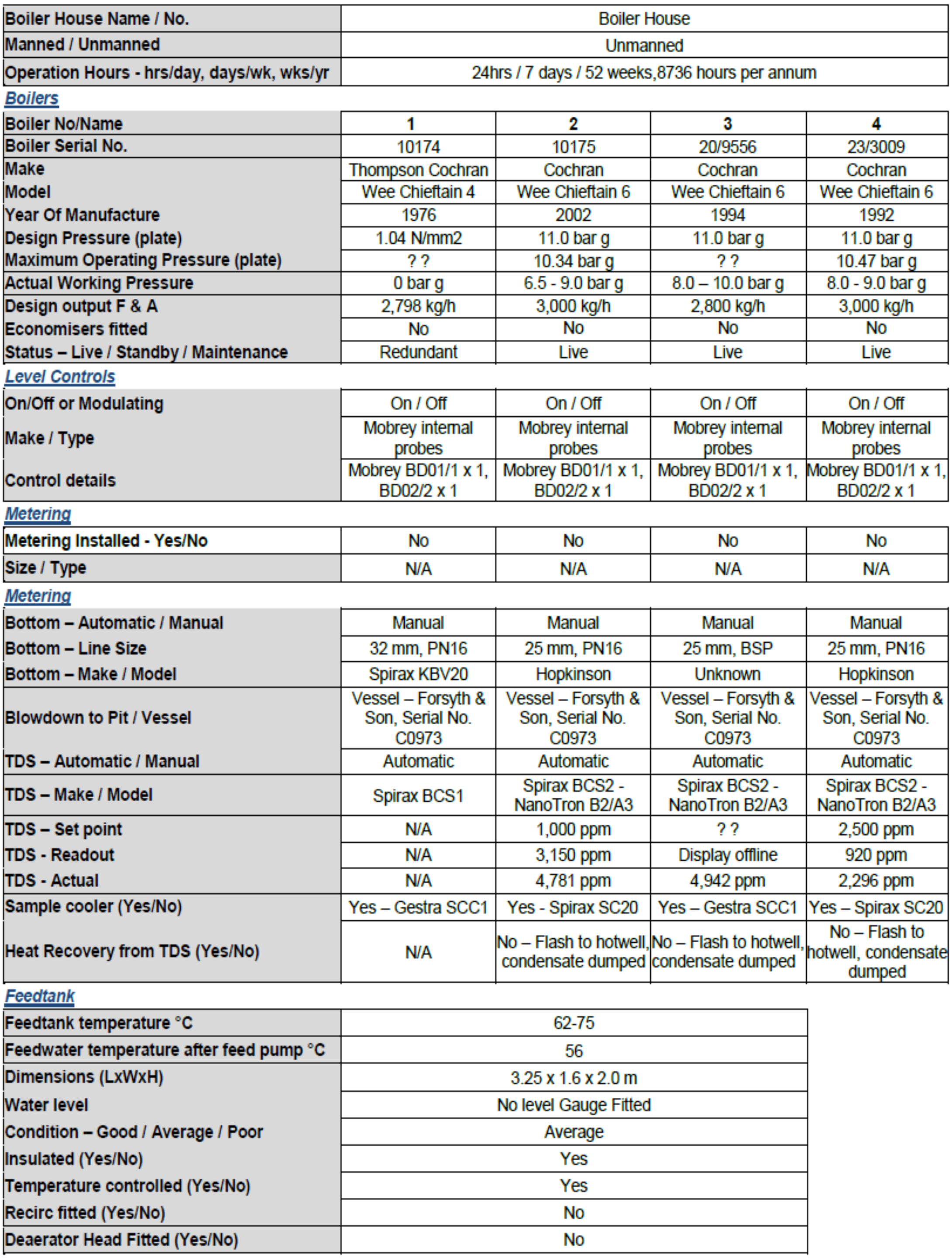
[2] As 1m^3 of gas is approximately equal to 10.60kWh

[3] Conversion factor for kJ to kilowatt hours

[4] Per unit cost of electricity

Appendix 1 (i)

Biolers' specifications at the factory



Boiler House Name / No.	Boiler House			
Manned / Unmanned	Unmanned			
Operation Hours - hrs/day, days/wk, wks/yr	24hrs / 7 days / 52 weeks,8736 hours per annum			
Boilers				
Boiler No/Name	**1**	**2**	**3**	**4**
Boiler Serial No.	10174	10175	20/9556	23/3009
Make	Thompson Cochran	Cochran	Cochran	Cochran
Model	Wee Chieftain 4	Wee Chieftain 6	Wee Chieftain 6	Wee Chieftain 6
Year Of Manufacture	1976	2002	1994	1992
Design Pressure (plate)	1.04 N/mm2	11.0 bar g	11.0 bar g	11.0 bar g
Maximum Operating Pressure (plate)	? ?	10.34 bar g	? ?	10.47 bar g
Actual Working Pressure	0 bar g	6.5 - 9.0 bar g	8.0 – 10.0 bar g	8.0 - 9.0 bar g
Design output F & A	2,798 kg/h	3,000 kg/h	2,800 kg/h	3,000 kg/h
Economisers fitted	No	No	No	No
Status – Live / Standby / Maintenance	Redundant	Live	Live	Live
Level Controls				
On/Off or Modulating	On / Off	On / Off	On / Off	On / Off
Make / Type	Mobrey internal probes	Mobrey internal probes	Mobrey internal probes	Mobrey internal probes
Control details	Mobrey BD01/1 x 1, BD02/2 x 1	Mobrey BD01/1 x 1, BD02/2 x 1	Mobrey BD01/1 x 1, BD02/2 x 1	Mobrey BD01/1 x 1, BD02/2 x 1
Metering				
Metering Installed - Yes/No	No	No	No	No
Size / Type	N/A	N/A	N/A	N/A
Metering				
Bottom – Automatic / Manual	Manual	Manual	Manual	Manual
Bottom – Line Size	32 mm, PN16	25 mm, PN16	25 mm, BSP	25 mm, PN16
Bottom – Make / Model	Spirax KBV20	Hopkinson	Unknown	Hopkinson
Blowdown to Pit / Vessel	Vessel – Forsyth & Son, Serial No. C0973	Vessel – Forsyth & Son, Serial No. C0973	Vessel – Forsyth & Son, Serial No. C0973	Vessel – Forsyth & Son, Serial No. C0973
TDS – Automatic / Manual	Automatic	Automatic	Automatic	Automatic
TDS – Make / Model	Spirax BCS1	Spirax BCS2 - NanoTron B2/A3	Spirax BCS2 - NanoTron B2/A3	Spirax BCS2 - NanoTron B2/A3
TDS – Set point	N/A	1,000 ppm	? ?	2,500 ppm
TDS - Readout	N/A	3,150 ppm	Display offline	920 ppm
TDS - Actual	N/A	4,781 ppm	4,942 ppm	2,296 ppm
Sample cooler (Yes/No)	Yes – Gestra SCC1	Yes - Spirax SC20	Yes – Gestra SCC1	Yes – Spirax SC20
Heat Recovery from TDS (Yes/No)	N/A	No – Flash to hotwell, condensate dumped	No – Flash to hotwell, condensate dumped	No – Flash to hotwell, condensate dumped
Feedtank				
Feedtank temperature °C	62-75			
Feedwater temperature after feed pump °C	56			
Dimensions (LxWxH)	3.25 x 1.6 x 2.0 m			
Water level	No level Gauge Fitted			
Condition – Good / Average / Poor	Average			
Insulated (Yes/No)	Yes			
Temperature controlled (Yes/No)	Yes			
Recirc fitted (Yes/No)	No			
Deaerator Head Fitted (Yes/No)	No			

Appendix 1 (j)

Boilers

Scope of energy efficiency opportunities based on behavioural, technical, and component installation/replacement specific to the case study site were evaluated. Some suggestions on steam distribution network efficiency were also made. These consisted of inspecting and repairing steam traps, insulating and maintaining the distribution and condensate lines, installing removable insulations on valves and fittings, cleaning fire-tube boiler waterside heat transfer surfaces, and minimising boiler cycling losses. Other medium- to high-cost measures are already discussed above. Additional measures suggested considering, steam metering, increasing boiler operating pressure, steam distribution management system installation, and de-aerators in the hot water well, some are discussed below.

Section a)

Other general energy management advice

Boiler operating pressure

Although the rated pressure of the boilers is 10bars(g) but these are operated at 9bar(g). It is well-established in Chapter 3 that boilers deliver maximum efficiency at maximum rated pressure. Therefore, it is recommended that the boilers should be operated at 10bars instead after consulting with the servicing company regarding boiler and steam network health and resilience. Also insurance compliance requirements must be double-checked.

Steam metering

Steam metering is essential to identify any steam saving projects. Due to the absence of these, consumption is not known leaving reliance on rough estimates. Metering, at least for the total steam production, could give better idea about total demand, monitoring, and controlling it. Having steam meters at departmental/individual boiler level can help analyse and control it even better results but the investment depends on suitability, cost, and the associated savings.

Steam distribution management system

Automatic steam distribution management systems to control and operate boilers in response to demand variation are available. These systems are effective to reduce gas consumption and can eliminate the need of manpower to open/close lines or switch on/off boilers when desirable. The system can be programmed according to the site specificity to maximise the savings.

Install de-aerators

Appropriately de-aerated water in the hot-well will carry less oxygen, which is a measure to reduce oxygen related corrosion in the boilers. In the presence of a good sparge system the temperature of the hotwell water can be maximised to ensure better quality feed water for the boilers. Installation of this measure was being considered at the factory lately. It is also advised that the sparge system selected to be installed should be electric instead of on dearer CA.

Future studies

Decentralise and rationalise steam supply

The steam distribution system in the factory is quite old and is spread all around to the far ends. In some buildings steam is only needed for building heating. Decentralising and rationalising steam supply for such buildings can save energy due to reduced losses and better management. The measure can help to reduce the steam load and probably can help to avoid running three big boilers in winter. Some buildings for example, yarn production, customer services, and parts of warehouse have been identified for such measures and evaluations for appropriate technologies must be carried out.

Appendix 1 (k)

a) Install an automatic blowdown system

Payback evaluation of retrofitting automatic total dissolved solids (TDS) blowdown control system in the boiler house

The boiler house total demand in 2013 was given in the Table 57. According to the Carbon Trust (2012d) installing an automatic TDS control system for TDS levels control automisation can save up to 2% on energy cost as discussed in Chapter 6.

However, these saving figures may not be realised after the retrofitting due to multiple reasons as given below;

- The operations of the boilers has significantly changed since 2013
- Some TDS controlling measures, e.g. change of the chemical use is already in place
- Although implemented in 2013 yet a regular manual blow down is still being carried out at least five times a day (however, the exercise wastes time of the engineers)
- In the absence of blowdown heat recovery system the loss of more hot water will reduce the overall efficiency of the boilers

b) Install blowdown heat recovery

Payback evaluation of installing blowdown heat recovery system in the boiler house

According to the Carbon Trust (2012d) an appropriately managed blowdown heat recovery system can save up to 4% on energy cost Table 57. Since, there was no heat recovery system to could capture heat from the TDS blowdowns. Therefore, having an automatic blowdown heat recovery system in conjunction with previously proposed automatic TDS control system will improve the healthy functionality and performance of the system. Depending on the rate of rise in TDS levels of individual boiler the blowdown system frequency will vary individually. Therefore, it is not easy to predict the daily blowdown frequency of each system but surely complimenting each other both the systems will promote a healthy and improved performance.

However, these savings figures may not be fully realised after the retrofitting due to the following reasons;

- The operations of the boilers has significantly changed since 2013
- It is inappropriate to claim a total 6% saving (2%+4%) through these two measures as TDS levels in the boilers are normally high and some boiler/s

may require blowdowns more than five times a day. Although some of the heat of the blowdown water will be recovered through the new heat recovery system but increased rate of redirecting water with higher TDS will mean more water subject to heat recovery. Therefore, the real savings will be less than in the theory.

Appendix 1 (l)

Heat recovery systems

Heat recovery options on different hot wastewater streams (Dyehouse and wet finishing) were evaluated. Calculating the thermal energy consumption and the effluent recovery, the report discussed all the options and relevant savings. This hot effluent recovery potential consisted of all the technologies in wet finishing, and dye pots and hank dyers in the dyehouse.

Appendix 2 Paper presented in a conference

Agha. and P. Jenkins, D., 2014. Energy analysis of a case-study textile mill by using real-time energy data. ECEEE Industrial Summer Study, Arhus, Holland.

Ali Agha (2-080-14)

Energy analysis of a case-study textile mill by using real-time energy data

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Key words
Textile Manufacturing
Energy demand
Energy efficiency
Peak- and off-peak season

Abstract

The textile industry has relatively high energy consumption compared to other small and medium industries. More energy performance studies are required to improve process energy efficiency. For any energy efficiency study, measuring the energy consumption quantitatively is the first step. This paper utilises high-resolution empirical energy data of a vertical case study textile mill to estimate its overall energy use and to find out any underlying efficiency improvement opportunities. Average seasonal load profiles have been calculated against shift patterns and weekly and annual consumption trends are investigated. Despite winters being at a time of off-peak production, heating related gas use was found to be significantly high during this period, with high specific energy consumption (SEC) per unit of production. The study identified some actionable energy saving opportunities that consisted of reducing the weekend baseline load for both electric and gas through behaviour change and simple management. Some site-specific processes and technology-based energy savings were also identified. The paper reveals how a more detailed energy analysis of a process-specific non-domestic building (such as a textile manufacturer) can provide much richer and actionable information than more standard energy audits and surveys. The key methods and techniques used in this analysis are outlined in the paper, such that they may be extrapolated to other non-domestic buildings in similar industries.

Introduction

Emerging climate change and sustainability compliance is increasing pressure on businesses to reduce their energy use. Energy efficiency is one of the most promising ways. In the case of small and medium enterprises (SMEs) in the industrial sector, there is a difficulty in studying a large number of industry-specific technologies of this diverse sector (Energy Research Partnership 2011). Therefore, most of the energy efficiency practices carried out in the sector are based on commonly shared technologies, e.g. air compressors, boilers, etc.; this can underestimate the real efficiency potential of a specific industry. Representing a heterogeneous and fragmented industry in the SME sector, textile is a less energy-intensive industry than, for example, cement, steel, chemical, etc. The industry has specific characteristics mainly due to multiphase production processes involving multiple units per phase and each having different production rates

(Karacapilidis and Pappis 1997) and, therefore, distinct energy requirements. This aspect of manufacturing can have a detrimental impact on the total process energy consumption. However, textile energy studies make up a relatively small share of all industrial energy studies (Hasanbeigi and Hasanabadi 2012). More energy studies in this sector will help to identify the energy efficiency potential for the industry itself as well as for the other similar industries.

Energy efficiency in a manufacturing environment can be achieved through two aspects: 1) a system approach, which appreciates energy efficiency opportunities lying both in the supply chain side as well as on the demand side (mostly outside the scope of this study), and 2) a component or technology approach which focuses on improving energy efficiency of individual technologies. Energy management, for example, may be carried out through equipment efficiency and controls development, and through change in behaviour and energy culture. These types of energy efficiency improvements are normally made possible through "Surveys" or "Audits", which are carried out by consultants and may consist of a one-off or a continuous improvement plan. Short-term energy audits and surveys do have limitations, such as only picking up a small number of improvement opportunities based on a one-off visit, but observations based on long-term energy studies can yield better results.

A different approach is that of Operation and Maintenance (O&M), involving timely maintenance of technology which encourages consistent efficiency. This might include, for example, changing the air filters on heating and air conditioning units, repairing air and steam leaks, oiling and greasing the moving parts of the machinery. Such a programme generally contains five distinctive components: Operations, Maintenance, Engineering, Training, and Administration, collectively called "OMETA". Studies have shown these measures working effectively (Richard, n.a.). Implementation of an energy management system can involve building upon different steps consisting of energy policy, planning, implementation and operation, checking and corrective actions, and a management review**.** The formation of an energy management standard ISO 50001 which provides a strong organisational framework for energy management is another way of implementing it. However, for any energy efficiency study, measuring the energy consumption quantitatively is the first step (Wang 2012).

Numerous methods are used to measure and estimate this energy consumption. For example, detailed methods for end-use energy consumption estimations in non-domestic buildings have been discussed elsewhere (Field at al. 1997, Bryant and Carlson 2002). An energy audit might be based on year-long monthly utility bills or, more reliably, daily demand meter readings. However, there may be chances of inaccurate estimate billing and risk of gaps and human error is involved with manual data. Inaccuracy related to estimate billing, for example, can cause ambiguity in industrial energy studies. The use of high-resolution automatic meter reading (e.g. every half-hourly for electricity in the UK) has reduced such risks considerably and provided an often under-utilised data source. Different visualisation techniques for such short-term time-series data have been discussed in Motegi et al. (Ferreria 2009) and have various applications and limitations. For example, Wijk and Selow (1999) used calendar profiles (cluster and contour plots) to identify consumption trends and patterns on multiple time scales (days, weeks, and seasons). Daily profiles (line plots) are commonly used for time series data and can be used to verify operation schedules, identify peak hours, and base load. The technique can lead to better consumption pattern understanding if the periods to compare are correctly chosen (Stuart et al. 2007). The analysis based on these plots helped to identify building system failures and opportunities for energy saving (Ferreria 2009, Kilpatrick 2012). As communication to the end-user is of paramount importance, reflecting the findings of such studies should increase the chances of theoretical savings becoming reality.

Studies focusing on technology aspects have shown efficiency improvements in all types of industrial activities. This can be from a change in technology, (such as replacement of an old iron melting furnace with a new electric arc technology), to technology alteration (inverter drives for motors), or reduction in energy waste (controls on air and steam leaks) (Gordic et al. 2010). Optimisation studies about production systems and process control in SMEs have shown notable efficiency improvement results (Mirade et al. 2012). Several energy studies in the textile industry have addressed different aspects, such as energy efficiency in a Toray textile mill case study (Best practice programme guide 148 n.a., Palainchamy and Babu 2005), energy intensity comparisons (Hasanbeigi and Hasanabadi 2012, Ines and Martinez 2010), and energy consumed per unit of production of a spinning unit (Koc and Kaplan 2007). To disseminate the scope of energy efficiency in this sector, several industry-focused organisations have produced reports (Department of Environment 1997, Hasanbeigi 2010, United Nations Industrial Development Organisation 1992). However, the actual implementation of energy efficiency measures can lag behind the theoretical calculations due to lack of implementation method, and lack of knowledge of the measures themselves.

In this study the total energy use, both for onsite production and operations, of a textile factory is estimated. Also, the energy efficiency improvement possibilities have been assessed therefore the main objectives are;

- To identify the major technology used and the potential for energy saving
- To assess the impact of departmental energy consumption on the total energy use
- To determine the effect of off- and on-season production on specific energy consumption

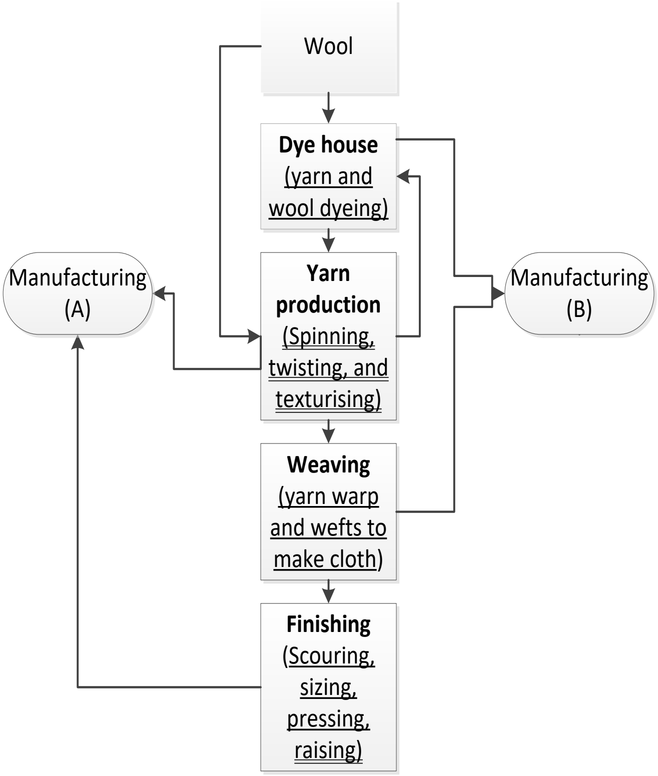
In the following sections a review of industrial energy, particularly within the UK textile industry, is taken. The methods used for the data analysis will also be described and site-specific energy efficiency opportunities are discussed. Also, total energy consumption, SEC, and energy trends/patterns are identified.

Industrial energy and textile case study site

Industrial energy accounts for one-third of global energy (Greening and Roop 2007). In the UK, 57% of industrial energy is used by more energy intensive industries i.e. iron and steel, cement, chemical, paper and pulp, etc. (Energy Research Partnership 2011). The textile industry in the UK uses 0.4% of national energy and is responsible for 0.4% of national greenhouse gas emissions (Allwood et al. 2006). 70% of the industry's process energy requirement is met by low-grade, below 200˚C, thermal energy which is provided mostly by gas in the UK. However, some textile manufacturing processes, for example for synthetic fibres, use more electricity as compared to others processes.

The case-study mill is a vertical textile mill, which means it carries out all the production processes from raw material finishing to fabric producing onsite. The factory has over 45 buildings with 22,800 m^2 treated area. All production departments—Yarn production, Finishing (manufacturing "A"), Dye house, and Weaving (manufacturing "B")Yarn production as shown in Figure 1, and operations (administration) departments work alongside each other in the factory. The on-production season or "on-season" starts in March and ends in September, and off-production season or "off-season" starts in October and ends in February. In other words off-season generally represents the winter. The operations departments/sections consist of information technology office, human resources and administration offices, customer services, factory retail and coffee shops, factory warehouse and stock room. These sections work throughout the year, and the holidays are adjusted accordingly. Depending on the amount of work occurring in the production departments, shown (bold) in Figure 1, this can be completely or partially closed during the holiday periods. Some departments can also undertake night shifts and Saturday overtimes. As mentioned above, such a complicated work environment makes production processes and energy use more difficult to predict, which is also observed in the energy consumption analysis section. A generalised shift pattern is assumed and shown in Figures 3a and 3b below.

Fig. 1 Production process flow at the mill



In brackets, single underlined text is predominantly gas based thermal energy and double underlined text is electric

Depending on the nature of the fibre, e.g. cotton, synthetic, wool, production processes in the textile industry may vary, as will the energy demand and type of fuel. In this case, gas contributes towards 80% of the total energy demand, shown in Table 1. It is worthwhile to mention that the factory is located in the north-east of Scotland, which has a significantly long and cold winter, the heating period in the factory spanning from early October through to end of May. Additionally, some of the buildings in the factory are up to 200 years old, and the factory runs a conventional steam heating system with a small number of buildings on electric heating. Figure 1 shows the process flow at the case-study mill. Each square box represents individual production department with the processes taking place within and are underlined to indicate major fuel type used.

Two main meters for electricity and gas supply energy to the whole factory, with no sub-metering around the production area in the factory. And the energy demand of individual department was estimated through profile analysis. Steam, which is produced by three conventional industrial boilers with a capacity of 3000kg/h. each, is the main heat carrier for both production and heating. The other main gas-based technology is a stenter frame, which consists of three large chambers in which hot air is blown to dry and set the size of the cloth in the Finishing section, which is further discussed later. Two compressed air units, 45kW each (one of which is generally on standby), are utilised to meet the compressed air demands. The other users of electricity are mainly motors**,** industrial dryers, lighting, building services and small power and IT (information technology).

Energy technology and demand analysis

By carrying out a technology audit at the factory, major energy user technology was identified. A review of energy efficiency opportunities for both process and technology based on industry specific publications and onsite observations is discussed in the section below. Utility bills data for gas and electricity for the year 2011 were reviewed and analysed to establish baseline energy use. The individual sums obtained from these, shown in Table 1, were divided by the total production for the year to find out their share of SEC per metre of production. Time-series electricity profiles (Figure 2) were constructed which showed a rise (weekdays) and fall (weekends) in demand. Half-hourly electricity demand data was used to calculate weekday average "on-season" and "off-season" profiles against generalised weekday shift patterns as shown in Figures 3a and 3b. Sections and departments with similar shift routines were identified and classified into three categories; i) Operations, ii) Manufacturing (A), and iii) Manufacturing (B) as mentioned above. A clear variation in energy consumption followed shift patterns and further analysis of these profiles confirmed increased energy demand in winter. It also quantified the expected reduction in demand during factory holidays. Through the analysis, it was also possible to find base load and manufacturing "B" demand in addition to the peak-demand. The estimated gas bills (from the energy supplier) were plotted against the manual data taken from the main gas meter and the discrepancies investigated (Figure 4). The gaps in the manual data, particularly for the weekends, were estimated by dividing the consumption with the number of days within the gap. The SEC was further reviewed on a monthly basis as shown in Figure 5.

Energy efficiency opportunities for the case study

Possible energy efficiency improvements for the factory are discussed below, with more detailed recommendations given in later sections.

Building services and IT

Lighting, heating, ventilation, and air-conditioning (HVAC), small power and IT equipment, in both the production and operations departments are significant. All the operations offices are lit, mostly, with T8 fluorescent tube lights. The production sheds use T12 8ft. fluorescent tube lights. Replacement of these phased-out fluorescent tube lights with efficient lighting would be the most obvious recommendation. Most of the production sheds have north-facing roof lights and some buildings are only occasionally used, therefore these buildings would benefit from lighting-level controls and occupancy sensors. The HVAC in most of the buildings is controlled by a building management system (BMS). The running times and temperature settings on the system have never been changed since the installation of the system. A critical time and temperature review can help to reduce the HVAC's running cost. Also, a thorough review of the motors in the systems can highlight saving opportunities through proper sizing and other measures as discussed below. To reduce the weekend baseline load an equipment checklist for each building has been designed and is passed on to the designated members of staff to ensure everything is shutdown at the weekends. These checklists also include the canteen areas and small power and IT equipment. Numerous guidelines for the IT and building services have been published by energy efficiency focussed organisations e.g. The Carbon Trust, and US Department of Energy (DoE).

Production process

Wet processes

These processes mainly involve dyeing in the Dye house and scouring (washing) in the Finishing area. These processes are mainly thermal and use steam. The technology used for these processes is simple consisting of large containers/vessels with closed coils for the steam flow. Programmable electronic control systems are used for water, washing chemical/dyes, cloth feeding in/out, process temperature and cloth/material dwell time control. Motors and pumps are used for pumping and agitation or some mechanical processes. The average daily demand of the water for the Dye house is 200 m^3 and roughly 30% of this is used for dyeing process. The dyeing process in the factory, starting with water at 50 ˚C, achieves a maximum temperature of 98 ˚C and then the water is discharged without heat recovery. The daily water demand of scouring is also 200 m^3 and roughly 40% of that is used for hot water washing at 40 ˚C. This hot water is also directed towards the drain without heat recovery, however water at this temperature is generally not suitable for heat recovery. Heat recovery and recycling from these processes could save significant energy and an account of heat recovery methods in thermal processes is given by (Hasanuzzaman et al. 2012). Both processes use hydro-extractors (spin dryers) equipped with heavy-duty motors, 25kW each, for centrifugal drying. The energy efficiency opportunities for these motors can be reviewed against the options discussed below. Some microwave and infrared ovens are used for dyed raw material drying in the Dye house. Studies have shown this type of drying as reasonably efficient (Buyukakinci 2012), but a thorough study of the operation of the machines could highlight further avenues for savings. Investigations of the stenter frame have revealed some potential for improved efficiency. As discussed elsewhere ((BREF 2000), optimising the exhaust air moisture, cloth dwell time, and heat recovery from the exhaust air could be explored further. Some manufacturers of these exhaust heat recovery systems claim up to a 30% increase in efficiency. The machine also has a 55kW burner and mechanical motors system and can offer efficiency savings through improved motors and variable speed drives. In addition to the technology side, some production process improvements are also achievable. These, according to (GPG 168), may consist of revising the dyeing and scouring programmes process times and reducing water usage to save overall energy input. Use of reactive dyes, needing lower temperatures (60 ˚C) for colour fixing, and the use of efficient mechanical drying, with suction slots, manglers, etc., can greatly reduce the drying energy cost on the stenters.

Other processes

These processes refer to Yarn manufacturing, Weaving, and the Finishing departments. Technologies in these departments mostly relate to rotation/vibration processes and conveyor belts, and extensively depend upon motors. This is reflected in the average power factor of the factory at 44% for March through to July (2012), which is also subject to improvement. These machines are automated and programmed through electronic controls. Most of the technology in these departments/sections is between 10-50 years old therefore some of these machines are strong candidates for more efficient motors, for example as advised by International Electrotechnical Commission**.** Motors in some newer machines have built-in variable frequency drives (VFD), and these drives could provide significant savings for some technologies where suitable. Considering the age of the technology in the factory, a review of the sizing of the motors is critical and should prove to be a helpful measure for energy saving. Studies on industrial motor energy efficiency have shown considerable potential in this area (McKane and Hasanbeigi 2011).

Utility plants

Compressed air and boiler units are common technologies across many different industries, with considerable guidance in published literature (such as Carbon Trust’s energy efficiency guides). Air and steam leaks in the distribution systems are the very first step that could be addressed to improve efficiency, and in many cases simple measures like lowering the steam and compressed air pressure can be quite beneficial. The compressed air units were manufactured in 2008 and can execute many energy efficiency features, which have not been fully harnessed. A comprehensive review on achieving energy efficiency in compressed air systems is given in (Schmidt and Kelly 2005). Boilers also operate 24 hours a day, seven days a week even when steam for production or heating is not required; this was specifically monitored through simple weekend boiler shutdowns by the author. Detailed studies about improving energy efficiency in boiler systems (GPG 369) are available for guidance. Inbuilt timers on both the boilers and the compressed air systems can be utilised to control their weekend/off-peak loads to make some simple savings. Also, both the systems are a good candidate for exhaust air heat recovery (Hasanuzzaman et al. 2012).

Energy consumption analysis

Table 1 shows the total energy consumption for 2011. Despite the demand for electricity being only one fifth of the total energy, its cost equals to half of the total energy bill. Therefore, even modest electric energy efficiency improvements could make significant contributions to cost savings. The table also shows the SEC which is discussed in detail below. Figure 2 shows daily electricity consumption with the number of factory holidays (taken from the factory’s holiday calendar) affecting the monthly demand, indicated with arrows. Reduced off-season demand can only be seen in October and November. This is when the production activity becomes slow and some sections in manufacturing (A) would either run smaller shifts or go on two-week holidays. The

Table 1. 2011 consumption

2011 utility	Energy Consumption		Cost		Specific Energy Consumption (kW·h /metre)
	MWh/year	%	£/year	%	
Electric	4,147.61	19.69	378,361	48.65	3.68
Gas	16,924.66 *	80.32	399,280	51.35	15.00
Total Energy	21072.27		777,641		18.68

**based on supplier's estimate invoices*

increased demand in December, January, and February, particularly representing the baseline and electric heating demand, indicates winter-related consumption. The on-season consumption is consistently high despite no heating being used from May through to end of September, indicating a production-related rise in demand. There are nine mechanical air handling units, 9.5kW each, that are used for both heating and cooling in the major production buildings. There are 10 air conditioning units, 3.5kW each, in the office buildings around the factory that are used for cooling only. This load considerably contributes towards demand in the summer.

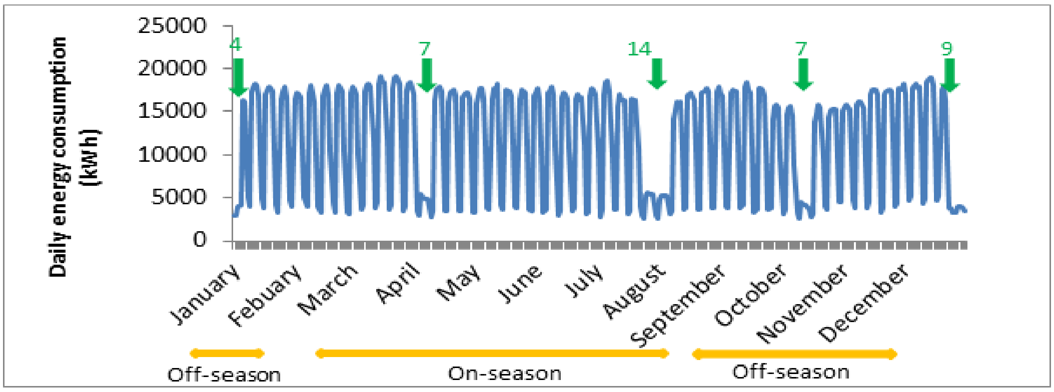
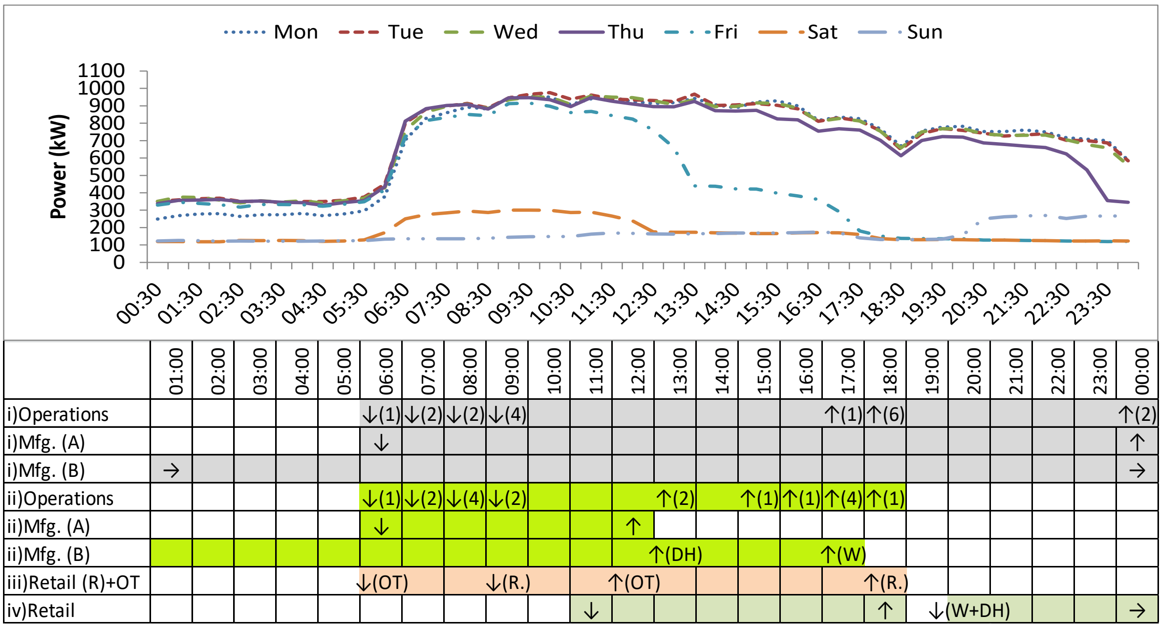


Fig. 2. Daily electricity demand

In Figures 3a and 3b, power demand profiles from Monday-Thursday are compared and peak-time for off-season shows a slightly increased demand, attributed to it being winter. However, off-peak demand, from 18:00 to 06:00, in off-season is relatively low indicating the reduced activity of manufacturing (B) as only the Weaving department works night shifts in winters. Another contributing factor is reduced activity in manufacturing (A) as discussed above. These factors happened to be the major contributors towards increased energy use and higher production costs in winter season as discussed in SEC calculations below. The fall of Friday curve at around 17:30 indicates the baseline demand. In spite of the reduced amount of off-season overtime between 06:00-12:00 on Saturdays, the curve looks similar to on-season. This also indicates winter related increase in demand and can also be observed through increased off-season baseline demand. The reduced demand between 20:00-00:00, for off-season Sunday, indicates that only one of the two departments of manufacturing (B) is working.

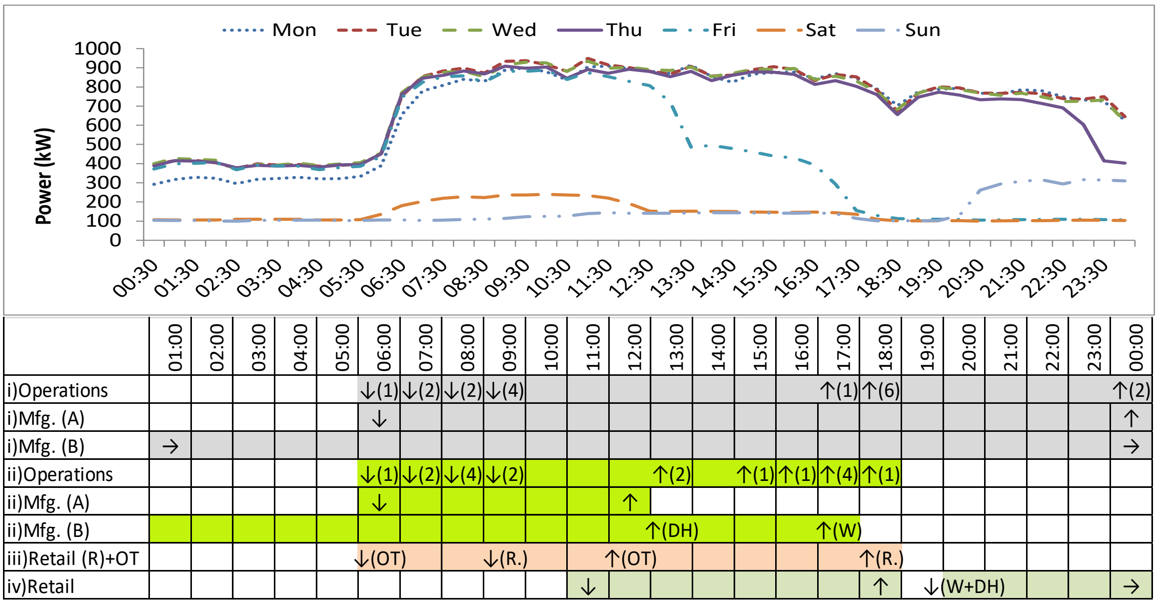
The analysis revealed an average peak-time demand between 850-950kW whereas for off-peak time it was reduced to between 250-400kW for both seasons, which represents the demand of manufacturing "B". The average baseline load was found to be 115kW, which might be considered reasonably high. The energy trend and patterns assumed through these profiles helped to understand energy consumption on a daily and half-hourly basis. The in-depth understanding at such a resolution was never possible by an ordinary energy survey or audit as mentioned above. The analysis also pinpointed some areas of energy saving, such as reducing the baseline energy use that would not have been visible through information collected on a monthly basis.

Monthly gas consumption, both estimated/invoiced (esti.) and manually collected (man.), are shown in Figure 4. In addition to disagreeing with the manual consumption curve, the estimate gas curve is found to be too high for



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
i)Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
i)Mfg. (A)						↓																		↑
i)Mfg. (B)	→																							→
ii)Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
ii)Mfg. (A)						↓						↑												
ii)Mfg. (B)													↑(DH)				↑(W)							
iii)Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
iv)Retail											↓							↑	↓(W+DH)					→

Fig. 3a. Off-season power demand



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
i)Operations						↓(1)	↓(2)	↓(2)	↓(4)								↑(1)	↑(6)						↑(2)
i)Mfg. (A)						↓																		↑
i)Mfg. (B)	→																							→
ii)Operations						↓(1)	↓(2)	↓(4)	↓(2)				↑(2)		↑(1)	↑(1)	↑(4)	↑(1)						
ii)Mfg. (A)						↓						↑												
ii)Mfg. (B)													↑(DH)				↑(W)							
iii)Retail (R)+OT						↓(OT)			↓(R.)			↑(OT)						↑(R.)						
iv)Retail											↓							↑	↓(W+DH)					→

Fig. 3b. On-season power demand

Legend

→	↓	↑	i	ii	iii	iv
Continued	Starting	Finishing	Mon-Thursday	Friday	Saturday	Sunday

The numbers in the brackets represent the number of sections starting/finishing. Manufacturing (A) includes Finishing and Yarn production, and the remaining sections of Operations finish an hour earlier before the midnight on Thursday. Manufacturing (B) includes Dye house (DH) and Weaving (W). R and OT symbolise Retail and overtime respectively.

June and July, indicated with arrows. This was to compensate for the missing estimated bill in May. Such problems with estimated bills, though common, not only lead to unfair charges but can seriously affect the SEC

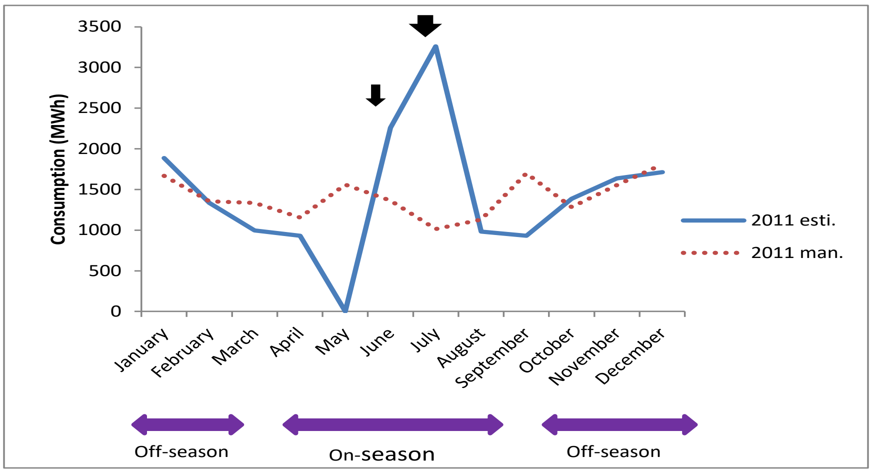


Fig. 4. Manual and estimate gas demand

calculations as discussed above and shown in Figure 5 below (where the total estimated energy consumption for May only shows the electricity consumption). However, when the total estimate/invoiced and actual annual consumptions were calculated, negligible difference was noticed. The graph also showed increased demand in off-season which is due to increased heating demand in winter. This drives the need of investigating the efficiency of the heating system as well as improving the quality of building fabric insulation. This analysis also prompted an urgent need for accurate billing.

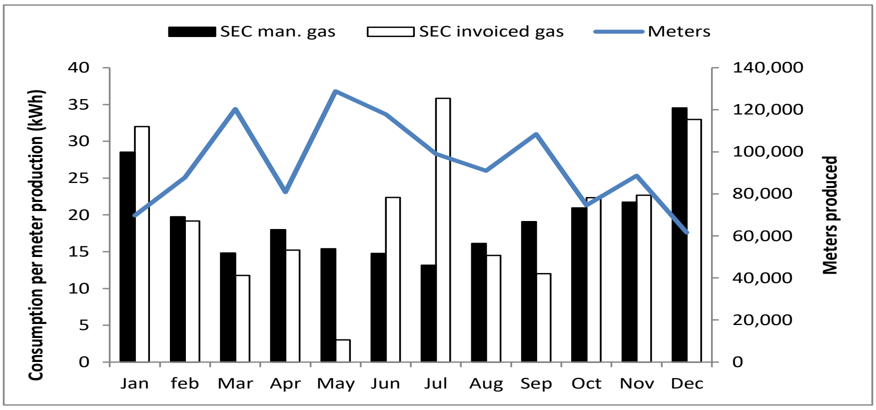


Fig. 5. Estimate and manual SEC and monthly metres produced

The effect of season and rate of production activity in the factory on SEC is shown in Figure 5. The SEC is low during on-season. It can be seen that higher monthly production rates improve the SEC, though increased heating demand in winter and slow production rates notably increase the SEC. It also shows that, other than the weather and season, there are more factors that could affect the SEC in such a complicated manufacturing process. Therefore, identifying these unknown factors (through sensitivity analysis and observing correlation with other parameters) and optimising their energy consumption through production management is another area that can potentially help to reduce and explain such patterns. The analysis based on higher resolution (daily meter readings) again offered a much better understanding of energy consumption, and energy saving opportunities, in the factory.

Conclusion

This study demonstrates that the textile manufacturing process is complex with a number of quite specific processes contributing to overall energy patterns. By using real-time energy data, the study attempted to estimate the energy consumption used in a case-study textile mill. The study revealed some technology and process efficiency improvements that might be feasible. Average energy demand profiles when compared to working patterns showed clear occupant- and activity-sensitive trends. Small differences in off- and on-season energy demand were attributed to winter related consumption in off-season. It was found that high monthly off- and on-season SEC variations were related to increased heating demand in winter.

Different areas of energy efficiency improvements in specific technologies were also identified. Waste heat recovery, improved performance of motors, and energy efficient lighting systems around the mill were found to be particularly promising. The energy audit and consumption analysis revealed some actionable measures directly supporting aims of energy saving. These included problems relating to a high baseline load, and investigations were made to benefit from this opportunity. The use of estimated gas bills was providing misleading information to the company (and their budgeting for energy), and this was highlighted as another area to address. The whole exercise proposed a thorough investigation of HVAC system and controls for possible opportunities of heating/cooling related savings. The study also suggested reviewing opportunities for building fabric insulation improvements. Some areas that were raised for further investigations include, disaggregating production and heating/cooling energy demands and the ways to reduce it, and identifying an optimum production rate for both off- and on-season for energy efficiency.

Such level of energy analysis is only possible through high-resolution real-time energy data and empirical observations that were made at the factory. This highlights the significance of energy data analysis for organisations wishing to improve energy efficiency and reduce production costs. The improved understanding of energy consumption that this can deliver can enable energy managers to make much better informed decisions on energy efficiency in an industrial workplace.

Acknowledgements

This study is part of a PhD project funded by the textile company Johnstons of Elgin, in collaboration with Heriot-Watt University.

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