ENERGY EFFICIENCY FRAMEWORK

AN APPROACH TO DEVELOP BEST PRACTICE IN THE CORRUGATED SECTOR OF THE PRINT AND PAPER INDUSTRY

Research conducted within

Smurfit Kappa

Research conducted by

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ABSTRACT

University of Derby

Abstract of dissertation submitted in December 2020 by Steve Parr for the degree of Doctor of Philosophy. Entitled 'Energy Efficiency Framework: An approach to develop best practice in the corrugated sector of the print and paper industry.

Purpose

The subject of energy efficiency plays a significant role in protecting future generations from the impact of carbon emissions in the environment. Morally and ethically everyone has a responsibility for improving efficiency and reducing energy use. It has been established that a key issue in doing this is one of addressing where to start. Therefore the research focuses on developing a framework to deliver energy efficiency best practice within the operational footprint of corrugated manufacturing operations.

Approach

The adoption of a framework approach was inspired by other researchers in the field of energy management. Whilst simple in its delivery the energy framework developed has been the subject of a significant research study. The approach has included action research with interviews and questionnaire research and its development can be considered emergent as knowledge and understanding is gained from experience.

Findings

The research has identified a gap in the knowledge within the corrugated sector of the pulp and paper industry. In defining this gap the research has actively developed an approach which has been trialled, tested and proven. In doing this the findings have

played a significant role in contributing to new knowledge and establishing an approach to adopting energy efficiency in the industry and developing best practice.

Considerations

This research has identified the need for a co-ordinated approach. Future opportunities exist in aligning standards, equipment and cultural aspects of delivering on energy efficiency. In terms of the research implications there are opportunities to establish credible literature and published materials from the study. It is believed that this research has a moral and professional responsibility to facilitate and enable best practice development throughout the corrugated industry.

Practical implications

The proposed framework was developed through action research and provides a structured way of implementing energy efficiency technologies within corrugated manufacturing operations.

Keywords

Energy Efficiency, Best Practice Development, Corrugated Manufacturing, Carbon Reduction, Action Research.

DEDICATION

In what has been a study of discovery and purpose I professionally dedicate this work to the industry in the hope that they will engage with the learnings, prosper from the outcomes and in doing so make the world we live in a more sustainable environment for future generations.

Personally this work is dedicated to the future of my grandchildren, Charlotte, Alfie, Jack and Ellie who will hopefully benefit from a world in which energy conservation preserves a way of life we have enjoyed for many years.

I would like to thank my family and friends for supporting me along the way with the many challenges faced with combining an academic research programme with the challenges of a full time role in industry. Special thanks must go to my wife Gill, who has been there when I’ve needed that extra push and motivation.

ACKNOWLEDGEMENT

I would not be the person that I am today without my parents (Ernest & Joyce Parr), my loving and supportive wife Gill and my family for whom I am eternally grateful for their support and understanding throughout my research studies. If in delivering this research I can improve the lives of my grandchildren in terms of the environmental impact of energy and carbon emissions then I will have achieved a great deal for all of them.

I am extremely grateful to the University for the support it has given me through my supervisors Simon Dupernex and Dr Tony Anosike who have worked with me and supported me throughout. They have understood the impact such a research project has when combined with a senior role in operational management. They have motivated me to overcome challenges in combining academic standards with business centred requirements in completing the research.

In thanking the research organisation, Smurfit Kappa, the input, support and commitment given to support the research study was truly inspiring. In providing time and the resource opportunity for the study. In supporting the development of the framework and in providing opportunities to network throughout the industry. I would hope their trust has been repaid in the delivery of the framework and associated benefits delivered during the period of the research activity.

Finally without the input of so many contributors the research would have been less insightful. Many years of experience have been assimilated and understood and for those experiences I am grateful and the research is much richer for them. A special acknowledgement to a friend and a true Master in his field of expertise, Ian Bailey.

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PROLOGUE

In setting out on this research I strongly believe I have a duty and responsibility to support the research organisation and also the corrugated manufacturing industry. Having worked within Operations for forty years it is not possible not to consider energy efficiency in some way or other. But I would propose that the need for energy efficiency is far clearer now in the 21st century than it has been before.

In setting out the goals and objectives of this research I am aiming to develop a framework that I strongly believe and propose will lead to the establishment and adoption of a best practice approach within the corrugated industry. My challenge will be how to develop such an approach and ensure that it is recognised and acknowledged by key stakeholders.

There is a recognition that sometimes we can jump into a subject and take actions that can deliver results, but in doing so sometimes underestimating the value of our actions and the reason for doing them. In setting out on this research I propose to establish the theory behind energy efficiency, the views of the key industry players and a way to practically deploy the developed theoretical approach.

Whilst starting out on the research study I recognise that I may be challenged by many aspects of commerciality, competition and conflicting / differing opinions. My goal is to determine what specific benefits and opportunities can and will be delivered within the research organisation during my research study. Having completed the thesis, post publication, I strongly believe that I have a role in developing a much wider awareness across the industry. In doing this it is my intention to help the research company, its customers and wider industry players and trade organisations to drive energy efficiency.

Steve Parr

Researcher at 'The University of Derby'

2015 - 2020

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LIST OF PUBLICATIONS

Publications related to this research topic

Parr, S., (2015), 'A proposed methodology to implement energy efficiency best practice,' *Critical Perspectives on Business Management, Derby University, UK, Issue 4, July, pp62-65*

Conference Papers

Parr, S., (2019), 'Delivering energy efficiency – framework approach to corrugated operations.' *Proceedings of the SK UK Corrugated Executive Committee Conference, Sutton Coalfield, UK, December.*

Parr, S., (2019), 'Energy efficiency - a framework approach to optimisation', *Proceedings of the SK Operational Directors Conference, March, UK. 4th-5th December.*

Parr, S., (2019)*, 'Saving energy and improving efficiency in the factory.' Proceedings of a Joint Consultative Committee Forum, Birmingham, UK. 29th-30th August*

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Parr, S., (2017). 'Energy savings opportunities in corrugated operations.' *Proceedings of an Operational Directors Conference, Bristol, UK, January 31st – 1st Feb*

Parr, S., (2016), 'How to develop a case for energy efficiency in a corrugated manufacturing plant.' *Proceedings of an Engineering Technology review, Norwich, UK, 26th-27th April*

Parr, S., (2015), 'A proposed route to improve energy efficiency within corrugated operations.' *Proceedings of the European Technical Operations Management Conference, Amsterdam, Belgium, March 4th-5th*

Chapter 1 Introduction

1.1 Introduction

The chapter provides an insight into the research background and rationale, outlining the aims and objectives. The environmental impact of the industry is reviewed. The research company is introduced along with key manufacturing processes.

As an introduction to both the research and the topic of energy the key areas and relevant issues and activity are considered. Firstly the subject of energy and climate change is considered as a global issue together with its impact. Having considered climate change the chapter will then focus on the pulp and paper industry, specifically ***corrugated*** manufacturing operations. The scale and scope of the industry will be considered together with the intensity of the operations.

The research has been facilitated through Smurfit Kappa, one of the leading providers of paper based packaging solutions across the globe. The scale, size and key drivers of the company are explained, along with an understanding of the approach currently being taken to manage sustainability. The chapter will then explain the paper making process, providing an understanding of each stage of the manufacturing process.

In conclusion the chapter will summarise the research aim, defining the rationale for the research, providing a suitable argument that substantiates the aim and objectives. It is proposed that the research will provide the corrugated business with a structured approach to energy reduction. This is intended to be replicated consistently in a standardised way to drive energy efficiency and carbon reduction.

1.2 Climate Change & Energy

Climate change is a subject that is widely communicated, publicised and has many individuals and organisations supporting the drive to reduce carbon and save the planet.

There is much evidence to support the belief that carbon emissions are directly linked to climate change as shown in a short review of published articles on the subject matter.

The first statement in the European Union's Intergovernmental Panel on Climate Change (IPPC, 2018) stated that human induced global warming has already caused multiple observed changes in the climate system. Through research of this subject it is suggested that there is very little evidence to disprove this theory from published materials.

For anyone wanting to question the relevance of climate change in our world today the report by the (IPPC, 2018) covers many aspects of scientific, technical and socio-economic importance. Having read the research and considered the views presented, an individual would find difficulty in not accepting the facts and importantly not being motivated by the need to mitigate further damage caused through climate change.

Evidence published and reported by the team at the NASA Goddard Space Institute (GISSTemp, 2017) suggests that Climate Change is already here and is only going to get worse. Temperatures are reported by NASA to be breaking records around the world, with the 21st Century having seen the most temperature records broken in history. Multiple studies are reported by (Riebeek, 2010) to show that 97 per cent of researchers actually believe global warming is due to human activity. It could be suggested that the issue is human activity and not humans per se.

There are many publications that explain the impact of climate change on the planet (Beggs, 2013). The work of Beggs would propose to substantiate the claims of a fragile planet under threat of further climate change. In it Beggs considers why climate change occurs as a result of greenhouse gases damaging the earth's atmosphere. The research is clear and provides clarity on how the world is changing through human actions. This supports the view that it is human activity that is impacting the energy environment.

It is reported (Foster, 2013) that respected climate change scientist James Hansen has suggested that it is already too late. The work by Hansen puts forward that it is the responsibility of generations of life on the planet to implement the necessary actions to protect life in a timely manner. This is suggested to be an engaging study and one that should stimulate morality in its readers.

It is suggested (Shove, 2018) that there are two ways to reduce carbon emissions, one is energy efficiency and the other is decarbonising the supply. Further work reported by Shrove references the European Council for an Energy Efficiency Economy in 2016 which put energy efficiency first in the line of responses to climate change. Supporting this the International Energy Agency (IEA, 2015) asserted that energy efficiency is key to ensuring a safe, reliable and sustainable energy system for the future.

It is recognised by this research that energy efficiency is only a part of a carbon reduction programme. However, specifically the research has the opportunity to develop and shape an approach for carbon reduction based on energy efficiency within the research organisation. Other published materials (Wolfe, 2013) recognise the benefit of a structured energy efficiency approach, and this supports the research proposed.

The Paper & Pulp industry globally has over 950 mills, 520 companies and is a high energy intensive operation, rankling fourth in the industrial sector for energy use. The corrugated division falls within this industry sector as an integrated operation that at times can be linked directly to the mill paper making operation.

1.3 Paper and Pulp Industry (Research Problem)

Published work (Kong et al, 2012) has already been undertaken to understand and assist energy efficiency and reduction and is supported by further work in this area (Lawrence et al, 2018). Both studies concluded that it would be difficult to generate new knowledge in the area of paper making and bring new insight into an already saturated area of research.

Work summarising the impact of energy efficiency in the paper industry is published and acknowledged (Farla et al, 1997), whilst the Energy Efficiency Report published by the International Energy Agency (IEA, 2015) looked at energy efficiency improvements in IEA countries in 2015 and 2018, showing marked reductions in the use of energy.

Long term energy efficiency improvements in the pulp and paper industry have been clearly defined (DeBeer et al, 1997). In German research (Fleiter et al, 2012) 17 process technologies were identified that existed to improve energy efficiency in the paper and pulp industry through to 2035. None of this research was transferable to corrugated operations as it was specific to the paper making processes.

There is much written in the area of paper and pulp, specifically within Europe. The Confederation of European Paper Industries (CEPI) has produced many papers on energy reduction and efficiency in the sector such as 'The Two Team Project' (CEPI, 2018). This covers the roadmap to 2050 and suggests the steps to achieve an 80% CO_2 emission reduction in paper mills and pulp.

It is believed that these published articles demonstrate a wealth of knowledge and experience in the area of energy within the paper making processes associated with mills. The extent of activity would appear to be significant, although the improvement in efficiency remains unclear. What is clear is the lack of reference with regards to corrugated manufacture as an area of study or energy efficiency work.

From data produced and reported in the Annual Report by Smurfit Kappa (Smurfit Kappa, 2015) a typical paper mill will consume over 1,350,000 GJ of energy produced through a combination of combined heat and power generation (CHP), national grid power and direct fossil fuels used for traditional industrial boiler operations.

A typical corrugating plant in Smurfit Kappa is reported (SK Annual Report, 2015) as consuming 75,000 GJ. So a much smaller energy requirement than a paper mill and differing opinions on the energy intensity are made.

It can be seen it the Annual Report (Smurfit Kappa, 2015) that corrugated operations represented 8.8% of the emitted CO2 in Europe within Smurfit Kappa. This is later recognised in the Smurfit Kappa Sustainable Development Report (Smurfit Kappa, 2018) as a significant area of opportunity and the company has committed to deliver further improvements in this area.

Previous figures reported by the Carbon Trust (2008), in 'A guide to the Paper Sector,' show the energy use within the secondary processes in the paper industry shown in Table 1.1.

Production			
Printings and Writings	(tonnes)	1,040,070	
Packaging Boards	(tonnes)	330,285	
Newsprint	(tonnes)	1,100,038	
Speciality and Other	(tonnes)	552,413	
Tissue	(tonnes)	825,810	
Corrugated Case Materials	(tonnes)	1,329,262	
Total	**(tonnes)**	**5,177,878**	
Energy Use			**CO_2e**
Total fossil fuel	(GWh)	16,718	3,344
Total imported electricity	(GWh)	2,512	1,356

Table 1.1: UK Paper production energy and use (Carbon Trust, 2008)

The data shows the energy use in what is considered a high intensity energy user group within the paper sector. Significantly the highest proportion of output manufactured from paper in tonnes is manufactured into corrugated case material. The data unfortunately does not segment the energy use into similar classifications, however it does show the heavy reliance on fossil fuels for the manufacturing process.

The scale, size and key drivers of the research company are covered within this research. However the literature review will seek to establish the focus on corrugated manufacturing, as it would appear there is a significant amount of work in paper, with very little in corrugated.

1.4 The Corrugated Industry (Research Gap)

From the published literature reviewed in Chapter 2, the review will set out to establish that the corrugated sector is overlooked when considering energy efficiency. It is suggested that whilst the focus is on energy intensive sectors in the mill system, corrugated plants should also be a focus area for energy and carbon reduction. Carbon produced from corrugated plants was reported to equate to 412 ktonnes in the Annual Report (Smurfit Kappa, 2015). In many ways this can be considered a significant volume of carbon emissions.

The corrugated market is reported by the Federation of European Corrugated Manufactures (FEFCO, 2014) as having a market size of 43.4 billion m^2 of manufactured sold product. Three key players dominated share of the European market within the corrugated packaging sector, based on information provided (Osment, 2015) in the Strategic Corrugated Sector Guide.

The three main corrugated companies, Smurfit Kappa, D.S. Smith and Saica are reported (Osment, 2015) to represent 55% of the corrugated market shown in Figure 1.1. As such it is suggested that they can be considered industry leaders with a responsibility to drive energy efficiency.

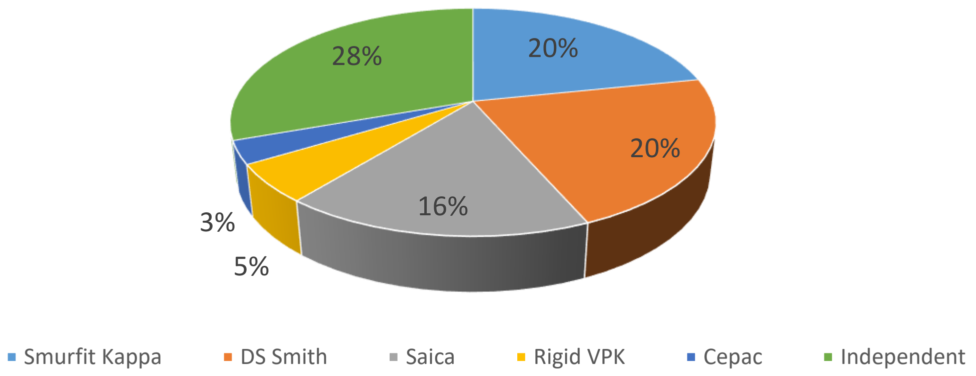

Figure 1.1: Share of UK Corrugated Market (Osment, 2015)

The top 3 companies in the industry sector, Smurfit Kappa, DS Smith & Saica all make statements in their Annual Reports towards carbon commitments and emissions.

Recognising the focus all manufacturers take on paper plants there would appear to be a lack of a similar approach to corrugated plant operations. There is a lack of comparative data reported across the industry sector.

From annual company reports issued by Saica (Saica, 2015) stated that they reduced CO2 emissions by 8.1% with respect to the previous year whilst DS Smith (DS Smith, 2015) reported that it delivered an 8.1% Co2E carbon reduction per tonne of product produced against the previous year.

In comparison Smurfit Kappa (Smurfit Kappa, 2015) reported a 22.6% reduction of fossil fuel CO2 emission per tonne of produced paper since 2005. This appears to show that all companies are working on energy efficiency, however there is no clear way of understanding the longer term trend or of comparative analysis of performance referenced.

The use of packaging materials (Osment, 2015) is considered to be in continual growth and in 2012 it was reported that paper and paperboard represented 36% of the total use of material across the world. This figure was second only to plastic at 38%, which has been suggested by Savinov (Savinov, 2013) will continue to see future decline due to green recycling pressures from lobbyist organisations and legislation.

1.5 Introduction to Smurfit Kappa (Research Organisation)

Smurfit Kappa Group (SKG) a FTSE 100 company, is one of the leading providers of paper based packaging solutions in the world. The company has approximately 370 production sites across 35 countries with around 46,000 employees. In terms of geography the business is located in 22 countries in Europe and 13 in the Americas reported in the Annual Report (Smurfit Kappa, 2017), represented in Figure 1.2.

Within its strategy SKG focusses on the environment, with products that are '100% renewable and produced sustainably'. The objective put forward by Smurfit Kappa

(Smurfit Kappa, 2017) is to protect the environment and progressively improve their performance.

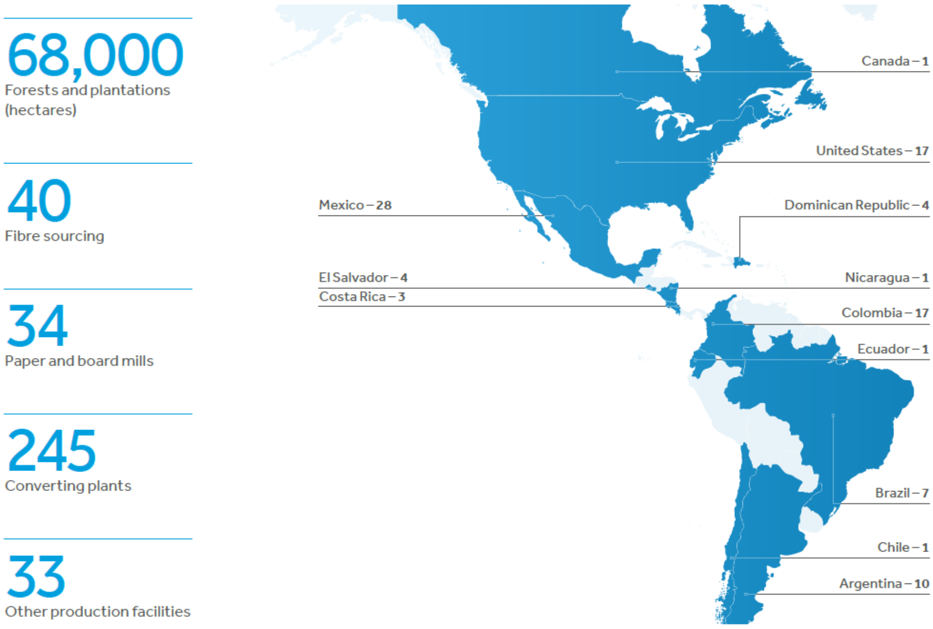

Figure 1.2: Company overview (Smurfit Kappa, 2018)

1.5.1 Sustainability

Smurfit Kappa stated its sustainability objectives in the published 'Delivering a better Tomorrow' (Smurfit Kappa, 2019) sustainability report with respect to carbon emissions as:

'***Reducing the carbon intensity of the energy mix by cutting fossil fuels and promoting renewable sources where economically viable.'***

The company suggest introducing closed loops in the production process to save energy through a three-pronged approach:

- Efficient energy generation
    - Investing in highly efficient Combined Heat and Power (CHP) systems.
    - Improving the efficiency of our current boiler houses, minimising heat losses

- Energy saving programmes
    - Reducing our energy use by investing in research and new technologies
    - Investing in fossil CO2 reductions
- Carbon emissions reduction
    - Shifting to lower CO2 fuels such as biomass and natural gas

There are four key areas of the organisation, Paper, Packaging, Recycling and Forestry. The company designs, manufacturers and supplies paper based packaging to package and promote their customers products. The company reported in its 2017 Annual Report that it manufacturers over ten billion tonnes of corrugated packaging per year.

Carbon is one part of the companies objectives stated in the company's Annual Sustainability Report (Smurfit Kappa, 2018). The targets from this are shown in Figure 1.3, which within the 2018 report were updated and aligned with the 2030 United Nations Sustainable Development Goals.

	Previous Target	Updated Target
FOREST	2020 Target **90%** of packaging solutions sold as Chain of Custody certified to customers	Continuous Target **90%** continue to operate at this level
CLIMATE CHANGE	2020 Target **25%** reduction in fossil fuel emissions intensity	2030 Target **40%** reduction in fossil fuel emissions intensity
WATER	2020 Target **33%** reduction in Chemical Oxygen Demand intensity	2025 Target **60%** reduction in Chemical Oxygen Demand intensity
WASTE	2020 Target **30%** less waste to landfill	2025 Target **30%** less waste to landfill
PEOPLE	2013 - 2018 Target **5%** reduction in Lost Time and Injury Rates annually	Continuous Target **5%** reduction in Total Recordable Injury Rate annually

Figure 1.3: Updated Sustainability Targets (Smurfit Kappa, 2018)

In a circular business model (Smurfit Kappa, 2017) shown in Figure 1.4, the company provides recycling facilities for corrugated packaging and paper is recycled responsibly, efficiently and reliably. Over 6 million tonnes of recovered paper is reported to be recycled across the globe. Completing the model SKG owns and operates over 100,000 hectares of forest globally, ensuring responsible sustainable development.

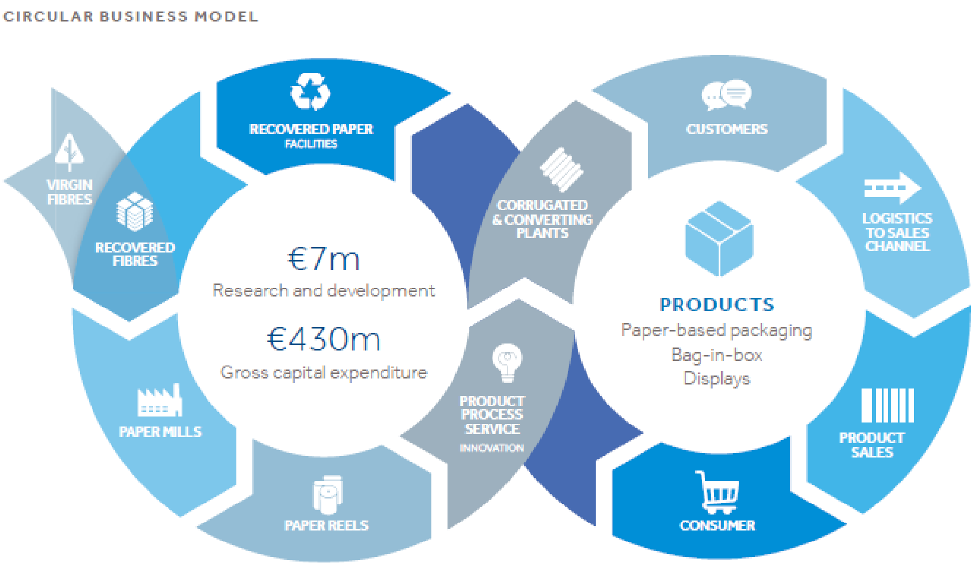

Figure 1.4: Circular Business Model (Smurfit Kappa, 2017)

1.5.2 Material aspects

In published Annual Reports (Smurfit Kappa, 2017) these key areas defined were expanded in the business model to look at 'Materiality' which relates directly to assessing the sustainability factors identified within a business environment.

Previously the company set itself a target to reduce fossil fuel emissions per tonne of produced paper by 25% by 2020 in comparison to the 2005 baseline. In was reported (Smurfit Kappa, 2017) that fossil fuel CO_2 emissions per produced tonne of paper had reduced by 26.1% since 2005. This was stated (Smurfit Kappa, 2017) was achieved through investment in energy efficient operations across the globe, with paper mills seeing a high degree of reduction in the high energy intensive operations.

MATERIAL ASPECTS FACING SMURFIT KAPPA

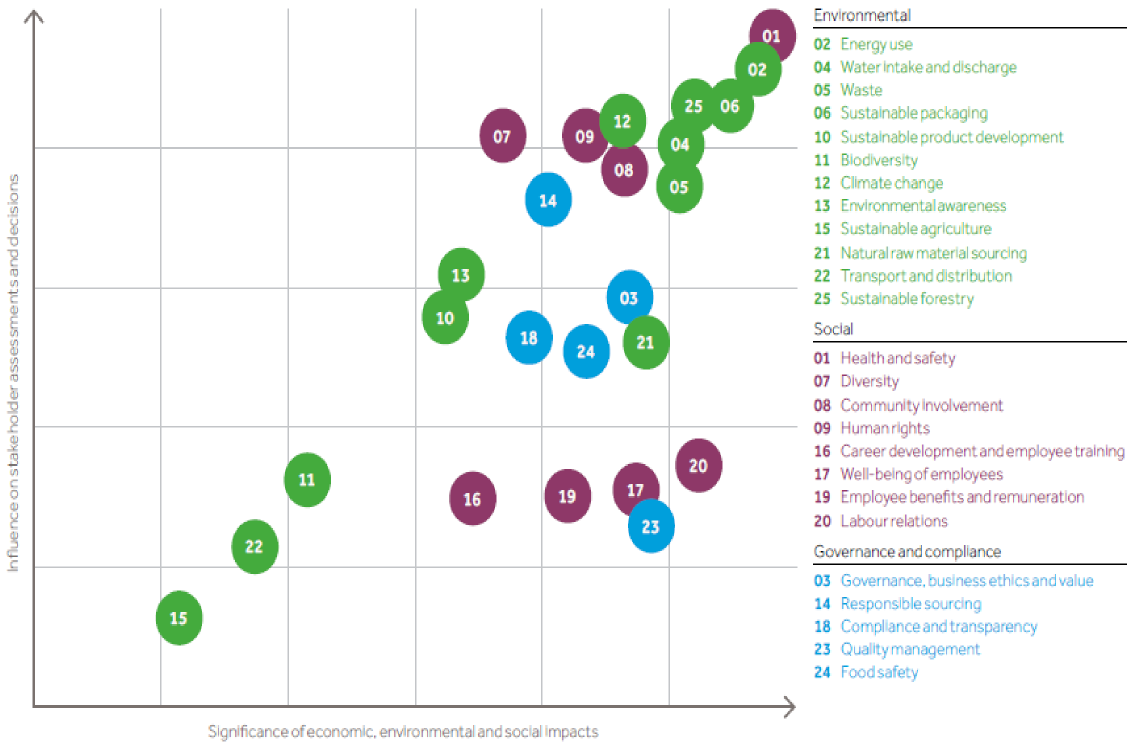

Figure 1.5: Material aspects facing Smurfit Kappa (Smurfit Kappa, 2017)

In considering these material aspects facing the company, shown in Figure 1.5 (Smurfit Kappa, 2017) the company identified that within an environmental context energy use had the highest significance of economic, environmental and social impact when plotted with the influence on stakeholder assessments and decisions.

The company has stated in its Sustainability Report (Smurfit Kappa, 2017) as having recognised that reducing specific fossil fuel emissions cannot be achieved without energy efficiency. Reviewing the performance figures the company has improved the energy efficiency of its paper mills by 13%. It is suggested by the report that corrugated packaging plants are by nature less energy intensive than a mill.

There is no mention of energy activity to reduce carbon emissions within the companies corrugated operations. The most recent reference to this was made in the Sustainable Development Report (Smurfit Kappa, 2019) in that SKG would assess energy usage reduction opportunities in its converting operations by 2020. This it is proposed would involve an active programme of energy activity following an initial review. This should deliver savings in line with the companies approach and performance within the paper side of the business.

1.6 Manufacturing plants in Smurfit Kappa and their operation

The typical flow from raw material through to finished product can be seen graphically represented in Figure 1.6. Within the industry it is suggested (Smurfit Kappa, 2015) that there are different types of supply chain models for corrugated containers. These are represented in the following diagrammatic representation of the supply chain;

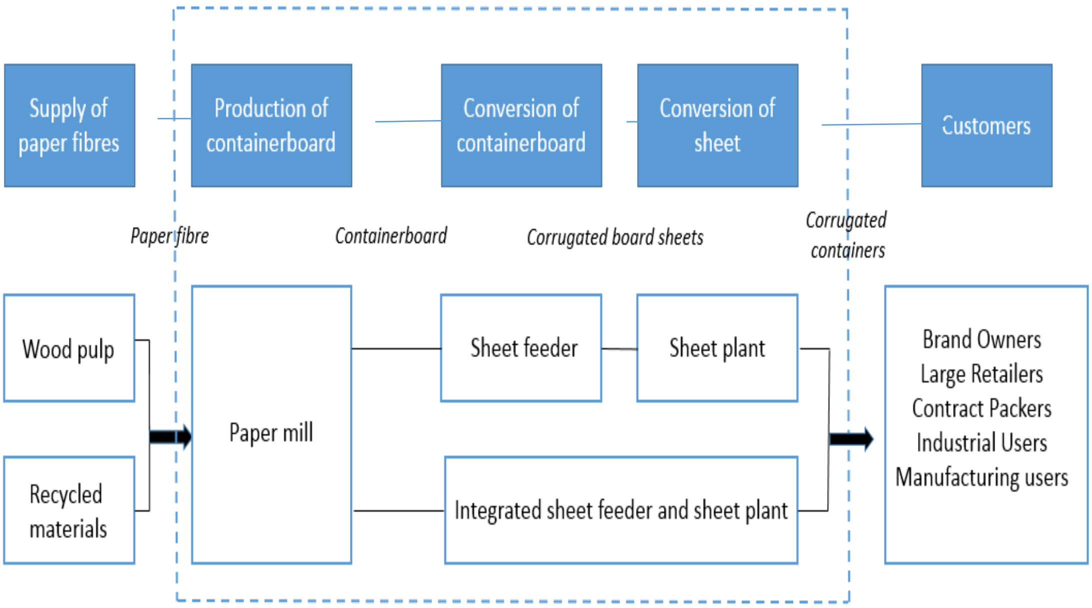

Figure 1.6: Integrated manufacturer in the corrugated industry (Smurfit Kappa, 2015)

The scope of the research focuses on the corrugating process which can be considered to be from receipt of manufactured paper to despatch of finished packaging solution to the customer. It is stated (Smurfit Kappa, 2017) that there are three recognised different types of plant, Sheet Feeding, Integrated and Sheet Plant (Converting). A sheet feeding plant has only corrugated board manufacture, an integrated plant has corrugated board manufacture and post manufacturing activities such as printing and box making. The third type of plant, sheet plant, has only post manufacturing activity such as printing and box making. Each type of plant will differ in size, energy consumption and output.

There are a number of basic operations involved in producing packaging solutions post the paper production process (Thompson, 2018). These are covered within the terms corrugating and converting and include;

- Combining layers of paper to form a corrugated board
- Printing
- Slotting and scoring the boxes
- Gluing

Whilst these are considered later with regards to equipment operation and energy consumption, the specific technical aspects of the process are not within the study. The following sections explain the primary processes of corrugating and conversion, with examples of finished packaging solutions shown.

1.6.1 Corrugating

The corrugator is a large automated and technically controlled machine, often around 100m in length. The corrugating operation focuses on heat treatment and conditioning of the paper. This is reported (Twede et al, 2015) as being carried out through steam filled rollers which transfer heat into the paper and enable a flute to be formed due to the pliability of the paper. The research suggesting a high thermal energy demand.

The manufacture of board is carried out on a corrugator as shown in Figure 1.7. The process brings together paper, starch and heat treatment to produce a layered board product. In order to produce strength in the resulting board layers of paper are bound together with glue starch to provide an inner, outer and fluted section of the board. The fluting can have different shapes and the paper can vary in thickness, all determining the strength and durability of the finished packaging.

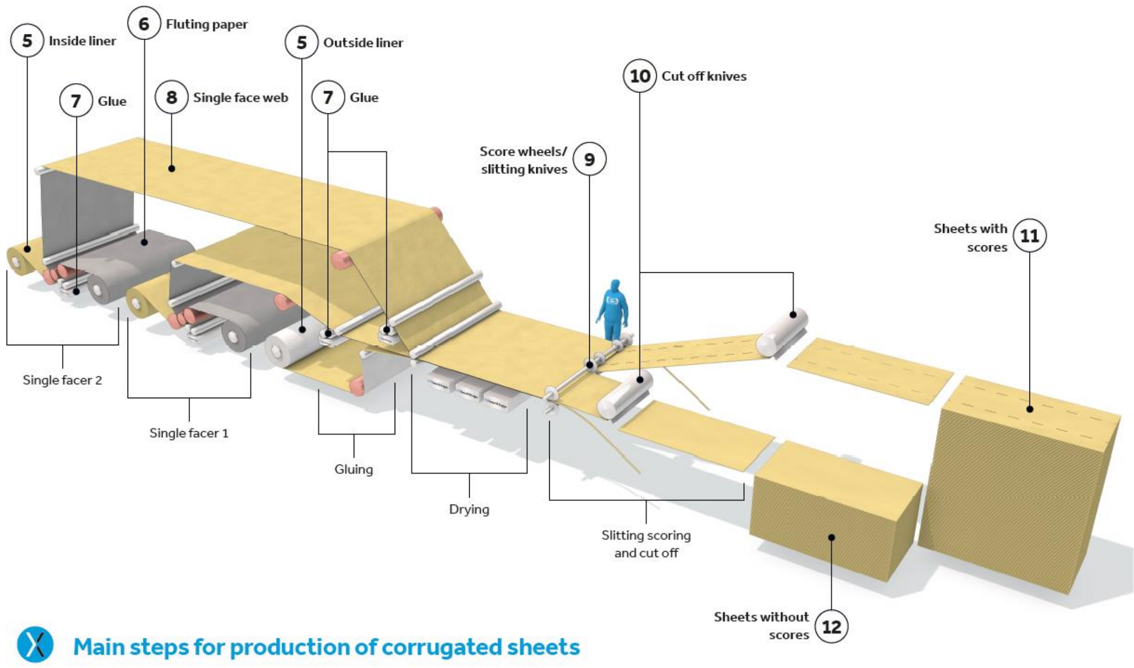

Figure 1.7: Typical stages of corrugating manufacture (Smurfit Kappa, 2018)

The corrugated board is made up of an inner liner, flute and outer paper material. The equipment facilitates the bonding of these through the application and use of glue. This glue enables adhesion due to its gelatinisation at high temperatures generated by the heat from the steam to produce a typical structure shown in Figure 1.8.

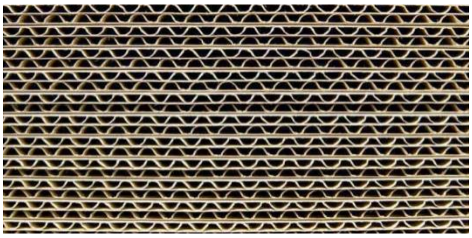

Figure 1.8: Corrugated board (Smurfit Kappa, 2017)

The process utilises energy in the form of steam and electricity at this stage to manufacture the board. Steam is used to pre heat the paper, before heat treatment with subsequent heat transfer utilised to enable fluting production.

The use of energy in the corrugated industry production process is an important factor in the conversion of raw materials into finished product and all conversion processes operate by consuming energy in one form or another. The amount of energy consumed in this process can vary greatly from one operation to another. The cost of energy playing a considerable factor in determining manufacturing cost price, and therefore competitiveness.

1.6.2 Conversion

Manufactured board is converted into packaging solutions through a number of equipment technologies. Products that are simple and have straight board lines are often made in a straight line process on a flexo folder gluer (FFG). More complex packaging designs were originally and still are made on a die cutter.

The FFG machinery takes corrugated board on the infeed and provides printing, cutting, creasing, and slotting operations to facilitate the finished box. The printing is delivered through flexographic printing processes. Having carried out these stages the FFG may have a final box making section that through a series of belts and folding rails takes the blank and creates a glued box.

Packaging manufacturers it is suggested (Twede et al, 2015) integrated die cutting machines to have FFG capability. These can be manufactured on a flat platen, such as a flatbed die cutter (FBDC), or alternatively at higher speeds on a rotary FFG machine. These converting machines use energy in the form of mechanical and electrical energy through the converting operations.

Other forms of printing that can be used include preprint, litho-lamination and more recently digital printing. Different print types provide a varying degree of quality resolution, accuracy and detailed print finish. Some formats of packaging are not printed, however more common is multi coloured printing.

Following the manufacture of board this is converted into packaging solutions. There are a number of different approaches to achieve this with packaging of trays, boxes, cases and simple layer board. At this stage the customer design for product merchandising is applied to the packaging. This is done normally through in line printing operations, with post print, flexographic, lithographic and recently digital print being suitable technologies.

The following schematic in Figure 1.9 shows the stages of converting corrugated board into finished packaging solutions within a typical converting process.

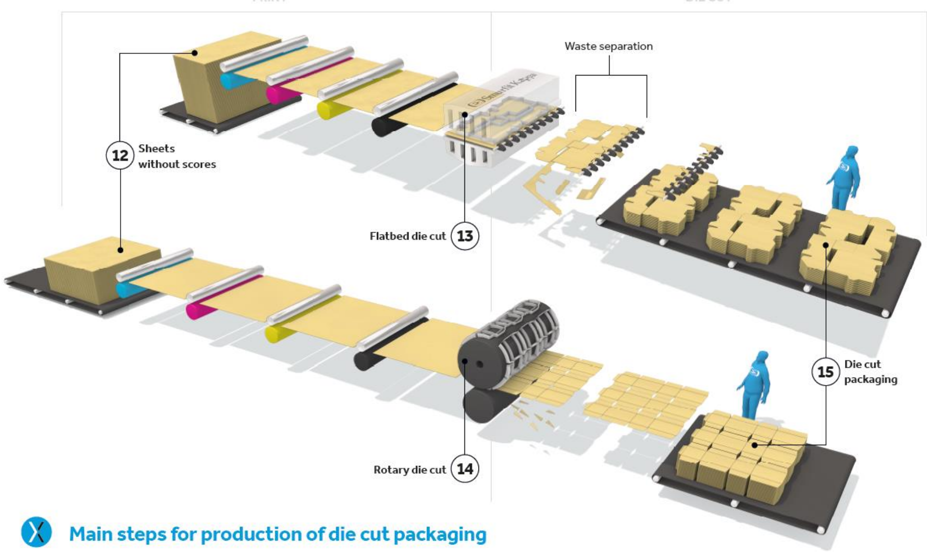

Figure1.9: Converting process schematic (Smurfit Kappa, 2018)

1.6.3 Corrugated Packaging Finished Goods

Once converted packaging is now fit for purpose and available for shipment to the customer. It is proposed that the supply chain is another area for potential further research outside of this study in the area of climate change impact. It is recognised (Smurfit Kappa, 2017) that supply chain dynamics impact on both the supply and customer use of packaging. In this way packaging impacts the carbon footprint of the supply chain.

In order for supply chain dynamics to be understood it is suggested in the Annual Report (Smurfit Kappa, 2017) that considerations must include packaging, transport, storage and product presentation and that sustainability will be influenced by such concepts as circularity, innovation and inclusivity. In considering the scope of the research this is the outer boundary of the study, where the supply of packaging leaves the factory and progresses onto the customer.

In order to better understand packaging formats examples of different packaging are shown for reference purposes in Figure 1.10 produced by Smurfit Kappa.

Standard packaging | Industrial packaging | Food packaging | Bag in box

Consumer packaging | Shelf ready | E Commerce | Point of sale packaging

Figure 1.10: Types of packaging manufactured (Smurfit Kappa, 2018)

1.7 Research Aims & Objectives

In defining the research programme the following aims and objectives and research questions were established.

1.7.1 Research aim

The research aims to understand the application of energy efficient technology in relation to corrugated plant energy consumption. In doing so it will seek to establish a validated energy framework for delivering structured improvement across the corrugated cardboard manufacturing operation within the research company.

1.7.2 Research objectives

The following objectives were set out for the research study and agreed with the company and academic institution;

Objective 1

Review and investigate the literature on energy reduction and energy efficiency to identify gaps in knowledge to formulate and build a foundation for primary research.

Objective 2

Develop an initial understanding of energy consumption by equipment within operational sites and carry out primary research to review opportunities for the application of energy efficiency technology.

Objective 3

Following resulting outcomes of objective two carry out a specific energy review across key factory sites to establish predictive improvements and implement identified improvement opportunities.

Objective 4

Having considered, predicted and implemented specific energy efficiency technology to reduce consumption within plants, evaluate the potential impact of these approaches.

Objective 5

From the research design and develop a strategic framework that can be implemented across corrugated factories to drive energy efficiency.

1.7.3 Research Contribution and originality

The literature review will identify and define the research gap. In doing this the study will also look to better understand the gap in current knowledge with respect to key industry stakeholders. This will be conducted through a structured questionnaire that is planned to be utilised within the research. This provides an opportunity to introduce a critical perspective from key corrugated industry players who have a major influence on energy within their operations.

In establishing new knowledge the research will seek to understand what is known now that wasn't known before and what can we do now that we couldn't do before. This will be predominantly with respect to the research organisation, but will obviously be expansive through the Literature Review in Chapter 2 and the Action Research in Chapter 6.

1.7.4 Research Gap

It is proposed by this research that a structured energy efficiency framework, when established and adopted, will deliver a more focussed and effective solution to carbon reduction. This research proposes that the gap in this area of energy efficiency within the corrugated sector provides a significant opportunity to drive improvement. The formulation of such an approach is proposed to provide the industry with the opportunity, validated through this research, to deliver new knowledge and thinking that will enable action.

Literature is reviewed and covered in detail in Chapter 2 with regards to energy efficiency within pulp and paper operations. These are detailed peer reviewed articles of research none of which contain references to corrugated manufacturing operations (Kong et al, 2012), (Utlu & Kincay, 2012), (Hong et al, 2011), (Rogers et al, 2018), (Helin et al, 2016).

German research (Fleiter et al, 2012) identified 17 process technologies that existed to improve energy efficiency in the paper and pulp industry. This work looked out to 2035 in discussing potential opportunities for energy efficiency. None of the reviewed areas in the work by Fleiter are relevant for corrugated manufacturing operations, as the focus is on the paper mill and the core paper making processes.

Other published work (Peng et al, 2015) with respect to energy efficiency in the Chinese pulp and paper industry was reviewed. The work concluded that the energy efficiency of the sector in China had improved but was still behind the world's advanced level of efficiency performance. This work again focuses on the heavily energy intensive area of paper making processes and mill operation.

Further evidence of work undertaken in Italy (Fontini (2014), from Taiwan (Lin, 2014) and in Sweden, Netherlands and Poland (Laurijissen, 2012) has been reviewed. A common theme of specific paper industry operations is evident which have no cross over to the corrugating manufacturing process.

There is a clear lack of published information specifically relating to the corrugating process and operation. This lack of published material shows the importance and need for further research within this area. The potential result of this gap is that it is suggested that there is a lack of knowledge and understanding with regards to what to actually do to drive energy efficiency.

It is suggested by this research that there needs to be a way to identify, select and implement technologies that improve energy efficiency. In doing this the research proposes that the development of an energy efficiency framework can significantly improve energy efficiency.

The research is intended to stimulate interest in the development of standards, the establishment of a technology approach that simplifies the process and also in heightening the awareness of energy efficiency within the organisation. It is anticipated that the research will inform the industry and in doing so deliver a positive carbon reduction during the life of the research study.

It is anticipated that upon conclusion of the research study the learnings and outcomes will be used to bring the corrugated industry forward in its thinking. The research will provide an approach that helps support carbon reduction in an effective way that is both cost effective and energy saving. The research will significantly advance the thinking within the industry whilst benefitting the research organisation from the research study.

1.7.5 Research alignment

The research proposal was reviewed in detail against the company vision and objectives. It was found that the proposal directly linked into the stated sustainability objectives and also into the specific UK country strategy. It was commented by the UK CEO of Smurfit Kappa, Clive Bowers in 2015 that the energy efficiency work would be a vital element of business performance over the coming years and would add industry learning, whilst contributing to the academic learning of the research proposal.

Additionally it is proposed that this research will enable the wider corrugated industry to benefit from the energy efficiency research and framework. The research proposal was presented and received support from the Federation of European Corrugated Manufacturers (FEFCO). In discussions with key stakeholders Marc Van Damme, Chairman of the FEFCO Production Committee commented in 2019 that ‘ The research will play a valuable role in helping companies understand the best approach to energy efficiency, which will save time and money for our operations’.

Following the outcome of the proposed research FEFCO would aim to publish content within their internal industry network, developing standards and policies for energy efficiency across the industry.

1.7.6 An approach to developing best practice

In establishing the research approach it is important to consider what best practice is and how it can be measured. Best Practice is defined (Cambridge English Dictionary, 2021)as ‘a working method or set of working methods that is officially accepted as being the best to use in a particular business or industry, usually described formally and in detail.’

Best practice can cover a vast array of disciplines which has become a catch phrase which is overused and misused (Osburn et al, 2011). In this publication Osburn suggests that there are three ways to classify best practices which include broad generic definitions, field specific definitions and technique specific definitions.

Often Good Practice is used as a term to reference a collection of working methods. In a Guide to Good Practice in energy efficiency (European Commission, 2018) the report suggests good practice examples. These are proposed as ways to improve energy efficiency and are not claimed to be best practice, but supported by recognised bodies as appropriate good practices. The development of the action research will provide good practices which it is suggested will be recognised by the research organisation and adopted.

The research sets out to formulate an approach that will develop working methods and procedures in a systematic way that over time may become recognised as best practice within the research organisation. In the classification (Osburn et al, 2011) it is suggested that the research will aim to facilitate the development of a field specific energy efficiency best practice. It is recognised that whilst the research will produce a framework that aims to provide energy efficiency, only time and established use of such an approach will develop into best practice.

For a best practice to be established there must be evidence required and shown for something to be a best practice (Jones, 2015). It is suggested in the work of Jones that those who defend the use of the term ‘best practice’ are seeking profit or fame and that best practice is a mere buzz word with little meaning. This is perhaps one perspective, but it recognises that for good best practice there must be proven and well established methods which stand the test of time and survive scrutiny.

A case based approach was used (Demartini et al, 2018) to develop best practice in the soft drinks supply chain. The context of the work was similar in some ways to this research study in terms of process, although not specific to energy efficiency or technology in relation to practices. The paper reports the determination of best practices for the soft drinks industry and reviews previous knowledge. However the claim of ‘best practice is unsubstantiated and lacking any definition or validation of how the best practices have been determined, established and known as best practice.

In consideration of the publications relating to Best Practice the research sets out to develop an approach providing a structured framework, with a clear process and methodology for delivering energy efficiency. It is suggested that this will provide Good Practices. In time it is proposed this will become best practice both within the research organisation and potentially the wider industry.

1.8 Research Methodology overview

The proposed methodology will consider an appropriate philosophy, approach and strategy focussed towards achieving the research outcome considered in Chapter 3.

The core of the research proposed will be undertaken based on an active participation in the evaluation by the researcher, together with formulation and delivery of energy efficiency. It is proposed that as a result action research will be carried out utilising a mixed methods approach. This will include a structured research questionnaire, case studies and a significant detailed amount of on-site observation as part of the action research activity.

1.8.1 Research questions

To develop the research and inform the desired objective of the study the following questions will be addressed across the participating organisation, the wider industry and also with selected industry experts. It is planned that these will also be supported through later collaboration with the European Federation of Corrugated Board Manufacturers. The relationship with the research questions and the overall objectives of the study is shown in Table 1.2.

No	Specific research question	Research Objective
1	What is current best practice in the area of energy defined from the literature review?	1
2	How might this defined best practice best be applied in the corrugated industry?	1,2,3,4,5
3	What gaps are there in relation to corrugated manufacturing industry?	1,2,3
4	What is the current best practice applicable within the corrugated industry?	1,2
5	How can energy load be identified, evaluated and potentially reduced within the corrugated industry?	1,2,3,4,5
6	What energy modelling and energy efficiency techniques can be employed to establish the costs and benefits of any potential changes within the corrugated industry?	1,4,5
7	What specific range of technologies can be applied to formulate a best practice methodology for the corrugated industry?	1,2,5
8	How can these be combined into a strategic modelling framework to be used throughout the corrugated industry to drive energy reduction best practice?	3,4,5

Table 1.2: Research questions

1.8.2 Research questionnaire

The literature review in Chapter 2 will seek to identify and define the research gap. In doing this the study will also look to better understand the gap in current knowledge with respect to key industry stakeholders. This will be conducted through a structured questionnaire that is planned to be utilised within the research. This provides an opportunity to understand a critical perspective from key corrugated industry players who have a major influence on energy within their operations that would not otherwise be available.

1.9 Thesis structure

The thesis will initially consider in Chapter 2 the wider industry context of energy within the paper and pulp industry, specifically attempting to understand the energy efficiency approach adopted within the corrugated sector. Having reviewed the literature the research methodology is presented and outlined in Chapter 3 and appropriate research instruments detailed in Chapter 4. The phases of framework development are presented in Chapter 5, before the detailed action research is put forward in Chapter 6. In Chapter 7 the finalised Energy Efficiency Framework is presented prior to the thesis providing research conclusions in Chapter 8.

This research will contain a wide and significant research study across the research organisation operating sites. The proposed thesis structure is shown in Figure 1.11.

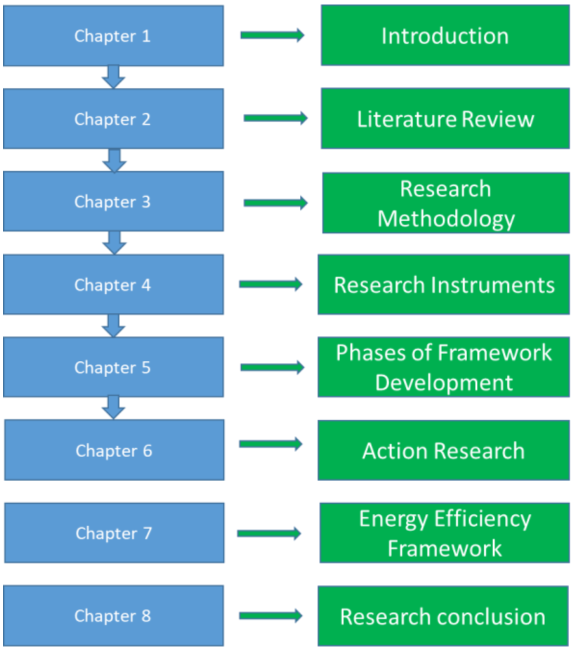

Figure 1.11: Research structure

1.10 Summary

In summarising the chapter it is suggested that it is clear from the science, from the facts and from the observed events that Climate Change is a factor impacting the sustainability of the planet. This has been proven beyond any current reasonable doubt and requires urgent action to deliver energy efficiency as part of a structured carbon management plan.

It has been demonstrated that the corrugated industry and its operations contribute towards climate change. However within the paper and pulp industry corrugated manufacturing does not have such an impact on the operation as the highly intensive paper mill operations. This may lead to misguided approaches to energy efficiency and a much slower carbon reduction than with an aligned energy reduction framework in place.

Whilst there is significant energy reduction activity in mills, there is little evidence currently noted in the corrugated operations. This lack of information is suggested to provide a significant opportunity for energy reduction in corrugated manufacturing operations.

The research company is a large multi-national operation with many sites which are striving to drive energy efficiency and carbon reduction, with 35 mills and 248 converting plants operating in 35 countries. Smurfit Kappa are focussed into sustainability and have detailed plans in place focussed around high intensity operations such as mills. It is proposed there is an opportunity for energy efficiency to improve the current carbon reduction plans.

It is recognised within industry bodies and within manufacturers that energy has a significant impact on sustainability. Whilst active programmes of energy efficiency and reduction are in place the proposed research has been agreed will provide a depth of knowledge and understanding that will contribute new learning and facilitate deeper and more sustainable delivery of targets to drive energy reduction.

What we know now that we didn't know before can be summarised below in summary and conclusion of this chapter.

- Climate change is real, is impacting the world and will only get worse over time
- The paper and pulp industry is an energy intensive sector with energy efficiency a key focus
- The corrugated sector is an opportunity for energy efficiency improvement

- The research organisation provides a significant opportunity for research and improvement and is committed to carbon reduction
- Currently there is no similar research work to the aims and objectives of this thesis being conducted in the area of energy efficiency
- It may be necessary to expand the research to take on board key stakeholders and industry experts to provide an insight into the current reality of energy efficiency if there is a lack of published information available.

This point, what we know now we didn’t know before, will be covered further in Section 8.10 at the end of the research together with answering the question what we can do now that we couldn’t do before.

Chapter 2 Literature Review

2.1 Introduction

There is recognition that this literature review will not cover all the potential areas relating to energy due to the significant field of published articles, material and reports on the subject matter. In order to consider a number of different perspectives the review has been structured to cover ***energy efficiency*** and technology.

The literature review is contained within two Chapters of the thesis. The main section considering wider elements of energy drivers, industry, policies and technology is contained within this chapter. Specific technologies are then researched further and reviewed in Chapter 5.

In order to closely review the specific sector, ***the corrugated industry***, the review was initially restricted to the paper and pulp industry, within which the corrugated sector is positioned. Whilst many efforts were made to specifically research energy efficiency within the corrugated industry, there was a notable lack of published material and reference to the sector specifically within printed published articles and journal conference publications.

In order to understand the current debate the area of energy is reviewed within the context of the paper and pulp industry. The literature review sets out to consider current and previous areas of debate and discussion on the subject matter. The review then goes onto review the current approaches to energy management and reduction.

When considered in terms of content, the published articles with reference to the corrugated industry, were significantly lighter and had a much shallower depth of study than other industries including paper. A significant amount of published information was reviewed which covered the paper and pulp industry with little or no reference to corrugated operations and energy efficiency in this sector.

The review progresses to provide a corrugated industry context seeking to establish that the corrugated industry sector is not considered as an important area in regards to energy efficiency. In this the review sets out to understand and challenge this concept and determine if there is as much focussed research on corrugated operations as there is on paper manufacturing processes.

In recognition of the development of knowledge over time and with respect to technological and market progression over time a second Literature Review was conducted in 2021 to ensure relevancy and to ensure any new knowledge was understood in respect of the research. This was a shortened re-run of the main search conducted in 2016, however during the research study ongoing interaction with published materials ensure new knowledge was captured and assimilated.

2.2 Literature Review Strategy

The literature review sets out to explore and review key areas of research within the area of energy efficiency. It is suggested (Hart, 1998) that the adoption of an effective approach to the literature review should be considered. In the work Hart suggested there is a wide range of structures, purpose and different interpretations which need to be considered and evaluated.

In other work (Ridley, 2008) it is suggested that there is an apparent lack of agreement on such reviews and a varying interpretation of what is required. Both viewpoints can be recognised and are understandable. The material presented by Ridley, whilst helpful in providing context, challenges the literature review to have a real sense of purpose in what it sets out to achieve. In summarising the Ridley work it suggests that the objective needs to be specific and the review should provide a clear justification for the research.

A number of relevant published reviews where considered in the field of energy efficiency. The benefits of energy efficiency investments have been considered

(Rasmussen, 2017). In this work by Rasmussen a systematic literature review and framework for categorisation is presented. Alternative approaches were considered and evaluated providing an insight into differing techniques adopted. A further literature review (Mickovic & Wouters, 2019) in the same field of energy cost information also conducted a systematic review which is suggested provided a comprehensive approach to energy costs information in manufacturing companies.

A further review of energy efficiency in the Food Industry (Pradella et al, 2019), provided a clear and concise approach to the stages of such a review. Whilst the information was lighter the format of presentation and readability was effective. A systematic literature review was considered with respect to air source eat pumps (Carroll et al, 2020). The publication is technical in its style and content, however it clearly explains the three phases of systematic review as Planning, Conducting and Reporting.

A further systematic review on energy efficiency is presented (Solnordal & Foss, 2018) in which there is a strong linkage to the Structured Literature Review methodology (SLR). The paper critiques alternative approaches considering the options available for such reviews.

It is important to undertake an effective literature review to provide the best evidence for informing policy and practice in any discipline (Tranfield et al, 2003). Having considered many published articles it could be suggested that the systematic review is commonly applied when reviewing the field of energy efficiency.

In considering alternative strategies for the literature review various approaches were considered (Saunders et al, 2016). A narrative/semi systematic approach was considered, but recognised as being too diverse as it would have taken in all aspects of energy across all possible disciplines. A methodological review was also considered which would have focussed on process and research approaches. However this was discounted as the research was focussed on understanding both the approach and more importantly findings from the research.

A narrative approach was rejected as it was considered to have been too theoretical, and whilst themes over time may have been established these were considered would have lacked the specific application to the research question of technology and approach. An integrative review was considered and dismissed as it was felt that the result required was not based on a new conceptual framework or theory as the proposed objective was to qualify the current position and thinking.

Having considered these strategies the research adopted a systematic review that provided a structured planned approach. This allowed the focus to be on the defined research questions with a clear aim to determine what was known and what had previously been done. This provided a solid foundation to build the research upon, ensuring originality and seeking out current knowledge and latest thinking. Importantly the systematic approach provided the emphasis on informing action which was a key factor in the action research.

The reason for adopting the systematic review was based on ensuring that the process for the review was clear and consistent in its approach and replicable and transparent (Tranfield et al, 2003). Following a structured approach the review defined specific search terms which would help to avoid researcher bias (Collins & Fauser, 2005). This was important to recognise in adopting the role of an internal research Practioner personal feelings based on perceptions and previous experience needed to be avoided.

In order to provide scientific rigorousness to the review it is suggested (Okoli & Schabram, 2010) that the literature review process is described in detail, which is covered within this section

2.2.1 Keywords used

The keywords which were defined were considered in line with the research objectives and aim. As a result the strategy adopted Energy efficiency, Energy Reduction and Energy Technology as the key search words.

2.2.2 Database search

The research was conducted through the University of Derby, the primary database engine utilised was Library Plus. This provided access to catalogues, databases, journals and reading lists as well as an extensive reference library on site. Specific examples of sources of information are listed below from the specific areas of the review;

Databases	Science Direct, Elsevier, Ebsco, Emerald, Google Scholar, Scopus
Journals	Applied Energy & Engineering
Technical	Government publications
Sectors	Confederation of Paper Industries, Corrugated Industry, Federation of European Corrugated Manufacturers
Trade sector	Combustion Engineering Association, Carbon Trust

2.2.3 Selection Criteria

It was considered the best way to ensure quality in the review process was to base the review on peer reviewed academic journals (Fink, 1998). As a result publications included within the scope did not consider theoretical and conceptual studies. Availability of materials would not be restricted, however use of on line publications was primarily adopted, with a significant reference library establish for ongoing research material.

It was felt that in being critical literature would become out of date and irrelevant after a period of time. The starting year of 1980 was felt to be the farthest back that could be referenced without information being redundant and obsolete. Both quantitative and qualitative reviews where included in the criteria for the review.

Issue	
Publication Type	Peer reviewed academic journal
Language	English
Availability	Available on line as full text, in Reference Library, or current Book Publication
Research Discipline	Energy, Environmental Science, Energy Technology,
Areas of review	Initially focussed on UK, widened to Europe and then global publications
Time period	1980 - 2021 (Search conducted in 2016 and subsequently reviewed in 2021)
Sector	Paper and Pulp, Corrugated, Manufacturing Industry
Additional areas considered	Carbon Reduction, Energy conservation, modelling
Relevance	Artciles related to energy efficiency, energy reduction in manufacturing industries

Table 2.1 Systematic Review Selection Criteria

2.2.4 Flow diagram of review process

For ease of representation the two literature review processes are were combined into one review process and reported together. The diagram below represents the structured flow process within the systematic literature review.

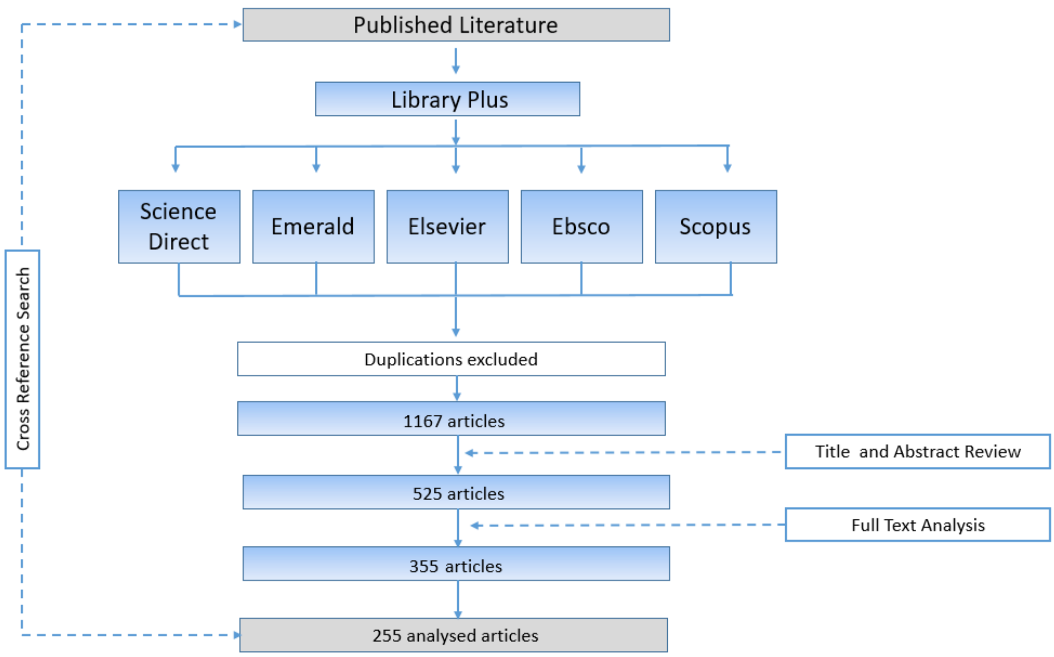

Figure 2.1 Workflow of the literature research process

2.2.5 Year of publication

In considering the published material review from the search data it can be seen that there is a considerable increase in the number of published articles since 2005 in Figure 2.2.

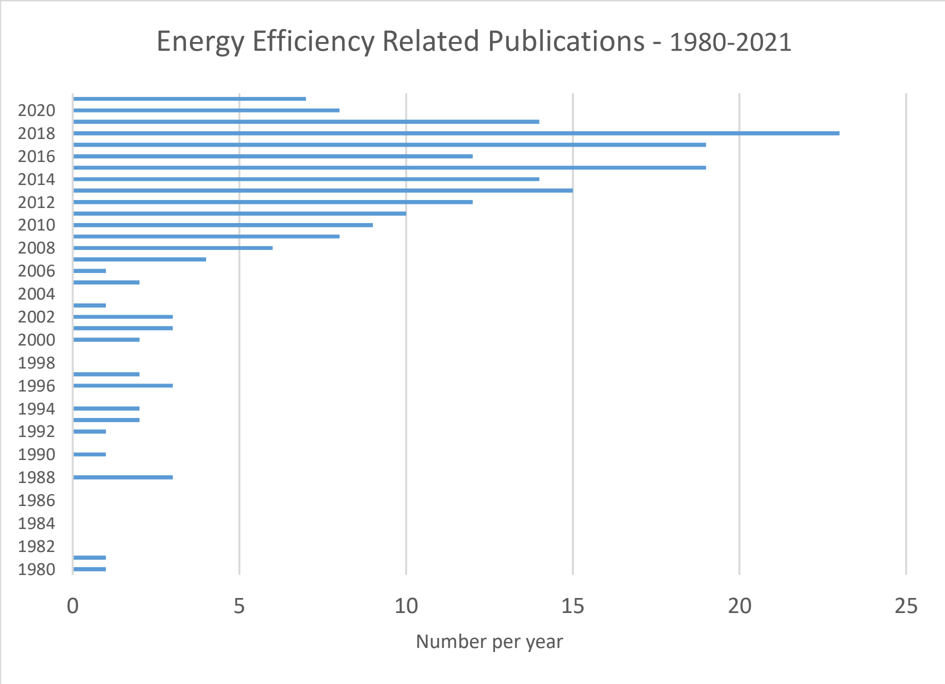

Figure 2.2 Review of publications by year

The growth noted in published papers since 2000 may be related to the effects of the Energy Crisis (McGowan 2011). The crisis is reported by McGowan to have given rise to significant concerns about energy insecurity, recording excessively high previously unprecedented oil prices. The work suggests the crisis was ostensibly a result of bilateral commercial disputes between energy companies in Russia and its neighbours with gas being the primary concern in the 2000s.

As a result of this crisis it is reported in reflection (McGowan, 2011) that the European political context shifted from one where the European Community was still institutionally underdeveloped and with a limited external role to one where the European Union had established a wide range of policy competences and a greater economic and political presence internationally. It may be the proliferation of the published articles is a reflection of the increased focus on energy efficiency and supply.

It is suggested that the publications noted in 2021 are lower than previous years due to the time to approve and publish papers and that this number is expected to rise. The depressed number in 2020 may be associated with reduced academic activity as a result of the impact of COVID. What is apparent is that the related materials for energy efficiency are increasing in focus and number over time.

2.3 Energy drivers identified

With regards to key energy drivers the following areas have been identified from the literature review that include effective plant operation, leadership, focussed improvement, energy supply and energy efficiency.

2.3.1 Efficient plant operations

Factors put forward (Oung, 2013) in regards to an efficient plant operation are reported as Economics, Business Drivers, Operations Management, Environmental Protection and Competitive Advantage. The suggestion made in the work by Oung is that all elements of these key themes together will produce the right outcome.

The work (Oung, 2013) suggests that without these key elements in place the resulting impact will be an inefficient plant operation. Whilst this research does not expand on all these areas it is clear that consideration must be given to engage key stakeholders and drive energy efficiency.

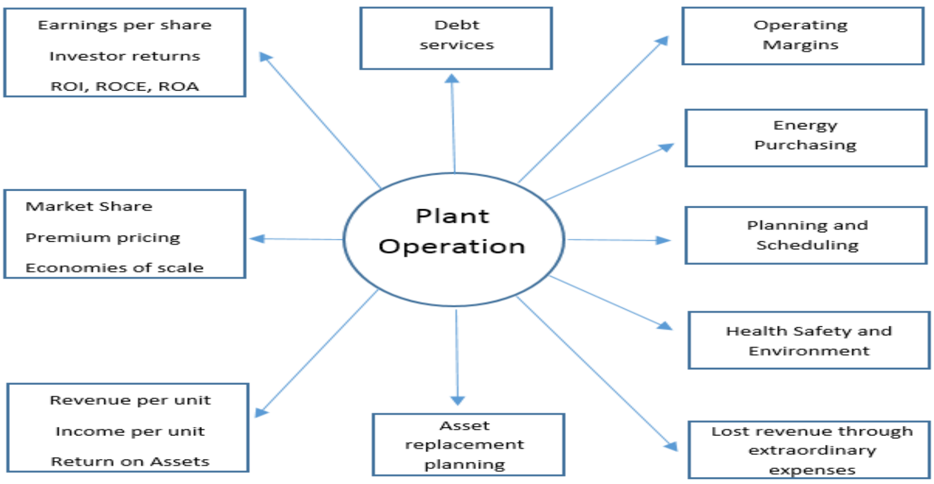

Figure 2.3: Impact of an inefficient plant (Oung, 2013)

The economics are driven by the need for a business to be successful, which are represented by those areas shown on the left of Figure 2.3, reflecting ROI, Investor returns and return on assets. In considering competitive advantage the income and revenue generated are key to business success, especially where energy prices can play a significant role in plant variable costs.

A business driver identified for this study was identified as asset replacement planning, where energy efficiency is considered in plant and equipment replacement. Within the area of Operations Management consideration with regards to energy efficiency and purchasing is identified as important, along with effective planning for machine utilisation and energy efficiency.

Within the research organisation these are all considered important factors in the research. There is a significant emphasis in respect of environmental protection and key aspects of energy efficiency and carbon management are large influencers of business decision making and operations.

The work (Oung, 2013) goes on to report that energy inefficiency in the factory can be predominantly ascribed to poor design in 40% of the losses. These are suggested to be as a result of the implementation of practices that have led to inferior design within the production process. This is proposed by Oung as the largest factor affecting poor energy consumption, followed by modifications at 21%, and maintenance losses at 15%.

2.3.2 Leadership

In an energy efficiency report by the International Energy Agency (IEA, 2015), it is argued that much work is ongoing in relation to energy and that the energy efficiency market is sizeable. The report proposes that political will and leadership at all levels is required. With different approaches it is strongly recommended by the IEA that companies have a clearly defined approach and standardised way to deliver energy reduction

With regards to leadership work (Birol, 2015), the Executive Director of the IEA in the 2015 Market Report suggests that mobilising energy efficiency is an urgent priority and that energy efficiency is 'the most important arrow in the quiver.' The work suggests that energy efficiency cannot be as a result of technology alone but requires effective leadership to be impactful.

Further publications (Potoski & Prakash, 2013) stated that energy sustainability is the cornerstone to the health and competiveness of industries that produce and manufacture in the global economy. For the research organisation it has been shown in Chapter 1 that energy is the second most important aspect of managing its business behind health and safety. This research would suggest that leadership is key to delivering a sustainable improvement.

For corrugated companies to succeed it is suggested by this research that they must have a desire to drive improvement through systems analysis. It has been suggested (Rossiter et al, 2015) that this can be achieved through management discipline and technical excellence. For this to be realised there must be evidence of these capabilities in place.

2.3.3 Focussed Improvement process

In work (Rossiter et al, 2015) there is specific reference to a case study in 'General Mills' in the USA where significant energy reduction was achieved. The work is extensive and concludes that three key aspects for energy management to be successful are worthy of note and reference. The first two being return on investment and innovation to fuel people and process.

It is the third area of the work put forward by Rossiter et al that is the main area of interest to this research. This being the principle that a focused process will drive sustainable results. From discussion with the research company there is no clear approach to energy efficiency across corrugated sites in place.

2.3.4 Energy supply

From a philosophical approach put forward (Ngo, 2010) it suggests that energy is necessary for all life and all economic activity. The work covers the more macro-economic and philosophical aspects of such things as nuclear energy and renewable sources. In the literature (Ngo, 2010) describes energy as playing a fundamental role in the development of civilisations over time. It is suggested by this research that the corrugated industry has not yet developed to rely on such 'modern' resources.

The work (Ngo, 2015) goes onto to state that 90% of the world's primary energy is relying on the burning of fossil fuel. It proposes that if these fuels continue to be consumed at the same rate it will upset the functioning of the planet at a speed and on a scale never experienced before.

The corrugated industry has a high propensity to using fossil fuel, an initial review of Smurfit Kappa data in the Annual Report (Smurfit Kappa, 2017), suggests a 60% fossil fuel 40% indirect fuel split. This brings more significance to the work of Ngo and it is proposed from this that if corrugated doesn't change its approach the industry may contribute towards damaging the planet.

From a review of reported data contained within the Sustainability Report (Smurfit Kappa, 2018) it can be seen that the overall business still has a high reliance on fuel from gas, whilst the company has reduced its exposure to high carbon emitting fuels such as coal with the use of biofuels, shown in Figure 2.4.

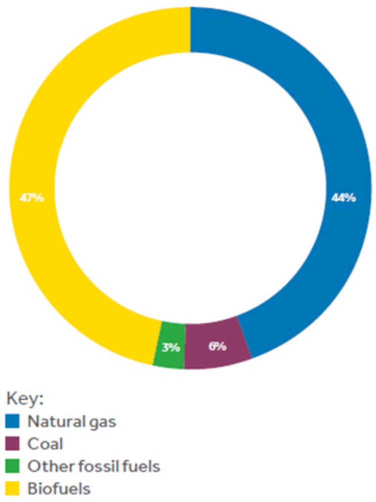

Figure 2.4: Direct fuel consumption, all operations (Smurfit Kappa, 2018)

Energy security and global politics is reported (Moran and Russell, 2009) to have resulted in the 'militarisation of resource management'. It is clear that the energy industry has become a target for terrorism and there is a risk to business in the sense of supply dynamics and continuity. The work by Moran and Russell considers the way in which regional and global markets need to be aware of the risk.

Whilst such considerations are not part of strategic energy sourcing for the industry, the risk of a loss in energy supply would be significant. A question posed by the review for future research is potentially around energy security. Studies into understanding when opportunities for renewable energy applications would be appropriate for corrugated operations could be valuable in understanding future energy supply.

It has been stated (Moran & Russell, 2009) that global energy poses a serious question regarding ongoing business operation for many companies. Any potential attacks on UK infrastructure across the electricity and gas network will stop manufacturing as no self-generation is currently in place at many sites within the UK corrugated industry.

For the corrugated industry the energy supply within regions and countries is somewhat fixed, with few considerations other than the use of renewable electricity and the purchase of green gas and electricity. It is therefore proposed by this research that the challenge of new equipment supply with manufacturers is important in ensuring an integrated energy efficiency approach.

The research does not consider what options are available to the corrugated industry to change its energy sources. In work (Moriaty & Honnery, 2014) the future earth state and the impact of energy use and economic output is reviewed. An interesting approach suggests that whilst mitigation of global warming may have some effect, why can suitable technology not be enabled to separate out CO_2 and directly reduce the levels post production.

Such technology was reviewed and discussed (McLaren, 2012) as 'negative emission technologies (NETs). These are a set of technologies that could retrieve greenhouse gases from the atmosphere. Such systems capture carbon dioxide CO_2 emissions coming from a bioenergy plant, i.e. electricity, biofuels, and hydrogen. These are then stored in a geological reservoir. One such approach is referred to as Carbon Capture and Storage.

Some interesting proposals were noted in a review (McLaren, 2012), such as tree planting and liming of oceans, with over 30 potential NET's considered. It is suggested by the work that this can only be a partial answer to the elimination and root cause of carbon emission in the first instance. The 21st century has seen rapid increases in such technologies as solar, wind and co-generation. These may be considered to have even surpassed nuclear as a fuel of the future.

From the review on energy supply there are a number of areas which are outside the scope of this research, but which are potentially areas for further study and research applicable to the corrugated industry. These are suggested to include security of energy supply, self-generation, green energy and renewable energy. A question that could be proposed is what are the fuels that as yet are not understood and how could they be harnessed. This whole energy supply area could be suggested as a future research topic.

2.3.5 Energy efficiency

The question put forward (Shove, 2017) is what is wrong with energy efficiency? The paper summarises the two approaches put forward by the UK's Committee of Climate Change to reducing carbon emissions. The two options are described that contain energy efficiency and decarbonising supply. The paper suggest that far from being an effective response to climate change, energy efficiency is counterproductive. The paper by Shove provides a controversial review and aims to stimulate discussion and generate activity. In conclusion the work reports that energy efficiency is important, but that life must change to use less energy in the first place.

It is suggested (Linares & Labandeira, 2009) that energy efficiency directly links and influences economics and policy. In the work it proposes a paradox surrounding energy efficiency, whereby it compares and contrasts the concepts of energy conservation and efficiency. Clearly to be energy efficient in having to use energy is different than working to reduce the need to use energy and conserve it.

The work (Linares & Labandeira, 2009) defines an energy efficiency gap and the 'rebound effect' which is suggested to be that an improvement in efficiency does not bring about a proportional reduction in energy demand. It was not considered in the publication how this might apply when business is expanding and the energy reduction is merely offsetting the increased energy consumed.

In the Energy Efficiency Report published by the International Energy Agency (IEA, 2015) it was recorded that energy efficiency improvements in IEA countries (all industries) since 1980 have avoided a cumulative 10.2 billion tonnes of $C0_2$ emission. The report by the IEA shows that energy consumption within IEA countries is as low as it was in 2000. It is unclear if this is through energy conservation or direct efficiency improvements within the paper and pulp industry sector and a clearer understanding would have provided more insight into the research presented.

2.4 Industry Context – Paper and Pulp industry

Having considered aspects of efficient plant operation, leadership, focussed improvement, energy supply and energy efficiency the chapter now goes on to consider the specific aspects of published material from the paper and pulp sector.

There is much evidence that reports the size and scale of the paper industry sector along with energy information and intensity levels. Most of this data focuses primarily on mills and the paper making process. In a report (Carbon Trust, 2011) specifically on energy in the paper sector, there is no mention of the corrugated sector.

The production of paper and corrugated board is reported and recognised (Fleiter et al, 2012) as a very energy intensive industry worldwide. The work attempts to understand a cross country comparison using physical production data. Again there is no quantification or reference to the corrugated manufacturing operation with this work.

Other published work relevant to the industry (De Beer et al, 1997), reviewed the long term energy efficiency improvements in the paper and paper industry. This work concentrates on a method for characterising and identifying technologies with specific reference to paper mills. The work concludes that there are six technologies that can reduce the specific heat consumption of a paper making process.

In terms of the work by DeBeer it suggests that areas such as sheet forming, heat recovery and air drying are key areas of potential energy efficiency within a paper making operation. However these are not relevant to the corrugated industry and are only appropriate for paper making processes.

A significant number of articles directly relating to energy and the paper and pulp industry have been reviewed in search of corrugated reference and context. The energy associated with paper making is reviewed within an energy management system (Lawrence et al, 2018). There is no reference made in the work to improving energy efficiency within corrugated plants.

In the work (Lawrence et al, 2018) it suggests that the industry is dependent upon energy efficiency for many reasons. It makes reference to profitability, energy security and economic competitiveness, whilst also mitigating climate change impacts. However whilst its conclusion establishes the need for energy management and systems, there is no direction towards effective technology and application within industry sectors.

A detailed review of energy use and carbon emissions in a mill within the pulp and paper industry is reported (Sun et al, 2017). The work provides a systematic review and meta-analysis without covering any reference to downstream corrugated manufacturing operations. The work by Sun et al discusses the life cycle environmental aspects of pulp making and paper making in what it refers to as a cradle to grave approach. However, for this to be true it must have considered the use of the paper and stages of life cycle before it returns to pulp. As there is no mention of the corrugating manufacturing process it is suggested this research is missing a vital step in the analysis.

A world model of energy demand and consumption is presented (Szabo et al, 2009) in which it introduces a bottom up global model of the pulp and paper sector. The research describes the whole paper market with its segmented and highly linked sub-markets. There is no mention of post paper manufacture technology with no reference to corrugating operations. The review looks at demand, energy consumption and emissions suggesting a model based approach can be used to good effect.

An assumption may be deduced at this stage that the paper and pulp industry does not include corrugated manufacturing operations. However from the Articles of Memorandum contained within the Confederation of Paper Industries (CEPI) the corrugated sector is part of the paper industry. Alternatively it is suggested by this research that the reason for a lack of reference is simply that there is a scarcity of published work in this area.

There is a growing number of academic papers published from the Asia Pacific area, which may be attributed to the size of the paper making market. Reviews of energy conservation and efficiency were conducted on literature produced from Taiwan and the Chinese paper making industry (Kong et al, 2012), (Lin et al, 2013). Whilst a number of the proposed technologies may be transferrable to the corrugated industry, none are specifically reviewed in the research being paper industry specific.

A publication of energy conservation through energy auditing was reported (Boharb et al, 2017) from Morocco. The article demonstrates the typical use of electricity and the specific key drivers. Whilst the literature refers to moulded packaging in the integrated mill there is no reference to corrugated manufacturing operation.

This perceived lack of reference to energy and corrugated operations is supported by literature from the Italian pulp and paper sector (Comodi et al, 2013) and also work published from Finland (Ruohonen, 2010) with no corrugated references. Additionally a case study reported from energy conversion in the European paper industry (Laurijissen et al, 2012) similarly has no corrugated reference

A key research objective was to review current literature and establish a gap in knowledge. The review can state at this stage that there is a substantial amount of research data and publications detailing findings within the paper and pulp industry. It is proposed by this research that there is a lack of insight or research into downstream manufacturing processes.

In a review (Yue et al. 2021) it is reported that several approaches to analysing energy efficiency and intensity in the paper and pulp industry in China have been presented. However the work goes onto state that few have been evaluated in terms of the energy saving potential. It goes onto to suggest that there are three process electricity saving technologies and 2 general measures. Unfortunately these are application specific and have little / no application in the corrugated manufacturing operations.

An energy efficiency study of the paper making drying process (Diaconescu et al, 2021) develops an approach to define energy usage and determine a data driven analysis of the process. In this it identifies heat recovery from the paper process as a significant opportunity for energy efficiency. Whilst this cannot be contested for the paper making process it has little viability and relevance for the corrugating operations.

In work (Roitman et al, 2018) energy efficiency in a cardboard manufacturing plant is reported. In this the work provides a technical and commercial analysis. The paper provides alternative opportunities for implementing technologies. There is an explanation of the quantification of the delivered benefits by application, however the work does not provide any suggested prioritisation of approach and ranges from the installation of LED lighting to the introduction of solar voltaic systems.

It was concluded that at this stage there is little researched work to assist energy efficiency and reduction within the corrugated sector that operates within the paper industry. As a result a further review was conducted to specifically research the corrugated industry.

2.5 Industry context - Corrugated industry

It has been suggested (Twede et al, 2015) that the most significant role of wood is the use of its fibres as the raw material for paper and packaging. Corrugated packaging is put forward by Twede as providing a total packaging solution from manufacturer through the supply chain and to the consumer. With the environmental impact posed by other materials such as plastics, the future for corrugated packaging can be suggested to be looking very positive.

A case study (Bujak, 2008) of a corrugated board machine within the paper industry looked at potential energy improvements for a steam system for corrugated board production. The paper discusses the potential improvement in energy associated with shell and tube steam boilers. In this work the energy consumption is reviewed pre and post modernisation.

The work (Bujak, 2008) is in reference to open and closed loop steam systems whereby condensate generated as a result of heat transfer during the process is managed differently. In open loop systems condensate is returned to the hot well boiler feed tank. However the steam can flash off and significant thermal losses can occur. In a closed loop system the condensate is recovered at high pressure and returned into the boiler inlet, maintaining heat within the system and reducing thermal losses.

Work done in relation to steam system audits and energy saving (Bhatt, 2000) whereby common technologies of water treatment, burner efficiency and blow down of the boiler are considered. The review is generic and has no reference to the corrugated industry. In work (De Beer et al, 1988) the area of suitable energy saving technologies for steam boilers was also reviewed. These may be transferrable technologies, however they are not deemed appropriate due to the varied steam demand of the corrugating industry operation.

Further work (Bujak, 2008) proposes an 8% saving in energy as a result of a closed loop steam system in a corrugated plant. It also suggests that economic analysis would offer a potential payback within 12 months. It is recognised that most corrugating plants have similar technology already installed to that put forward. However what the work (Bujak, 2008) does identify is that there is a gap evident in the measured improvement in energy efficiency derived from such technology.

In a paper presented to Super Corr Expo in the U.S an approach to energy savings in a corrugated box plant is proposed (Pallini, 2008). The study presented areas of opportunities including immediate, mid-term and future long term savings opportunities. These were reported at a high level and gave no indication of technological approach.

In work presented (Simko, 2008) data was presented to show the level of savings potentially attributable to lighting, compressed air, corrugated plant operations. The specific industry was paper and pulp and this data will be considered as relevant to this research study and considered during the action research.

In a review of work (Donahue, 2008) it considers heat balance and thermal energy loss opportunities in a corrugated plant. It recommends action with regards to steam losses and condensate recovery previously suggested (Bujak, 2008). In developing this theme of thermal energy savings work (Stickle, 2008) proposes that steam leaks may be contributing significantly to plant losses.

Whilst work presented (Pallini & Donahue, 2008) is specific to the industry it is unpublished and as such lacks peer review, being presented at a commercial exhibition. Data is presented relevant to the 'Fosber' corrugating operations as a main manufacturer of equipment. The work is insightful, but lacks measurement, whilst generic in its suggestions it does not provide a structured approach to energy efficiency in a corrugated plant.

What can be deduced from these studies is that the scope and breadth of a study needs to provide a clear understanding of what is and what isn't included and specifically in relation to the actual corrugating manufacturing process. It would appear that at times corrugating and converting are processes may be simply integrated into paper making operations. In this way there is no/little reference to the proposed area of research and it is not possible to carry out comparisons of energy usage.

In reviewing the literature one of the most insightful and most closely associated to the scope of the proposed research (Chow et al, 2005) looks at opportunities for energy efficiency and demand response in corrugated cardboard manufacturing facilities. The literature is now dated, being almost fifteen years old. The source is in the United States, however it does directly research corrugated plants and their energy consumption.

The work (Chow et al, 2005) focuses on one sole aspect of energy, that of 'Demand Response' as a potential opportunity. The argument for its application is not clear and not justified with clear quantifiable data. Whilst data is presented showing a study across 12 corrugating plants, it does not identify specific areas of plant activity when comparing energy usage, cost and energy intensity.

It is suggested by this research that the work by Chow et al is not represented as a detailed study but more a generalisation and opinion, lacking definition and reference. The reference list in the paper cites only two references, which may suggest a lack of depth to the research material.

2.6 Energy policies, systems and legislation

Having considered the literature reviewed within the paper and corrugated industries the key drivers and legislation are now considered along with the current thinking in this area and how it potentially may impact on energy reduction.

2.6.1 World wide

Far reaching governmental legislation has been introduced across the world to support and drive the focus on energy reduction with items such as the 'Conference of the Parties' COP 21 Paris agreement. Such legislation supports the drive for energy reduction with many published international standards, articles and regulations, not all of these being compulsory or enforceable. (Christoff, 2016).

A worldwide political response to climate change first began at the Rio Earth Summit in 1992, where the 'Rio Convention' included the adoption of the United Nations Framework on Climate Change (UNFCCC, 1992). The UNFCCC which entered into force on 21 March 1994, was reported by Christoff to now have a near-universal membership of 195 parties.

The main objective of the annual Conference of Parties (COP) is to review the Convention's implementation. The first COP took place in Berlin in 1995 and significant meetings since then have included COP3 where the 'Kyoto Protocol' was issued by the UNFCCC (UNFCC, 1998) and was adopted.

At the COP11 the 'Montreal Action Plan' was produced by the UNFCC and reported on (Maier, 2018) and at the COP15 in Copenhagen an agreement was discussed to succeed the Kyoto Protocol. The COP17 led the way for the 'Durban Platform for Enhanced Action' which was issued (UNFCC, 2011) where the Green Climate Fund was created which was reviewed and summarised in an article (Fouquet, 2013).

The adoption of the Durban agreement at COP21 (UNFCC, 2015) achieved for the first time in over 20 years of UN negotiations a legally binding and universal agreement on climate change with the aim of keeping global warming below 2°C. The negotiations were seen as a major diplomatic success (Christoff, 2016) to have regenerated faith in the United Nations Framework Convention on Climate Change as a forum for 'dynamic multilateralism.'

The work of the UNFCC would suggest that articles of legislation can engage worldwide reaction to climate change. What is unclear in the work is the sustainable future of such an agreement if the parties are not intrinsically motivated and personally engaged in its delivery.

In other work (Zhang Hai Bin et al, 2017) it suggests that President Trumps U.S withdrawal in 2017 from the Climate change agreement has 'profound implications' for the prospects of compliance with the agreement.

In the work by Zang Hai Bin et al it argues that China's response and the potential impact that may result is the terminal decline of the worldwide approach to climate change reduction. It is suggested by this research from the work that legislation alone will not provide the desired driving force for a step change climate change programme, delivering sustainable energy reduction.

In a wide reaching study of the policy effect of legislation and directives (Nabitz & Hirzel, 2019) it is suggested there is no 'one fits all' solution to develop progression in adherence to energy legislation. However the paper does promote the use of energy audits and energy efficiency as the 'first fuel' suggesting the adoption of such approaches actively supports delivery of articles of legislation. It can be suggested that the publication provides weight to the conclusion that legislation alone cannot bring about energy focus and efficiency.

It is reported (Garcia-Quevedo & Jove-Llopis, 2021) that there are growing advantages of putting energy efficiency at the top of policy and science agenda’s at an international and national level. The paper discusses the need for such policies to be assessed and evaluated in terms of the aim and delivered results. To attempt to determine such an evaluation, the work provides an evaluation of different environmental policy measures with regards to energy investment in Spanish manufacturing industries. The findings show clearly that subsides given towards energy investment have a positive and significant relationship with increasing investment in energy efficiency.

In a review of energy efficiency in industry (Malinauskaite et al, 2019) EU and national policies are reviewed in Italy and the UK. The paper reviews the EU strategies and policies on energy efficiency and argues that the further focus should be placed on industrial energy efficiency. The work concludes in recognising that the energy efficiency market is evolving and that different schemes and reporting mechanisms can place an unnecessary burden on companies. It could be suggested from reviewing the work (Malinauskaite et al, 2019) that driving an energy efficiency agenda and programme should be supported by aligned legislation that recognises and rewards improvement as opposed to attempting to enforce such approaches.

2.6.2 International Standards

Beneath such wider agreements, standards and codes of practice are used to shape a more local approach which may assist in delivering the overarching agreement. The ISO 50001:2011 energy management standard is discussed (Brown & Desai, 2014) to be based on the management system model of continual improvement. It is proposed that such an approach makes it easier for organisations to integrate energy management into their overall efforts to improve quality and environmental management.

Such an ISO standard is suggested (Howell, 2014) to provide a framework of requirements for organisations to help deliver energy reduction as a must for every organisation. However, what is unclear in this work is what is needed to deliver energy reduction and how to deliver a plan successfully.

The work (Howell, 2014) supports the approach of the international standard in delivering a road map and path for continually improving energy performance. Such a standard would appear to concentrate on systems and procedures and provide key metrics and key performance indicators.

ISO 50001:2011 specifies requirements for establishing, implementing, maintaining and improving an energy management system, whose purpose is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy use and consumption.

Figure 2.5 shows the key areas of an ISO 50001 system with its process and approach explained within published standards (ISO, 2011). The format is based on a continual improvement process reported (Javied et al, 2015) created by Deming, based on the cycle of Plan, Do, Check, Act that has been shown to support improvement.

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Figure 2.5: ISO 50001:2011 energy management model (ISO, 2011)

This research proposes that a structured framework approach to energy efficiency will deliver more benefits than the introduction of an energy management system. An ISO system prescribes a management approach with processes and key measurement of energy metrics, suggesting that delivery of energy reduction will follow once the systems are adopted. It is proposed that the short coming of such a system is in the capability and understanding to deliver a technology approach.

This research sets out to contest that management systems for reviewing energy may not deliver energy efficiency. This can be suggested to be due to the fact that technologies that power corrugated manufacturing plants determine the energy consumption of the plants. Energy efficiency is suggested by this research to be as a result of technology and approach. Whilst a management system can provide approach through focus, measurement and awareness, such a system does not provide specific technology based on the industry sector.

The research objective does not directly consider the implementation of an ISO style approach to management. This is a potential area of further study which may be considered in comparing plants with such systems against those without. The research aim is to provide a specific engineering technological solution to energy efficiency and reduction, and in doing so quantify the direct impact of technology in energy efficiency.

In considering further standards application ISO 14001:2015 (ISO, 2015) specifies the requirements for an environmental management system that an organisation can use to enhance its environmental performance. ISO 14001:2015 is intended for use by an organisation seeking to manage its environmental responsibilities in a systematic manner that contributes to the environmental pillar of sustainability.

It is proposed (Potoski & Prakash, 2013) that ISO 14001:2015 helps an organisation achieve its intended outcomes of the environmental management system, which provide value for the environment, the organization itself and interested parties. However, the work questions the voluntary nature of such systems, questioning the effectiveness of voluntary environmental programs. Whilst the approach provides evidence of conformance, in itself it does not deliver a proactive energy reduction strategy supporting the context and rationale for the proposed research.

Whilst legislation, policies and codes of practice provide the context for energy management, it is suggested that the adoption of these strategies will not drive energy reduction. The establishment of internationally recognised and accredited standards provides an expectation of what may be required. However it could be argued that without a technology framework for action the expected outcomes may remain just that, expected.

2.6.3 United Kingdom

The UK has a comprehensive range of policies driving energy efficiency across industry. The Department for Energy and Climate Change (DECC) provides many reports and guidance papers on behalf of the government in this area.

The UK governments Carbon Plan 'Reducing Greenhouse Gas Emissions' has been published (DECC, 2011). The data showed a 25% reduction in carbon emissions since 1990 through energy efficiency improvements. However, whilst this demonstrated a significant reduction the 2050 aspirations are to deliver a reduction of 90% reduction by moving to a more efficient low carbon sustainable economy across all industry sectors. This is seen as a significant challenge and one which currently is not chartered.

The foundation to improvement is suggested by DECC to come through reduced energy requirement driven by energy efficiency. This initiative commits UK business to implement energy efficiency savings, which companies have to participate in. Such a commitment can be seen in the annual report (Smurfit Kappa, 2015), already stating its commitment to a 25% reduction by 2020.

The UK Government updated its Energy Efficiency Strategy Paper which was issued (DECC, 2013) where it set out to explain the UK approach to energy efficiency. In the paper UK Prime Minister David Cameron at the time explained that the UK is in a global race, the countries that will succeed in that race would be the countries that prosper and they will be the countries that are most energy efficient. In this energy efficiency strategy the government gave four key barriers to the deployment of energy efficiency investment in the UK.

These four key barriers presented by DECC where discussed in relation to embryonic markets, information, misaligned financial incentives and undervaluing energy efficiency. For companies the work suggests barriers to energy efficiency take up will have to be overcome as business becomes aligned to energy saving.

Importantly 'under-valuing' energy efficiency, as described by an Energy Efficiency Strategy published (DECC, 2013), was a key factor in companies not adopting energy efficiency. This suggested that the long term financial value and wider benefits of investment are often regarded as uncertain. It could be interpreted that this could be attributed to a lack of trusted information in the market.

It is proposed that companies need to be aware of this and evaluate and deliver energy savings, recognising the longer term implications. Significantly these findings put forward by DECC directly support the area of proposed research, which intends to provide a sector specific energy efficiency framework that can lead to delivery of energy reduction plans.

For business faced with legislative and mandatory challenges a structured framework is proposed to be a simple, efficient approach to meeting and ensuring compliance to regulatory requirements. Whilst management systems can ensure processes are in place it is proposed the research energy efficiency framework will better inform and deliver energy reduction in an accepted and structured approach.

Having considered some of the wider key themes overarching the research the review now goes onto consider publications and materials more specifically in relation to energy efficiency technology, in considering equipment and approach. The review is carried out to review the impact of technologies that have a bearing on energy efficiency.

2.7 Technology

2.7.1 Introduction

In developing an understanding of energy efficiency a number of different technology approaches to potential applications were reviewed. This enabled a research perspective to be provided on the current work into energy efficiency. Technologies have specifically been considered that are applicable for the corrugated industry and these have been reviewed in terms of wider generic industrial applications and published material.

There are numerous reports and published articles that provide wide ranging suggested benefits from selected technology applications. A challenge facing those seeking to implement energy reduction initiatives is to understand the size of the opportunity for energy efficiency. Outlined in the Guide to Implementing Energy Efficiency Savings (DECC, 2014) typical implementation times for technology investments are proposed. These are shown in Figure 2.6 to identify potential technologies which may be considered.

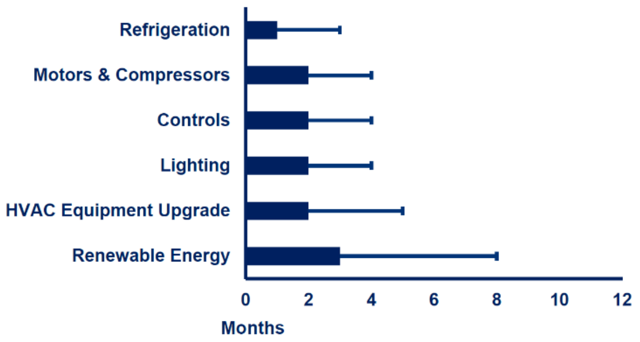

Figure 2.6: Typical technology implementation times (DECC, 2014)

It is suggested by the DECC report that lighting for example has a typical implementation time from review to completion of 5 months, whilst renewable energy solutions take much longer to implement. Within the work by DECC there is no mention or reference to anticipated payback periods or technology costs of application.

Without payback forecasts technology may be installed in a manner that does not optimise cost efficiency. It could be suggested that there is a danger that simple technologies with quick payback maybe overlooked by more attractive large projects with extended payback times. For energy efficiency to be effective cost efficiency must follow, without this business may not invest money into carbon reduction.

Further literature specifically for the corrugated industry in a 'Guide to Energy in the Corrugated Sector' (Department of the Environment, 1988) suggests some potential savings levels for improving energy efficiency as shown by area below with corresponding saving percentages in Table 2.2.

	Potential savings %	
Energy efficient practices	**From**	**To**
Efficient use of steam	5	20
Variable speed drives	5	10
Efficient space heating	10	15
Pneumatic waste transfer systems	2	3
Compressed air efficiency	5	10
Monitoring & Targeting	5	10
Workforce motivation and training	5	10
General energy management	20	30

Table 2.2: Energy efficient practices (DoE, 1997)

The work (DoE, 1997) goes some way to suggesting energy efficiency as a key measure in delivering cost savings, although at the time there was no link to carbon emissions. The work has since been withdrawn as it was recognised to be out of date. There have been no further updates to the work since the publication date and as a result there is no corrugated industry energy standards or official industry energy efficiency publication. The research will seek to redefine such potential savings, defining a standard framework approach for energy efficiency.

The challenge in adopting energy efficiency may be proposed to be in selecting appropriate technology in a logical and considered approach. Published work (Aflaki et al, 2013) outlines the conclusion that there are many profitable energy efficiency projects in almost every industrial enterprise that are not actually implemented. This viewpoint is supported (Ayres & Warr, 2009) and a frequent reason for lack of implementation is given as the lack of an internal management approach. It is suggested that this potential failing may be brought about by a lack of clarity in what to do to become efficient.

2.7.2 Energy efficiency technologies considered

The following areas of energy usage and consumption have been identified as areas for review within the study, with corresponding literature on energy efficiency within each area reviewed.

- Compressed air Electricity
- Steam Gas
- Motors Electricity
- Lighting Electricity

These areas of energy use will be measured in action research later in Chapter 6 and reviewed in detail in terms of their percentage usage of the overall site energy demand. Additionally other areas may be considered if identified during later research stages.

To gain a wider perspective on energy efficiency across the corrugated industry an industry wide piece of research was conducted to understand current thinking. This was conducted by means of a questionnaire, which was facilitated through the Federation of European Corrugated Manufactures (FEFCO).

2.7.2.1 Compressed air (Electricity)

Compressed air is used across factory operations and widely across industry providing power and pressure for machinery equipment. In the USA a study by the US Department of Energy (US DoE, 2002) reported that compressed air was the third largest user of electricity among all US industrial systems. In a further study (Nehler, 2018) it is recognised that only 10-15% of the energy input is utilised as useful work. The generation and distribution systems for compressed air are reported (Roosa et al, 2018) to have inefficiencies and therefore many opportunities to reduce energy.

Compressed air as a source of power is argued (Capehart et al, 2012) to be misused and be prone to inappropriate use. It is suggested that at times it can be used as a way of cleaning plant and equipment or transferral of product/motion along a packaging line. There are a number of key areas that make up the system that include the compressor, the air dryer, the distribution system, potentially air storage tanks and ultimately air leaks. Such systems consist of a supply side and a demand side, effective energy consumption is suggested (Thuman et al, 2013) to require management of both aspects.

In work presented to the 21st Conference on Life Cycle Engineering (Mousavi et al, 2014) it was concluded that compressed air systems have a significant impact on the energy consumption and efficiency of manufacturing systems as shown in Figure 2.7. The work supports this research approach in understanding the energy efficiency of what is stated by Mousavi as 'the least efficient form of energy.'

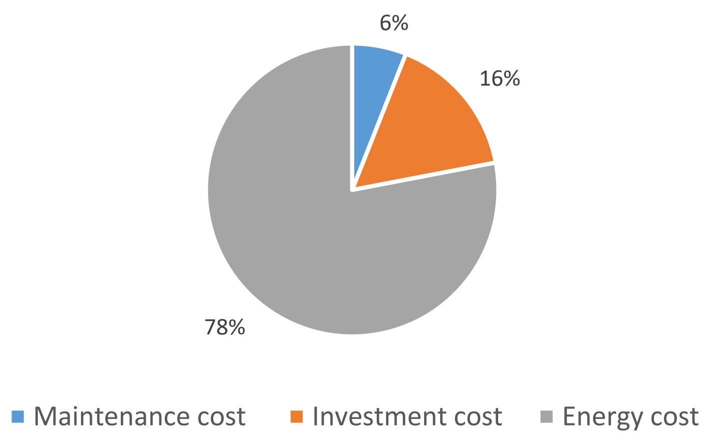

Figure 2.7: Life cycle costs of compressed air systems (Mousavi et al, 2014)

Further opportunities for compressed air energy saving are discussed (Scales et al, 2009) whereby examples of guidance to improve performance suggest areas relevant for the research such as compressor size, type and loading. This work is specific and informative and directly relevant in supporting the background to this study.

In a detailed review of compressed air energy use and savings (Saidur et al, 2009) areas of relevance to the research are covered including pressure drop, leak prevention and conducting energy audits. Whilst very thorough in its findings and conclusions the data presents both theory and tabulated results against many of its findings shown in Figure 2.8.

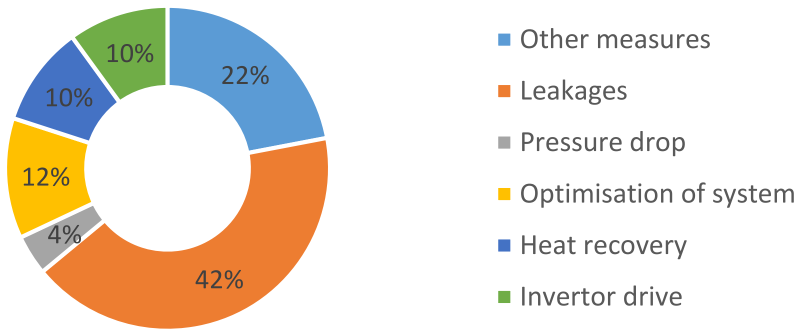

Figure 2.8: Areas of compressed air loss (Saidur et al, 2009)

In the work by Saidur there is reference to a comparison between a corrugated box plant in the US and food processing plants. There is direct relevance in this and the research will seek to establish further data in this area.

In a further study (Dindorf, 2012) it suggests energy saving opportunities are present everywhere in compressed air systems. The work discusses the calculation of the potential savings and concludes that savings are often overestimated. The proposed research will use electronic equipment to quantify and validate potential savings. In this way ensuring the potential error identified is considered and taken account of.

2.7.2.2 Steam (Gas)

It is summarised (Martins et al, 2018) that traditionally fossil fuel consumption has been used as the main resource to obtain energy. This proposed reliance will be considered for the corrugated industry and its operations and evaluated in line with the action research approach.

Boilers and fuel fired systems are suggested (Roosa et al, 2018) to be classified as one of the most significant energy consumers. Boilers fuelled by gas, oil or in some cases renewable sources can supply primary energy and also be involved in the generation of indirect energy in the case of electricity.

A typical heat balance of a boiler is referenced (Barma et al, 2017), shown in Figure 2.9, in which consideration is given to heat losses from a boiler system. In the energy balance 10-30% of the energy input is lost through the flue gas which is stated as the highest source of loss in a boiler.

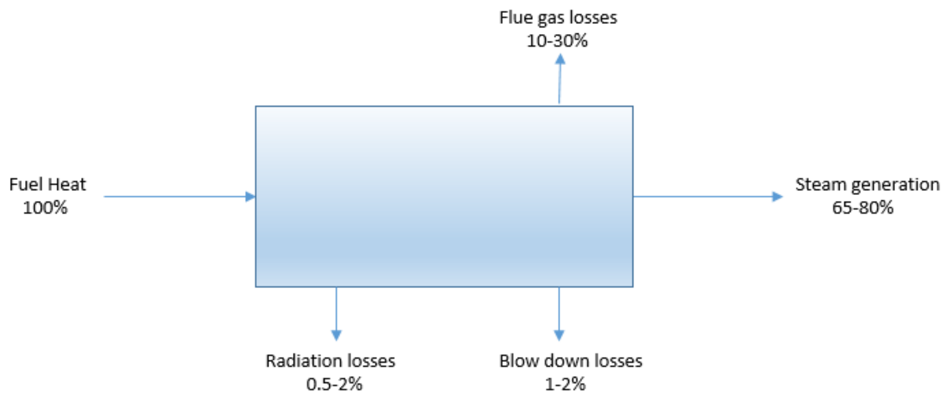

Figure 2.9: Thermal energy loss (Barma et al, 2017)

Such areas will be considered for corrugated operations, which may utilise different technology specific to the industry sector. Additionally the steam distribution system will be considered along with boiler efficiency and management within the research study.

The efficiency of the boiler is reported (Capehart et al, 2012) to have a direct impact on the fuel required to generate steam. The efficiency can be managed through control of the oxygen and air/optimisation, load management and maintaining the boiler. In a case study reported (Oung, 2013) efficiency savings were stated that consisted of generation, control and distribution aspects of boiler operations.

The efficiency of boilers is considered (Patro, 2015) and it is suggested that areas of heat loss are known and can be defined from a heat balance sheet. This is theoretical and is not applied, however the work by Patro suggests that areas of heat losses are applicable which include flue gas, evaporation, moisture, carbon monoxide, surface radiation and unburnt carbon.

The work by Patro is based on heat loss from 1kg of steam and provides detailed calculation procedures and formula. The proposed research will look to consider such losses in a practical way and attempt to quantify some of the suggested losses in an applied manner in the corrugating operation.

Further work (Regulagadda et al, 2010) identifies energy losses associated with steam raising and boiler operations. The study suggests that effective boiler maintenance will minimise thermal losses and is a key part of the operation. In this work Regulagadda puts forward that keeping the boiler clean, improving insulation, and minimising blowdown water will all maintain/improve boiler performance. It is proposed that such areas will be highly relevant to the research and will be areas of focus.

Whilst the work (Regulagadda et al, 2010) concentrates on a coal fired boiler the approach it proposes will have similarity and relevance, and the proposed research will look to apply the concepts to the corrugating industry.

There is a conclusion reported (Einstein et al, 2001) that condensate recovery and steam traps are an area of loss for thermal energy in boiler operations. Both are specifically to deal with heat recovery post thermal duty, but both may impact a corrugator operation. In the work presented by Einstein it is suggested that 10% energy savings can be delivered through condensate recovery and that steam trap maintenance delivers a further 5% energy saving. Whilst the work is generic and not industry applied, it will be considered within the research. The corrugated operations utilise a closed loop approach and the thermal efficiency of this process will be considered.

A review presented on the US Corrugated industry (Chow et al, 2005) stated that corrugated manufacturing was an energy intensive industry and compared gas usage and costs. In the work it put forward conclusions based on the most recommended number of times energy efficiency measures were applied along with potential paybacks shown in Table 2.3.

Energy efficiency opportunity	Recommended % in studies	Typical pay back years
Repair steam leaks & traps	69.2%	0-0.2
Insulate hot plates on corrugator	46.2%	0.3-1.5
Install a preheater on the boiler	46.2%	0.8-5.5
Insulate steam and condensate mains	69.2%	0.6-3.3
Control air to Fuel ratio on boiler	15.4%	0.3-0.4

Table 2.3: Summary of energy measures recommended (Chow et al, 2005)

Whilst it was relevant data put forward by Chow et al, it is suggested that technology has moved on from this research study and that the equipment application and usage needs to be reviewed in context of the UK energy market and equipment manufacturers. This will be challenged and reviewed through the research.

In further work on efficiency (Spirax Sarco, 2014) it is suggested that the efficiency of the boiler has a significant impact on steam costs and should be run as efficiently as possible. Other areas of energy saving are suggested by Spirax Sarco to be thermal pipework lagging, condensate control and boiler water chemistry. All being directly attributable as areas of further applied research for the study.

2.7.2.3 Electric motors

Motors drive a significant energy usage in factory operations. It is believed (Capehart et al, 2012) that motors can account for over 50% of the electricity use of a manufacturing plant. The work suggests areas of loss that can affect performance, such as worn bearings, lubrication alignment and maintenance. However there is little reference in the Capehart work regarding the impact that deterioration in equipment health can have on energy efficiency.

It is recognised (McCoy et al, 2014) that the selection of motor application can have considerable impacts on the lifetime energy consumption of motor applications. The work adopted a standard for premium efficiency motors in the USA and establishes a guide to selection of available and emerging technology for HP (horsepower) rated motors. Data is shown in Figure 2.10 comparing varying efficiency of different motors.

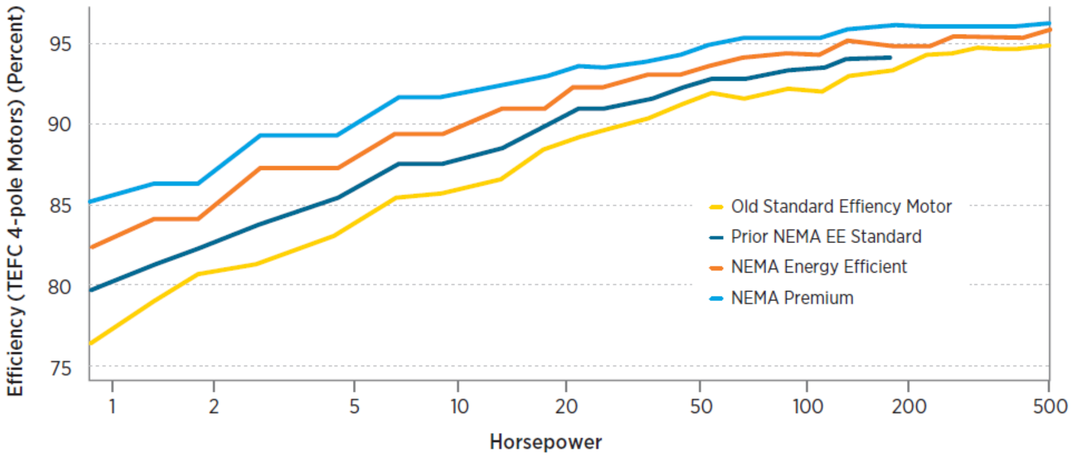

Figure 2.10: Motor energy efficiency curve, (McCoy et al, 2014)

Obviously such a selection is defined by cost as well as efficiency and the report by McCoy covers additional areas such as rated capacity, motor losses practical considerations in motor selection. Whilst it relates to the US marketplace the alignment with European standards, where the US premium efficiency motor correlates with an IE3 efficiency motor, helps to provide some context. This is comprehensive and directly supports the objective of the proposed research.

The McCoy work is supported in further global standards (DeAlmeida et al, 2011), where IE ratings for motors are explained and discussed with regards to motor selection and energy efficiency. This does not cover industry use and concentrates on stages of pre use and equipment selection.

In work (Thuman et al, 2013) it is concluded that there are various types of motors installed within factories that include alternating current, AC Induction motors, direct current DC Motors and synchronous motors. The history of the electric motor is traced back to 1831 (Roosa et al, 2018), when Michael Faraday demonstrated the fundamental principles of electromagnetism. Since then they have developed into highly complex equipment which are now an integral part of many manufacturing operations.

It has been reported (Roosa et al, 2018) that the most effective way to drive energy efficiency with respect to motors is to understand how they operate .This can be true in factories where an abundance of electrical motors, drives and controls can present the user with a difficult optimisation challenge. It is believed that identification of motors whilst in situ may present a difficult challenge and energy audits are proposed as a good way of classification of installed equipment.

Energy efficiency is not only important with regards to selection of equipment, but also in its use and application within the manufacturing system. It is suggested (Lawrence et al, 2016) that the effective operation of electrical motors needs to consider the electrical environment, such as supply rating and configuration and voltage range and distortion. The work was presented to the Pulp, Paper & Forest Industries Conference, but appears to lack any reference to the sector activities.

The work by Lawrence discussed proven methodologies for the selection of suitable applications for adjustable speed drives are discussed. These would appear to support the relevance and positioning of the proposed research, whilst emitting any reference to the specific industry application of paper and pulp. Whilst energy saving is discussed there is little/no quantification of potential deliverable savings.

Energy efficiency in manufacturing industry is considered (Tamboli et al, 2020) with regards to an analysis of industrial motors. In this work it describes a process of analysing peak load as a way of determining energy focus for efficiency improvements. In work specifically aligned with industrial motors, Tamboli defines oversized electrical motors as a concern within industry, stating that most of the industrial motors are designed to run at 50-100% of their rated load. The work proposes that induction motors should be replaced with synchronous motors which are far more efficient.

The suitable application of inverter drives for electrical motors is presented (Jeftenic et al, 2006) with regards to a specific paper machine application. The work reviews the theory and application of such technology when applied to the refurbishment of a paper machine. The outcomes clearly define the suitability of such technology as a relevant factor in energy efficiency and importantly improving machine performance.

This work by Jeftenic provides an important conclusion in that any reduction in equipment performance as a result of applied technology would present a problem for the proposed research. However many of the direct conclusions cannot be referenced or related to the corrugated industry or machine operation due to the difference in process applications and scale of equipment.

2.7.2.4 Lighting (Electricity)

It is argued (Rossiter et al, 2015) that lighting systems are installed for human comfort, safety and quality. This could be understood in that often higher than required light levels are needed when lower task lighting could deliver the manufacturing role required. It is suggested in supporting work (Bremer, 2015) that lighting systems can be as much as 10-15% of the site energy cost and that often these costs can be overlooked.

Within factory operations the lighting specification, design and control play important aspects of the energy consumed within the operation. Within factory operations systems for offices, production areas, warehouses and external lighting need to be considered. It is suggested (Roosa et al, 2018) that within each area there are key considerations that need to be evaluated with regards to the type of light, the colour, and the number of units, sensor control and maintenance.

It is suggested (Schratz et al, 2013) that LED lighting offers significant advantages for pulp and paper facilities. The work suggests lower total cost of ownership and improved performance and reliability through LED solutions. Data is presented by Schratz in Table 2.4 that compares and contrasts the energy of a number of light sources.

Light source	CRI	Lumens / watt	Lifetime in hours x1000
High pressure sodium	30	60-120	10-24
Metal halide	70-95	60-100	6-20
Fluorescent	60-90	40-100	6-45
Induction	50-90	60-90	100
LED	70-90	up to 160	100+

Table 2.4: Comparison of light sources, Schratz et al, 2013)

Although the work by Schratz is potentially superseded by modern technology, the explanation given of light sources and their approach is helpful in understanding potential considerations for later in the research. The research presented is heavily LED influenced as a technology, with little other comparative data. There is also no reference in the literature to the industry being presented to, pulp and paper, although the paper was presented to the IEE Conference, and would have benefitted from specific application comparative data.

In comparing this work with alternative lighting solutions (Roosa et al, 2018) there appears to be some contradiction to the efficacy (lumens per watt) in that slightly higher light levels are stated. The work however considers in much greater depth alternative lamp types, together with control, sensing options and a proposed energy saving checklist.

One consideration that will have direct relevance to the research is the linkage proposed in an internal presentation to the SK Operations Directors (Clements, 2018) between burning hours and output, often termed light degradation. It can be seen in Figure 2.11 that for differing light sources the rate of degradation changes dependent upon light type and burning hours, with a significant step change from 60% reduction on metal halide at 10,000 hours burnt, with a 60% degradation on LED at 52,000 hours.

Interestingly albeit different outputs can be assumed, the degradation is compared from 100% lumen output.

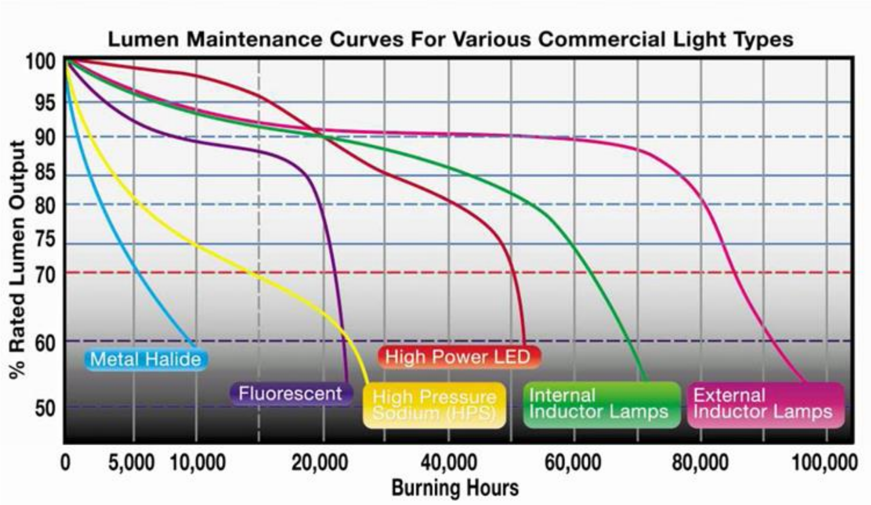

Figure 2.11: Comparison of lumen output v burning hours (TCS, 2018)

It is suggested (Singh et al, 2012) that energy audits can assist in reducing lighting costs. The research study conducted looks at energy use at a mill in India and compares and contrasts the use of halogen, florescent and incandescent lamps across the factory. The work by Singh suggests that an increased use of metal halide lamps should be used. Whilst the work is supported by further research (Ashok et al, 2007) it is felt that this should be challenged and this research will seek to further determine an applicable position.

2.7.2.5 Renewable technologies

Renewable energy is a boundary technology within this research. It would be wrong not to include reference to the emerging growth of renewable technology as a potential fuel source for industry operations and potential future research. The main focus for the proposed research will be to target energy efficiency options that are low cost high impact and deliver short to medium term energy reduction opportunities.

The consumption of fossil fuels for energy generation accounts for the majority of greenhouse gas emissions as reported by the (IPPC, 2012) and contributes heavily to an operations carbon footprint. This work put forward by the IPPC showed at the time that renewable energy has a large potential to mitigate climate change through lowering emissions. Renewable energy can consider such technologies as bioenergy, solar power, geothermal energy and some further non-industrial opportunities such as hydro, ocean and wind power.

The cost of renewable technologies has previously been reported (Kaberger, 2018) as a barrier to entry for many countries and companies. As such the research by Kaberger suggests that renewable energy, such as those previous listed, will see an increased take up with a lower conversion cost once technology prices fall. There would not appear to be any contra argument to this, in that whilst the energy is not damaging the climate and could be produced at a lower cost per unit, why would there not be a more rapid take up than to date.

It is noted (Kong et al, 2012) that many of the emerging energy efficiency technologies for greenhouse gas mitigation are applicable for the paper and pulp industry. Such technologies are summarised in the very detailed report by Kong, however whilst this specifically references paper and pulp, there is no reference to corrugating operations.

Potentially of more relevance for consideration from the literature review would be specific technologies of solar, wind and a technology that is sometimes placed within a similar alternative field of technology, combined heat and power. These may be considered more applicable to the research, but whilst being considered are defined as areas of further work.

Solar has been defined (Boxwell, 2017) as providing electricity from sunlight shining on photovoltaic panels. Corrugating sites have many roof applications that may lend themselves to such technology. Solar is contested by Boxwell as a good source of power where the power requirements are modest. This is not expected to be the case in corrugating operations within the research study and whilst informative the work was not deemed relevant.

When considering solar the Boxwell work suggests there are many elements to consider in the establishing of the potential solution. These are noted as the position of a solar array with respect to physical and sun trajectory. However solar deployment has a vision (International Energy Agency, 2016) in a roadmap to provide 5% of global electricity consumption in 2030, rising to 11% in 2050.

Currently it is anticipated that the UK, and in fact the corrugating industry will be behind such targets. Current provisional government figures reported (BEIS, 2019) there is a total of 13,306 MW installed UK solar capacity across 1,022,716 installations. This was a modest increase of 1.5% (201.5 MW) since November 2018. There are currently no corrugated industry applications of solar deployment known within the literature review or published data.

In considering wind power it is simply explained (Roosa et al, 2018) that a windmill is a device that converts wind energy for mechanical applications such as wind turbine generators which produce electrical energy. Issues encountered in harnessing such power from wind are considered in the Roosa work, such as wind availability, turbine performance and power storage. Roosa reports that a typical wind device cannot furnish energy to match the exact energy demand, which fluctuates widely within a corrugated plant operation.

From studies (Capehart et al, 2012) in the US it was noted that the potential for wind energy was far greater than its application. It was suggested that the potential would never be effectively converted into application due to aesthetics, construction cost and radio/TV interference. This potential theory was supported (Beggs, 2013) in that it was suggested that 300,000 nuclear power stations would be required to generate power equal to that produced by winds around the world.

Studies (Capehart et al, 2012) reports that 40% of the available wind power is harvested due to conversion losses. It is also suggested (Beggs, 2013) that wind can only be relied upon to provide part of a facility energy demand. This is unrealistic for corrugating operations as the research focuses on energy efficiency as opposed to energy supply.

As a result of such technology considerations of variability in wind generation, storage and grid connection are all important factors required to enable energy demands to be balanced with energy availability. Additionally variations in wind output are said (Roosa et al, 2018) to present challenges in terms of location and peak time energy loads disrupting energy availability. Such an approach is not considered as part of this research as appropriate. However, its application for the corrugated industry is recommended for further research.

The concept of co-generation of combined thermal heat and electricity is not new and has been recognised (Breeze, 2018) as a key emission control strategy for the 21st century. The operation of combined heat and power (CHP) is a technology whereby the simultaneous use of electricity and heat is provided from a single energy source.

In a study (Carbon Trust, 2010) a 20-30% reduction in energy bills is claimed to be achieved with CHP. This does not reduce the energy consumed in the manufacturing facilities, but does generate the energy for consumption more efficiently. The report by the Carbon Trust clearly explains the stages of power generation, hear recovery and heat use in principle. It is suggested that this may well be an area for further work and research at a later date.

Work presented (ENER-G, 2015) on the benefits of CHP suggests the technology provides a reduction in running costs, reduced carbon emissions, and security of supply. Whilst it is stated that the CHP process is highly efficient in its use of fuel, this is for primary generation of heat and power at a manufacturing site. The technology is not applied in enabling a site to become more energy efficient and is therefore not considered further in this research.

It can be seen that in all cases whilst the technology is widely available there is no reference or application specifically to the corrugated industry. Additionally there is no verifiable data to establish potential reduction benefits or scale of energy reduction aligned to each applied technology. At this stage whilst not dismissed, such renewable technologies are considered outside of this research and potentially an area of later research.

2.8 Literature Review – Summary

It is clear from the literature researched that the corrugated industry does not yet have a clear framework for energy reduction. However there is a substantial amount of research data and publications detailing findings within the paper and pulp industry. Surprisingly, and of note, there is a gap with regards to any mention of downstream corrugated manufacturing processes.

The paper and board industry is recognised as an energy intensive sector. Whilst there is published information on the paper industry, there is a clear lack of published information regarding the corrugated board operation within this sector, specifically applied to engineering technologies and generally across the industry. The literature review establishes that work has previously been carried out extensively in many paper mills across the world.

The review identifies that the theory of energy reduction is one widely documented and theorised over by many industry writers and academics in this field. Energy reduction linked to climate change is promoted by UK government and international organisations. Legislation driven by governments, voluntary codes of practice driven by approved bodies and multi-agency campaigns in many areas all portray the virtues of effectively managing energy.

It is proposed by this research that a clearly understood framework for energy reduction, with verified savings delivered through a model application, will enable a more effective and timely approach to energy reduction and efficiency across the industry. The proposed research has a role in widely informing the industry and publishing its findings following the achievement of its aims and objectives.

The key issues identified from the literature review taken forward into research can be summarised as:

- What is the most appropriate way for a corrugated manufacturing plant to become energy efficient?
- What technologies could be adopted to enable energy efficiency in a corrugated manufacturing operation?
- Which are the most suitable energy efficiency technologies for a corrugated operation and why?
- What opportunities for improvement would an energy efficiency approach deliver and how could it be measured?
- The research should consider why there would appear to be a lack of published information and aim to bridge this gap through published research.

Chapter 3 Research Methodology

3.1 Introduction

The chapter aims to provide an overview of the methodology adopted and explain the selection and impact of those techniques utilised in this research. In doing this the chapter explains the overall research proposition and route through to a successfully applied outcome

3.2 Research areas

Research as reported (Myers, 2013) requires a purpose, an aim and a clear process to deliver a successful outcome. This viewpoint is supported (Remenyi et al, 2010) in a publication where the need for a clear aim is recommended. In the case of this research the aim focusses on delivering energy efficiency in the corrugated sector.

In work (Hussey & Hussey, 1997) it is suggested that it is important to classify the research in order to understand what the researcher is setting out to achieve and deliver. This approach is generally accepted by other researchers (Saunders et al, 2015), (Cameron, 2011) in that research purpose can be categorised into three categories of exploratory, descriptive and explanatory. It can be concluded from this work that for research to be effective there needs to be a road map to define its philosophy, approach, strategy, time horizon and techniques.

3.2.1 Purpose of the research

The research sets out to understand, develop and establish a framework for energy efficiency that once having been established can be easily implemented into factory operations to drive energy efficiency and energy reduction. In this way this research can be considered as exploratory.

This research can be aligned with work (Saunders et al, 2015) in that it intends to research existing events and develop new knowledge as yet not established. Therefore by its nature (Ghauri & Gronhaug, 2010) research can be defined as a process that people undertake in a 'systematic way' to 'find out things.'

This research proposes that from the literature review presented in Chapter 1 there is a lack of knowledge in the area of energy efficiency in the corrugated industry that could be considerably improved through research.

3.2.2 Process of research

The process of this research will be both quantitative and qualitative in nature as research evolves. The research will be derived through mixed methods and will incorporate questionnaire, survey, direct observation and action research. The process of research is described in detail in Chapter 4 where the research instruments utilised are further explained.

The action research at sites employed within this research study will be heavily influenced by analytical data and will be accurately measured through calibrated equipment. However the survey cannot be classified in this way as the views and opinions of key industry stakeholders are, as put forward (Walliman, 2017), expressed in words rather than numbers.

3.2.3 Logic of the research

It is suggested that the research logic will be implemented to provide data driven evidence that will help form an overall conclusion. Whilst the data itself is not the purpose of the research, the evaluation of the data will help to shape a framework proposition. This can be considered to be building a theory from the collected data which is verified and validated towards the end of the research process (Goddard & Melville, 2001).

3.2.4 Outcome of the research

This research will be established within a real life application where the outcome of the research will be applied. Applied research (Kothari, 2008) aims at finding a solution for an immediate problem facing industry. Once developed it is proposed that the outcome will be widely applied both within and external to the research organisation and across the industry.

3.3 Research methodology

A number of research methodologies have been considered that are summarised in Table 3.1 in terms of their philosophy, approach, strategy, method, timescales and techniques. Methodology suggested by numerous writers was considered (Saunders et al, 2012), (Quinlan, 2011), (Gill & Johnson, 2010), (Walliman, 2005) (Cameron & Prince, 2009) is considered.

Author / Theme	Saunders et al (2012)	Quinlan (2011)	Gill and Johnson (2010)	Bryman and Bell (2011)	Walliman (2005)	Cameron and Prince (2009)
Philosophy						
Positivism	X	X		X	X	X
Interpretivism	X	X		X	X	X
Pragmatism	X					X
Approach						
Deductive	X		X	X	X	X
Inductive	X		X	X	X	X
Strategy						
Survey	X	X	X	X		
Case Study	X	X		X		X
Action Research	X	X	X	X		X
Method						
Qualitative	X	X	X	X		X
Quantitative	X	X	X	X		X
Timescales						
Cross sectional	X		X	X		
Longitudinal	X		X	X		X
Techniques						
Data collection	X	X	X	X	X	X

Table 3.1: Potential research methodology considered

It can be seen from the review, summarised in Table 3.1, that not all approaches provide a full coverage of the differing themes. For example the chosen approaches of Quinlan are relevant to far fewer areas than that of Saunders et al which covers all listed areas.

It was considered that the work (Saunders et al, 2015) provided the most appropriate comprehensive coverage of all areas shown that align with this research. In order to provide clarity this chapter is organised into sections which relate to the research onion structure, applied by Saunders et al, which includes section 3.4 Philosophy, 3.5 Approach, 3.6 Strategy, 3.7 Choices, 3.8 Time horizon and 3.9 Data collection techniques.

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Figure 3.1 Research Onion (Saunders et al, 2015)

3.4 Research philosophy

It has been stated (Saunders & Lewis, 2015) that research philosophy relates to the development of knowledge in its relation to research. Within philosophical research there are five possible suggestions put forward by Saunders & Lewis in the work. These are shown in Table 3.2. These have been considered with a view to this research aim, consequently a number of these, such as interpretivism, can be discounted as a theory based philosophy. Whilst this research is based in a technological philosophy, it does not strive to adopt a postmodernism philosophy.

Philosophy	Definition
Positivism	Highly structured methods used to facilitate replication and formation of law-like generalisation often utilised in sciences.
Crictical realism	Focuses on experiences to shape understanding the underlying structure of reality
Interpretivism	Philosophy that suggests that it is necessary to understand human interaction
Postmodernism	A philosophy that promotes language and relationships that challenge accepted norms and promote alternative views
Pragmatism	Philosophy argues that the most improtant factor are the research questions and objectives with the aim being to provide practical solution

Table 3.2 Definitions for philosophical approaches (Saunders and Lewis, 2015)

Pragmatism (Keleman & Rumens, 2008) asserts that concepts are only relevant where they support action. Therefore in reality this approach enables the research to be both objective and subjective, handling facts and values to arrive at a solution to the problem defined within the research aims.

The research starts out with the problem that there is currently no defined best practice approach for energy optimisation within a corrugated plant within the paper industry. It would appear there are many business reasons to address this problem, including financial, moral and sustainability focussed.

The pragmatist approach will aim to define a practical solution that will contribute towards future practices within the industry in regards to this stated problem. The research will provide a strategic framework that may be developed to provide a recognised energy best practice.

The philosophy will enable the research to focus on problems and practices relevant to both energy efficiency within the plants and also the practical application of research in complex manufacturing environments. This will help to reflect that the outcome desired and the defined reality (Saunders et al, 2015), is the consequence of a range of multiple qualitative and quantitative action research applied to the research aim.

In considering an appropriate method for the proposed research it was considered important to understand the current action and feelings toward energy, in ways of both beliefs and also physical actions. It is proposed (Kivunja et al, 2017) that it is key to ensure that the research method is aligned with the paradigm of the research. In the work of Kivunja it is argued that the paradigm will guide the action and comprises three elements of epistemology, ontology and methodology.

Epistemology is reported (Grix, 2004) to support the paradigm as it can be considered as focusing on the knowledge gathering process, being concerned with developing new models or theories that are better than competing models and theories.

In reviewing such an approach (Burrell & Morgan, 1979) suggest that Ontology raises the question relating to the nature of reality. The work of Burrell & Morgan suggests that Ontology raises the difference between the real world and the 'product of one's mind'. From a different perspective in the work it is suggested that Epistemology can determine how the world is interpreted and how this is communicated.

In the work (Burrell & Morgan, 1979) Methodology is explained as focussing on how knowledge is acquired. In this the notion of knowledge and how it is interpreted is considered. In work (Schommer-Aikins, 2004) it is suggested that a person's epistemology is embedded within personal beliefs. This can be suggested to be built up from life experiences and feelings. It is argued that a person's ontology shapes the basis for their perception of a situation. The research supports the view that Epistemology in this context is more focused towards the study of knowledge to provide a distinction from opinion.

This method realistically provides a pragmatic decision and rather than one methodology being superior to another. This is supported (Silverman, 2010) in that it recognises quantitative and qualitative approaches as complementary parts of the systematic empirical search for knowledge.

3.5 Research approach

In reviewing the theory development put forward (Saunders and Lewis, 2015) there are three approaches which are shown in Table 3.3.

Approach	Definition
Deduction	An approach designed to collect data for the purpose of testing a theorectical proposition.
Induction	The approach involves the building of theory from analysing data already collected.
Abduction	Involves the collection of data to better understand a phenomenon, identifying themes and explaining patterns to test theory.

Table 3.3: Definitions for research approaches (Saunders and Lewis, 2015)

In considering these approaches the research can be considered to be inductive in nature in that it will involve a significant amount of data collection as part of the research. This will help to build and develop an approach which has not yet been developed in theory or in practice.

3.6 Research strategy

Different strategies were considered in deciding upon an appropriate solution. There are eight categories defined (Saunders & Lewis, 2015) that were considered and are summarised in Table 3.4.

Strategy	***Definition***
Experiment	A research strategy involving the definition of a theoretical hypothesis
Survey	Involving structured collection of data from a sizeable population. May take the form of questionnaires or structured interviews.
Case Study	Involving the investigation of a topic within a real life context
Action Research	Concerned with the management of change and involves close collaboration between practitioners and researchers.
Grounded theory	Theory is developed from data generated by a series of observations involving an inductive approach

Ethnography	Focuses on describing and interpreting a social world through field study
Archival Research	Analysis of administrative records and documents as principle source of data
Narrative	An account of an experience told in a sequential way, indicating a flow of events that convey meaning

Table 3.4: Research strategy definition (Saunders & Lewis, 2015)

In terms of this research the strategy is not considered from a theoretical hypothesis, the outcome will be applied in a factory environment and does not therefore lend itself to experimentation. The last three strategies shown in Table 3.4 are not considered relevant due to the definition not being directly relevant to the field of this study as the approach does not consider the social world or utilise records as a source of data.

Action research (AR) will be the predominant strategy. The concept of 'research in action rather than research about action' is proposed by this study (Coughlan & Coughlan, 2020). This research will further inform a 'worthwhile practical purpose', a view proposed in work (Reason, 2007). This practical purpose is also supported by resolving real organisational issues which are described (Shani & Pasmore, 1985).

AR is described as being participative (Coughlan & Coughlan, 2020), where members of the system being studied participate actively in the research. This is important within the research organisation where key stakeholders are involved in interviews and also within the industry where an industry wide survey promotes participation.

The study will require the researcher to be actively involved in the research and the outcome, referred to (Platts, 1993) as taking research one stage further. The success of the research depends upon the researcher directing and influencing the research activities. Additionally the approach will require resources to be adopted in terms of time and money, which need to be managed

A further aspect put forward (Coughlan & Coughlan, 2020) is that AR is research concurrent with action. The goal being to make action more effective and simultaneously build a body of scientific evidence. This is an important factor in considering the development of the Energy Efficiency Hierarchy. Finally Coughlan described AR as a sequence of events and an approach to problem solving. In the case of this research the problem of how to improve energy efficiency within corrugated operations. .

The process of action research will be emergent and iterative as the thinking will change as new learning is assimilated during the research. The stages of research will follow a pattern subscribed (Saunders et al, 2015) as a process of diagnosing issues, constructing theories, planning action, taking action and evaluating action.

It is reported (Eden & Huxham, 1996) that AR generates emergent theory, in that the theory emerges from a synthesis of what emerges from the main data. Additionally it is put forward (Eden & Huxham, 1996) that theory building with AR will be incremental, moving from the particular to the general in small steps. In the work it is reported that AR requires an explicit concern with theory that is formed from the conceptualisation of the research experience in ways which are expected to be meaningful to others.

The nature of this research will provide the opportunity for a wide range of viewpoints and opinions to be collected from industry experts during the action research at sites. It has been argued by (Greenwood & Levin, 2007) that action research is a social process and that participation is a critical component. For this reason the research provides a wealth of opportunity for interaction and the key stages of research, action and participation to take place.

Action research has been suggested (Reason, 2006) can be difficult to develop and put into practice. However the research will be carried out primarily within a multi-national company with the organisational dynamics and barriers to entry much reduced due to inclusion. Action research is suggested (Greenwood & Levin, 2007) to work best when the objective is to improve the situation for the participants and the organisation.

Deliverable actions that provide improvement are required as an outcome of this research. Therefore an action research approach aligns itself well to the objectives.

The other strategies which support the action research approach are complimentary in their adoption and supportive. These supporting strategies include Survey and Case study. In considering the research (Bryman, 2006) it is suggested that a adopting a mixed methods approach is being recommended on an increasing basis with such research and this is proposed due to the research complexity and scope.

In considering the adoption of AR as the dominant research strategy the potential threats to validity have been considered. There are four specific points raised (Fisher & Torbert, 1995) which have been suggested to be key to enacting the AR cycle, these include framing, advocating, illustrating and inquiring. The adoption of these aspects will ensure the internal practitioner role remains impartial and relates to the action research process and not to personal beliefs and pre conceptions.

3.7 Methodological choice

This research utilises a mixed methods approach to better understand the background to the problem. This principle is supported by the work of Tashakkori and Teddlie (2009) in that mixed methods (MM) research has emerged as an alternative to the dichotomy of qualitative (QUAL) and quantitative (QUAN) traditions during the past twenty years.

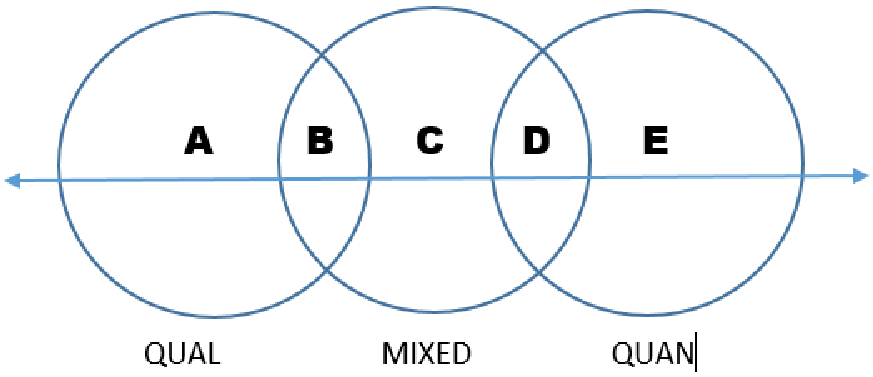

Figure 3.2: The QUAL-MM-QUAN Continuum (Teddle & Tashakkori, 2009)

In Figure 3.2 Zone 'A' represents totally qualitative research, Zone 'E' representing totally quantitative. Zone 'B' representing primarily qualitative research with some quantitative components. Consequently Zone 'D' is the reverse of this with primarily quantitative data and some qualitative components. Zone 'C' representing a totally integrated mixed methods research. The arrow represents the continuum.

This study sits within **Zone 'D'**, the emphasis being on the capture of rich quantitative data which is evaluated and tested further. In this way one phase informs the next and is referred as 'sequential mixed design' (Tashakkori & Teddlie, 2009). As a result during the course of the research one method may lead to the discovery of new insights and enable further problem solving. This is supported in work (Bryman, 2006) that also suggested that mixed methods approach provides a diversity of approach and can provide greater confidence in the conclusions.

3.8 Research time horizon

There are two options (Saunders & Lewis, 2015) in terms of time horizon which are cross sectional and longitudinal, within the work they are described as;

Cross sectional study:	Study of a particular topic at a particular time i.e. 'snapshot'
Longitudinal study:	Study of a particular topic over an extended period of time

Within the research the approach will adopt a longitudinal study as the research will be carried out over multiple sites across the UK and over a considerable period of time. Specific data collection and reviews conducted at operating sites may be considered as a snapshot of current activity at that particular time, potentially being classed as cross sectional. However the research adopts a broader longitudinal approach as it is not constrained by time or resources as is argued as a negative contributing factor to research (Saunders & Lewis, 2015).

The research will be carried out with the role of an internal practitioner. Guidance will be considered to ensure recognition of the research application in regards to analysing, interpreting and theorising about the research data whilst remaining detached to allow a non-distorted view of the organisation as put forward (Tietze, 2012).

3.9 Data collection and data analysis

In providing an overview of the data collection and analysis during the research the following methods have been adopted:

Questionnaire	Face to Face conducted within Smurfit Kappa
Survey	Conducted by On Line survey tool
Action Research	Observation
	Direct measurement
	Energy audit

This research is reviewed in respect of the research objectives put forward in section 1.7.2 and the research questions defined in section 1.9.3. These are repeated in Table 3.5 for ease of reference.

No	Specific research question	Research Objective
1	What is current best practice in the area of energy defined from the literature review?	1
2	How might this defined best practice best be applied in the corrugated industry?	1,2,3,4,5
3	What gaps are there in relation to corrugated manufacturing industry?	1,2,3
4	What is the current best practice applicable within the corrugated industry?	1,2
5	How can energy load be identified, evaluated and potentially reduced within the corrugated industry?	1,2,3,4,5
6	What energy modelling and energy efficiency techniques can be employed to establish the costs and benefits of any potential changes within the corrugated industry?	1,4,5
7	What specific range of technologies can be applied to formulate a best practice methodology for the corrugated industry?	1,2,5
8	How can these be combined into a strategic modelling framework to be used throughout the corrugated industry to drive energy reduction best practice?	3,4,5

Table 3.5 Research Questions

These were considered in terms of participants, data collection method, and population size, sample size and sample criteria. This was referenced along with the time horizon within the study and is shown in Table 3.6.

Research question	*Participant*	*Data collection method*	*Research Strategy*	*Reason for choice of method*	*Population size*	*Sample size*	*Sample criteria*	*Time horizon*
1	None	Literature research		Wide scope of work	200	over 100	Related to energy efficiency	2015
2	Internal & External	Questionnaire & key informant interviews	Survey	To understand breadth of perspectives	250	50	Sector expertise	2016
3	Internal & External	Questionnaire & key informant interviews	Survey	To understand breadth of perspectives	250	50	Sector expertise	2016
4	Internal & External	Key informant interviews	Survey	To understand a number of approaches	250	35	Industry experts	2016
5	All relevant parties within the research	Observation, direct measurement, discussion	Action Research	Define actual site energy usage	22 manufacturing sites	22	Site experts, plant & equipment, calibrated instruments	2016-2019
6	Internal & External	Observation, direct measurement, discussion	Action Research	To gain knowledge from experience and action research	22 manufacturing sites	22	Site & Industry experts	2015-2016
7	Internal & External	Observation, direct measurement, discussion	Action Research	To gain knowledge from experience and action research	500	50	Corrugated manufacturing sites within research organisation	2015-2016
8	None	Observation, direct measurement	Action Research	Action research approach	22 manufacturing sites	22	Corrugated manufacturing sites within research organisation	2016-2019

Table 3.6: Data collection considerations

Action research data collection and analysis employed observation and direct measurement on the packaging manufacturing sites over the course of a three year period. Within this phase of research an energy audit was delivered as a focussed 5 day study period per site followed by a series of follow up visits over the course of six months. Due to the scale of the task action research at sites was conducted in series, whilst some of the follow up visits overlapped.

During the 5 day energy audit at site direct measurement was employed to gain data relating to energy use associated with gas and electricity consumed within the manufacturing process. This detailed piece of work includes the direct measurement of sources of energy supply, identification of energy costs, generation costs of utilities such as compressed air, plant running hours, energy management systems and measured energy consumption details down to line and equipment level. The majority of this data at a total site level is validated and approved data used for business sustainability reporting and as such can be described as official.

Metering equipment was made available by the research company to measure boiler efficiency, electrical loading, light levels, air leaks and thermal energy losses. All equipment was calibrated and results were taken from industry recognised portable meters such as FLIR, Alpine Components and UE Systems. These commercially available instruments have analysis tools inbuilt and allow up load of data into spreadsheet formats for further evaluation and analysis of results.

Data analysis for action research will be conducted during each site visited and the accuracy of forecasting considered within a simple modelling tool developed to assist with the research. This will forecast the savings by each efficiency technology and suggest energy savings and carbon reductions later derived through actual application.

3.10 Ethical considerations

The research proposal was presented to the both the Smurfit Kappa UK Corrugated Executive Board and also to the European Federation of Corrugated Manufacturers (FEFCO) to ensure ethical approval for dissemination across the European industry bodies. In terms of ethical considerations the following points were considered important in relation to the study.

Consent for the research was covered by participant briefing letters and consent given for inclusion of information within the research study by individuals and organisations. The research was open and did not use a covert or deceptive approach.

Debriefing is explained within the participant briefing and consent letters, some of which may be retained as internal confidential information at the early stages of research to be disseminated within the wider industry post research completion.

Individuals were given the opportunity to withdraw from the research at any time and this was covered by the participant briefing and consent letter and corresponding participant debriefing and withdrawal letter.

Confidentiality is covered by the participant briefing and consent letter and also discussed and agreed in advance with the research organisation. It was recognised that the research provided an opportunity for potential competitive advantage. As a result publication of results and research outcomes was agreed to be post research with approval from the research organisation.

The participants involved in the research will not be at risk of physical, psychological or emotional harm greater than encountered in ordinary life. All data protection is covered by the participant briefing and consent letter.

In consideration of requirements of the General Data Protection Regulations detailed in a Guide to GDPR issued by the Information Commissioners Office (2018) all data was specified as specific to this research in understanding energy efficiency within the corrugated industry and research confirmed that this data would not be passed on. Data responses collected through the survey were anonymous with no ability to track personal data to individual responses.

3.11 Summary

It is suggested by this research that for any specific research there is no one designated approach that is laid out to define the research. More importantly the research is designed to provide flexibility and structure without constraining the emergence of new thinking leading to new knowledge. As explained at the beginning of the chapter this research has adopted an approach based on Saunders and Lewis (2015) that has enabled the following structure to be adopted.

Philosophy	Pragmatism
Approach	Inductive
Strategy	Action Research
Methodological choice	Mixed methods
Time horizon	Cross Sectional and Longitudinal
Techniques and procedures	Observations, questionnaires and physical data collection

This approach is summarised diagrammatically in an applied form for this research in Figure 3.3.

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Figure 3.3: Applied approach

The research will provide a qualified approach based on empirical data researched over multiple sites of the projected energy efficiency benefits of implementing a selection of technologies. This will support the construction and evolution of an energy efficiency framework, which is currently not in existence across the industry

Chapter 4 Research Instruments

4.1 Introduction

Following the literature review presented in Chapter 2 it is suggested by this research that there is an absence of published data in the field of energy efficiency within the corrugated industry. As a result the research design chose to carry out primary research to further develop a more informed understanding of the current situation. This research was conducted in both survey format and semi structured interviews.

In section 3.7 the methodological choice was explained as 'Mixed Methods' shown in Figure 3.2, which represents the QUAL-MM-QUAN Continuum (Teddle & Tashakkori, 2009). The research sits within **Zone 'D'**, and whilst predominantly based on quantitative research methods the study adopted an element of qualitative research.

Three research elements, survey, interview and observations, identified in Section 3.9 as data collection tools, were selected to extend the research information beyond the literature review and into new areas previously not published or researched.

To research further the area of energy efficiency a decision was taken to study the wider industry perspectives to ensure a solid research base was established. This was conducted with qualitative methods through industry wide stakeholders by means of a survey and through structured interviews with research organisation leadership. Some elements of the survey were also categorised within quantitative research.

In order to obtain detailed manufacturing plant based information quantitative research enabled the focus on numbers, data and energy efficiency forecasts and results which provided a more tactical focussed business perspective from within the research organisation.

4.2 Quantitative research analysis

Quantitative research deals with numbers and statistics and has the advantage of replication, comparison and handling large sample sizes. In quantitative research, the data can be quantified and because the samples are generally large they can be considered representative of the population. The results are taken as if they constituted a general and sufficiently comprehensive view of the entire population (Martin & Bridgmon, 2012).

Quantitative research (Queirós et al, 2017) focuses on objectivity and is especially appropriate when there is the possibility of collecting quantifiable measures of variables and inferences from samples of a population. Quantitative research adopts structured procedures and formal instruments for data collection. For the site observations and data collection this was considered appropriate to enable site based data collection of energy consumption, energy load and energy usage.

4.2.1 Observations

Observation within this research is a key part of Action Research conducted during the research study at corrugating sites and detailed in Chapter 6. In terms of its design, process and results this is explained within this section.

4.2.2 Observation design

Action research carried out at sites is conducted through observation. It was suggested (Wellington, 2015) that the significant part of using observation as a research instrument was that information could be gathered first hand from live data in situ. With the adoption of a structured approach described in Chapter 5 many aspects of the energy use would be observed on plant and equipment in a live situation.

Type of observation	*Reason for observation*
Prespecified	Specific areas of energy use across the corrugated manufacturing operations
Quantative	Establish specific energy usage on plant and equipment
Qualitative	Gather views and opinions of key stakeholders at sites
Time bound	Energy audits on site and follow up site reviews over a four year period
Structured/Systematic	Targeted approach with defined areas of inspection and review
Participant observation	Carried out by the researcher directly at sites
Highly focussed	Direct energy measurement through equipment and tools
Descriptive	Data determination of kWh and energy measurement
Overt	Inclusive particpant inclusion of key individuals
Natural settings	Research sites across UK, specific corrugating manufacturing process
Direct observation	Research carried out with physical presence on site and measurement
Indirect observation	Equipment utilised to record energy usage where direct observation impractical

Table 4.1: Continua of observation, Cohen et al (2017))

It is suggested (Cohen et al, 2017) that observation is a powerful tool for gaining insight into situations with many reasons for observations shown in Table 4.1. However this research recognises that data collection and observation can give rise to concerns regarding validity and reliability. This research has been constructed to ensure that within the action research observations will be conducted across twenty four sites and analysed to ensure the correlation and accuracy of the research.

4.2.3 Observation process

The process adopted follows a standardised approach considered further within the Framework Methodology within Chapter 5. This is important due to the scope of the observations in terms of geography within the UK, size of plant, energy consumption and availability of equipment and resources. A standardised approach is essential to ensure project management and research effectiveness.

The process of observations will be based on measurement of data as primary research and this requires analytical calibrated instruments and equipment that can accurately measure energy consumption. Where the survey and interviews considered qualitative and quantitative data the observations are based entirely on verifiable quantitative data taken directly from plant and equipment during the research.

4.2.4 Observation results

The results of the observations are detailed within the action research contained in Chapter 6. These results shape the energy efficiency framework proposed in Chapter 7 in meeting the research objectives and delivering energy efficiency.

4.3 Qualitative research analysis and presentation of results

Qualitative data collection is classed (Cassell & Symon, 1994) as usually being dependent on interpretation. This suggests that the data collected may require several explanations. It has been reported (Cohen et al, 2011) that data analysis in qualitative research is distinguished by merging of analysis and interpretation. This suggests that there is an overlap of analysis and interpretation of results to reach a final conclusion.

In both cases of survey and interview qualitative analysis was required to collect a diverse range of comments and themes. Once the information was gathered, an appropriate method for analysing the analysing the data was defined. There are many ways to analyse interview discussion (Mahrer, 1988), (Spradley, 1979) with such approaches as grounded theory and thematic analysis presented.

Thematic analysis is one such way which is recommended (Boyatzis, 1998) as it illustrates the data in great detail and deals with diverse subjects via interpretation. Thematic Analysis is essentially a method for identifying and analysing patterns in qualitative data. It has been suggested (Marks & Yardley, 2004) that thematic analysis can allow an opportunity to understand an issue more widely, which is relevant for the interview based research.

Grounded Theory is argued (Braun & Clarke, 2006) to be very similar to Thematic Analysis in terms of their procedures for coding 'themes' or coding from data. One difference reported is that in grounded theory processes run in parallel where the data analysis process starts at the same time as the data collection process. This research starts with interviews and survey to support the establishment of the research and key insights into energy efficiency. Following this data collection and analysis is conducted much later during action research.

The flexibility of thematic analysis is suggested (Frith & Gleeson, 2004) to allow both inductive and deductive methodologies. This is considered important for this study in that using an inductive approach the majority of the data that is collected will start with a precise content and then move to broader generalisation. This will develop a theory that will establish the Energy Efficiency Framework. A thematic approach is suggested (Patton, 1990) to ensure the themes are effectively linked to the data.

The following sections explain the stages of design, process and findings for all three research implements of survey, interviews and observations in supporting the research objectives.

4.3.1 Research survey

The survey set out to clearly understand the current attitudes towards energy efficiency and its importance to business. This is achieved through a structured questionnaire. The research was carried out between November 2017 and February 2018, with the research findings published in an internal report (Parr, 2018) to the research organisation.

4.3.1.1 Survey design

It has been suggested (Wilkinson & Birmingham, 2003) that the most commonly used research instrument is a questionnaire. This enables the process to be researcher led as opposed to a participant led approach such as observation and video. The survey was designed to investigate energy efficiency and understand the gap that exists between knowledge, application and awareness.

For the purposes of this research a large number of participants were identified across multiple organisations throughout Europe. Therefore the questionnaire was considered the most appropriate method for this survey.

The adoption of an on line commercially available system, Survey Monkey, provided a low cost route to deliver the survey. Whilst being easy to administer, the system was able to reach all designated respondents within a short time scale. It has also been commented (De Leeuw et al, 2008) that computer-assisted self-administered questionnaires produce a higher response rate than their paper-based counterparts

Questionnaires can be designed with closed questions, multiple-choice, ranking questions, and open-ended questions. The first part of the survey provided direct multi choice questions. Whilst the second part of this survey adopted an open ended approach, allowing responses to be more reflective on the energy efficiency approach to gain an insight into current activity. The research was cognisant of the potential for information security and the University Code of Ethics. The survey was approved for distribution by the research organisation.

The following questions in Part 1, shown in Table 4.2, were adapted for on line response within the internet based software system providing an approach that required a scale of response similar to the 'Likert Scale' (Joshi et al, 2015) with a scale of response from 1 being '*Disagree*' to 10 being 'Strongly *Agree*'.

A Likert scale is a psychometric scale that has multiple categories from which respondents choose to indicate their opinions, attitudes, or feelings about a particular issue. Likert-scale questionnaires can be used to research investigations into individual difference variables and in this way an understanding of the current reality of energy efficiency across the industry can be provided.

No	Question	1	2	3	4	5	6	7	8	9	10
1	The business has delivered significant energy reduction in the last three years (in excess of 10% reduction)										
2	The improvement in energy can be demonstrated on a site by site basis across all operational sites										
3	There is a detailed site energy balance in place that enables specific areas and levels of use to be evaluated										
4	Detailed energy usage is measured and there is a good set of reporting metrics in place across the business										
5	Key metrics are commonly discussed with operational teams to engage their support in improvement										
6	Sites have developed a good energy culture and a positive approach towards engagement										
7	Teams and individuals are well trained in energy management & have capability to deliver improvement										
8	All operational sites have an appropriate targeted energy reduction plan in place										
9	Energy audits are fully utilised as a tool to assist with sustaining improvements in energy reduction										
10	There is a full ISO 50001 Energy management system in place across our operations										
11	Automated energy monitoring / targeting systems are in use across our operations										
12	The approach to energy reduction is targeted at switch off campaigns										
13	The approach to energy reduction is targeted at removing energy losses and improving equipment										
14	The approach to energy reduction is targeted at introducing renewable energy technology										
15	The approach to energy reduction is targeted at carbon capture technology										
16	Energy efficiency & reduction ranks in the top 5 key priorities for the business										
17	The key driver for the energy reduction activity is Legislation and the impact it can have on business										
18	The key driver for the energy reduction activity is commercial and financially driven										
19	The key driver for the energy activity is the moral responsibility with regards to sustainability										
20	To support the goals external experts and consultants are used to develop and deliver energy objectives										

Table 4.2: Survey Questions – Part 1

Advantages of using a Likert-scale questionnaire (Nemoto & Beglar, 2014) is that (a) data can be gathered relatively quickly from large numbers of respondents, (b) they can provide highly reliable person ability estimates, (c) the validity of the interpretations made from the data they provide can be established through a variety of means, and (d) the data they provide can be profitably compared, contrasted, and combined with qualitative data-gathering techniques, such as open-ended questions, participant observation, and interviews.

The output required from a Likert analysis is targeted to a limited range of possible responses with typical options being Disagree/Agree. In table 4.2 a ten point scale is used to attempt to force categorisation of opinions and increased measurement precision. It can be seen that the scale moves from a weaker endorsement (disagreement) to a stronger endorsement (agreement).

Part 2 of the survey utilised open ended questions to understand more individual perspectives and thinking. The questions were constructed to achieve this objective shown in Table 4.3.

Q1:	What would you consider to be current best practice in the area of energy management, energy efficiency and energy reduction within the Corrugated industry today?
Q2:	What gaps do you see with respect to energy performance within the Corrugated Industry?
Q3:	How do you measure energy performance and what key metrics do you use to drive improvement and focus
Q4:	Where you have used energy modelling software have you been able to quantify the benefit of the investment in deliverable savings
Q5:	What does your vision of energy best practice look like applied to manufacturing plant?
Q6:	What barriers, if any, prevent you from delivering energy best practice
Q7:	What enablers help you to achieve significant energy reduction?

Q8: How do you ensure that energy is considered when buying new equipment?
Q9: How developed is the energy culture in your company and what have you done to engage others in such an approach within your company?
Q10: What do you see as the key challenges in meeting your climate change targets for 2020?

Table 4.3 Survey questions – Part 2

It is suggested (Gillham, 2000) that when designing a questionnaire it is easy to overlook mistakes and ambiguities in question layout and construction. In order to prevent this and to ensure an appropriate and effective approach the questionnaire was piloted within the research organisation. The design was tested with a pilot group of stakeholder managers. During piloting a number of minor formatting errors were noted and amended accordingly. Piloting is suggested (Verma & Mallick, 1999) to increase reliability**,** validity and practicability of the questionnaire

4.3.1.2 Survey process

During this research the perceptions and views of corrugated industry leaders and suppliers of equipment were taken into account and considered. This was a significant piece of work that was undertaken with the support of the industry and its suppliers. Those involved included a wide range of respondents including the key organisations who have contributed towards the research shown in Figure 4.1.

Figure 4.1: Key research contributors

The research was conducted across all key manufacturing producers and suppliers within the corrugated industry after its launch at the Federation of European Corrugated Manufacturers (FEFCO) Technical Conference in Vienna in October 2017. The resulting 31 manufacturers' respondents and 25 supplier respondents represented an 88% engagement return rate from the sample population.

There were no companies that withheld from the survey and a number of stakeholders requested further information of the research study. As a result of the return rate the survey included all five international major corrugated manufacturers, along with a number of privately owned businesses. Respondents included the major suppliers to the industry who manufacture and provide equipment for corrugated and converting machinery.

4.3.1.3 Survey findings

The findings were presented (Parr, 2018) to the members of the Federation of European Corrugated Manufacturers (FEFCO) on the 16th April at their Production Committee in Remshalden, Germany and published for internal communication. Extracts from the research conducted have been summarised within this section.

4.3.1.3.1 Results from Industry Suppliers

The result of the survey indicates that suppliers are key to enabling an embedded sustainable approach to energy efficiency within the industry. Research within the study would suggest the following views from responding equipment suppliers within the industry.

From the views of respondents 95% of all suppliers consider energy in their equipment design, however variation in approach exists due to a lack of standards for energy efficiency across the industry. It was felt by suppliers that 50% of customers purchasing equipment do not consider energy as a key purchasing decision as shown in Figure 4.2.

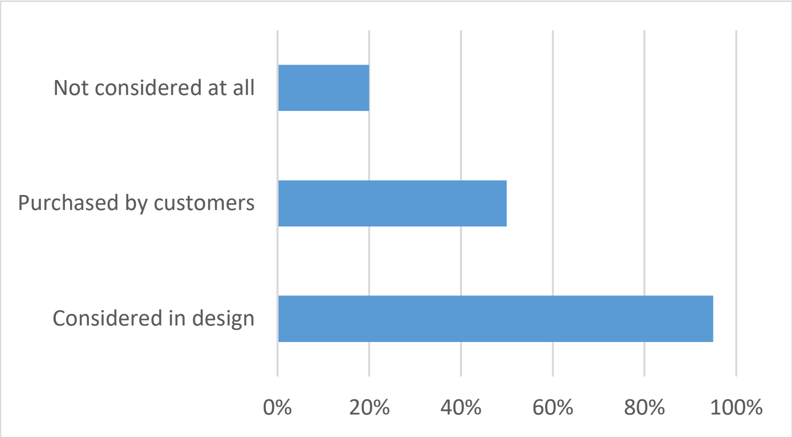

Figure 4.2: Influencing equipment purchasing discussions

In terms of purchasing strategy less than 50% of all responding suppliers discussed energy life cycle cost analysis during negotiations with manufacturers, with cost an overriding factor when considering energy efficiency. Surprisingly 20% of responding suppliers confirmed that energy is not considered as part of the equipment selection and purchasing decision in their opinion.

In considering integrated technology only 30% of respondents provide measuring and monitoring within their equipment for energy. No supplier stated they gave a statement regarding the carbon footprint of supplied equipment.

It was noted from the research that responding suppliers are aware of what to do and how to improve the energy efficiency of their equipment. It was evident from Figure 4.3 that 62% of respondents suggested high efficiency motors as the most appropriate energy efficiency option in relation to equipment design and provision. This was followed by the application of inverter drives and then compressed air, which surprisingly was only quoted as a low level opportunity by 7% of respondents.

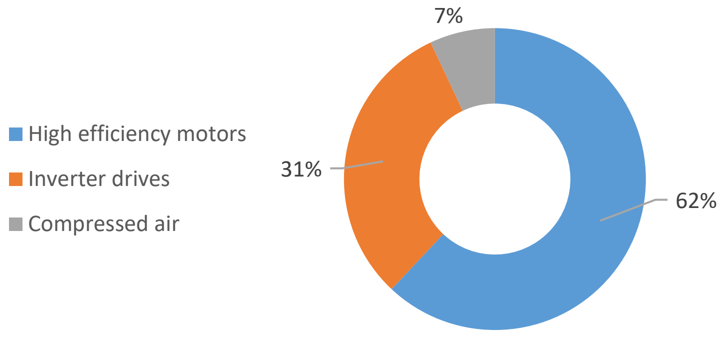

Figure 4.3: Suppliers perspective – key energy drivers

Suppliers also commented on how manufacturers should look internally at their plant operations to improve energy efficiency. Areas of engineering maintenance, operator training, energy management and process operation being suggested as key to energy efficiency. However, responding suppliers believed that there remains a culture of reactive management with no clear defined best practice or approach.

In terms of defining a gap between desired and current reality responding suppliers stated there is no specification for energy within the equipment design. This together with no industry standards and a low awareness of energy efficiency was suggested to be a reason for no aligned strategy for ensuring energy efficiency.

Respondents suggested that ignorance was sometimes a barrier to energy efficiency, with a lack of awareness being a factor. Cost was overwhelmingly felt to be a barrier to entry for energy technology within equipment supply. Restricted capital and essential payback and return on investment being a driving factor, especially when considering the threat of new entrants to a market with no established energy standards.

The research shows in Figure 4.4 that over 65% of all responding suppliers felt that the responsibility was on the purchaser of equipment to provide a design specification aligned with industry standards for energy efficiency. This it is suggested is to balance the fact that suppliers believed that cost would prevent energy efficiency being built into the purchase request.

ANSWER CHOICES	RESPONSES
Morale ethics are really important to us	9.52%
Cost will always be an overriding factor	28.57%
A customer design specification will drive improvement	23.81%
Industry standards will drive the way we operate	38.10%
TOTAL	

Figure 4.4: Industry response to survey – suppliers

Over 55% of respondents believe the industry would commit to adopting an energy efficient approach if the cost was right and more than 30% felt energy efficiency was morally the right thing to do. In concluding suppliers believed that the following areas would improve energy efficiency:

- Perfect maintenance
- Operator training
- Built in power management systems
- Air leakage and compressor control
- Reduced steam pressure
- High efficiency motors

4.3.1.3.2 Results from Corrugated Manufacturers

The research showed that corrugated manufacturers are committed to energy efficiency and are actively pursuing an energy efficiency approach. This encompasses manufacturing processes, equipment supply and supply chain operations which are all fundamental in developing a sustainable circular approach.

When asked about performance regarding energy efficiency improvements over 65% of all responding manufacturers stated they had delivered a significant improvement (more than 10%) in energy efficiency in the last three years.

More than 60% of manufacturers reported a detailed energy balance in place and clearly understood their energy key drivers, shown in Figure 4.5, with clear metrics and reporting to assist improvement in place.

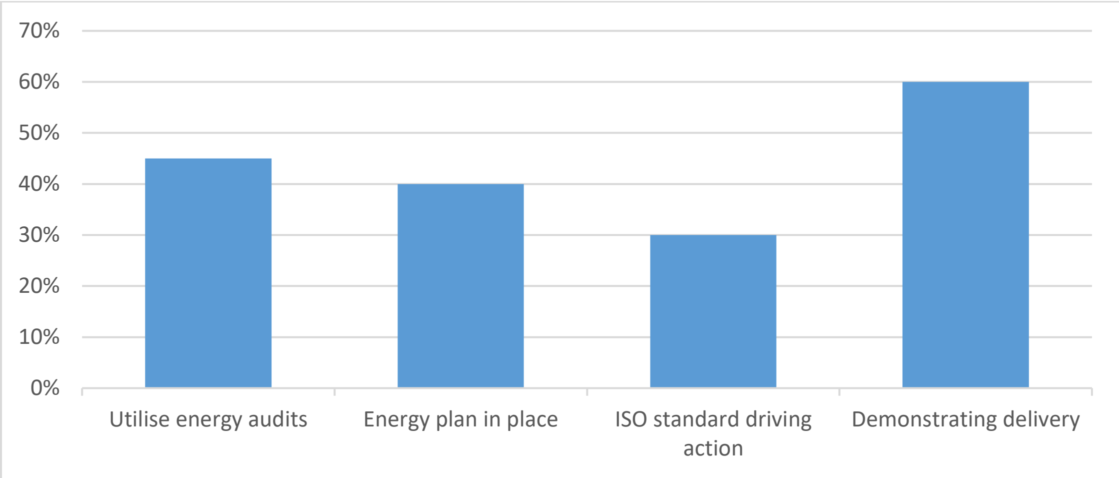

Figure 4.5: Considering energy efficiency

The approach being taken by responding manufacturers focused in more than 55% of responses in utilising improvement teams to drive an effective energy culture. Whilst responses confirmed a growing positive energy culture, it was stated that only 40% of those manufacturers had developed the capability and understanding in their teams to drive a sustainable approach.

From the research findings it can be stated that manufacturers are somewhat aware of where to focus to drive energy efficiency. The following areas were noted as being key areas of improvement;

- Factory lighting systems
- Compressed air
- Electric motors
- Steam

There is synergy when comparing this to supplier's viewpoints, however it would appear that the manufacturers have a wider scope of energy efficiency than suppliers, having to consider site infrastructure as well as equipment.

Monitoring and review was considered an important factor. The feedback stating in some occasions that management processes such as ISO 50001 are being used as the controlling process for review. It was felt that these areas where well understood and had high levels of action and focus. However areas of boiler control and efficiency, printing technology, equipment design and renewable energy were as yet under developed and areas of opportunity.

It is suggested that within the research study manufacturers had clearly defined their aims and objectives for energy efficiency, with clearly defined targets for energy efficiency and corresponding measurement and control built within equipment. This was supported by a goal to have highly capable and competent teams who have a clear understanding and awareness of energy efficiency enabling a behavioural culture with passion, motivation and desire to succeed.

It should be noted from the research that not all responding manufacturers shared this overall vision. It was apparent that some had not yet embarked on the journey and where unclear what steps to talk along the way.

Manufacturers responded that cost was a factor, although not always a barrier. They stated supplier resistance to discussion on the subject of energy as a barrier, along with not enough action. Technology innovation was deemed to be lacking in the area of energy efficiency whilst it was felt that too much measurement sometimes prevents simple action. The research suggested time and focus was a barrier in that resources did not always consider energy due to time and pressure.

Where energy was seen as a key initiative manufacturers in the whole stated drive from the top as being one of the key enablers in engaging the workforce. This provided the catalyst to motivate business and enable teams to strive towards energy efficiency. In doing this respondents stated audits, measurement and defined action plans as being essential.

The research found that many manufacturers believed that suppliers were key enablers in delivering technology and equipment to deliver an integrated sustainable approach. In simple terms one responding manufacturer stated that 'we know what to do we just all need to align to drive a sustainable energy efficiency climate going forward working towards a common goal.' It is proposed by this research that the survey supports the research gap identified in requiring a clear framework for the adoption of energy efficiency technologies across the industry to be developed.

4.3.2 Research interviews

4.3.2.1 Interview design

This research has already proposed that a gap in the knowledge within the corrugated industry with respect to energy efficiency has been established through literature. The interview process was designed to challenge this assumption and qualify the research gap. Interviews were conducted to define the current level of knowledge and awareness from key stakeholders appropriate to this research within the research organisation sites. The objective of this being to inform this research with current thinking and perspectives not published within current academic or general articles or reports.

This research utilised semi structured interviews to develop a much deeper understanding of energy efficiency during the study. It is suggested (Kvale, 1996) that *inter-views* represent an exchange of views for knowledge production which in the respect of energy efficiency would be suitable. It was felt by this research that as suggested (Hochschild, 2009) interviews can do what surveys cannot in terms of developing deeper conversations.

By adopting semi structured interviews this research provided an opportunity to research in depth key aspects of energy efficiency with many key individuals located at the research organisations sites from a number of differing levels within the organisation. The process of interviewing was time consuming and the aspect of access to individuals was made possible by the Internal Practioner role adopted by the researcher within the research organisation.

The type of interview was based on the categorisation (Paton, 1980) as being informal conversational, but with an interview guide approach. Due to the depth of research conducted within the interviews questions could potentially emerge from observations. To support the process topics covered were identified in advance to provide some preparation time and this as suggested (Cohen et al, 2017) allowed interviews to remain conversational.

Interviews were conducted before the action research at sites. It was important to recognise that such an approach outlined (Paton, 1980) needed to recognise that differences in responses would be obtained based on individual feedback, knowledge and understanding. During the interviews an unstructured approach was adopted which provided more flexibility and freedom to explore the situation. In work (Kerlinger, 1970) there is a suggestion that this puts more responsibility on the interviewer, which in this instance was acceptable due to the experience and internal role of the researcher.

4.3.2.2 Interview topics

To establish the interview format a list of key prompts was developed, represented in Table 4.4. This was explained (Marchiori & Demartini, 2017) to clarify participant responses in relation to probe and guide questions to subject areas of response. It is suggested (Aldridge & Levine, 2001) that there are two types of probe. This research considered both types in that the first prompt sought more factual information, whilst the second prompt enabled the interviewee to explain their own opinion and perspective on energy efficiency.

No	Interview question	Prompt
Q1	How is the energy consumption measured and evaluated on site	
a		What is the apportionment of energy across site
b		Which equipment has the biggest energy usage
c		How is energy monitored and evaluated
Q2	What energy efficiency technology is used on site	
a		Why is this used
b		What does it achieve
Q3	What energy efficiency technology has been considered before on site	
a		What impact did it have
b		How was the application considered on site
c		What were your views on its success
Q4	With regards to electrical motors what is your approach to energy efficiency	
a		How many DC drives are still in plave on site
b		What is your approach to high efficiency motors
c		Does your plant benefit from motor control
d		How much of your plant has effective inverter control
Q5	Has your site invested in a lighting improvement upgrade project in the last five years	
a		What solution was implemented
b		What energy was saved and how did you measure it
c		How much more opportunity for improvement is there
d		What is your approach to lighting control across site
Q6	How do you manage compressed air across the manufacturing operations on site	
a		What pressure do you generate air at and why
b		How do you manage leakage and minimise waste
c		What is your maintenance / replacement policy
Q7	How energy efficient is your boiler operation and how do you measure it	
a		How is the boiler oxygen controlled and monitored
b		How do you measure and monitor the burner efficiency
c		What challenges do you have if any with water chemistry
d		Are there any thermal losses on site and how are they managed
e		What is the condensate return percentage and is it effiecient
Q8	How effective is your baseload management in supporting energy efficiency	
a		What is the site energy baseload and how is it managed
b		What are your shut down procedures for plant and equipment

Table 4.4 Interview questions and prompts

4.4.3 Interview process

Interviews were conducted with members of the corrugated site operational teams within the research organisation shown in Table 4.5. These were scheduled as an open meeting at each site visited following a site introductory tour. The research included experts from the following positions on site who would be categorised as knowledgeable by position and having a direct responsibility in energy efficiency.

Position within Company	*Rationale for selection*	*No. interviewed*
General Manager	Accountable for carbon and cost of energy	16
Operations Director	Responsible for factory operational performance	19
Engineering Manager	Responsible for energy usage and operation	15

Table 4.5 Key stakeholders interviewed

The process was designed to incorporate interviews from all key positions at every site where applicable and captured 100% of the targeted key subject experts. Not all sites had generic titles and therefore roles of similar levels and responsibilities were chosen to ensure consistency of approach.

4.3.2.4 Interview results

Whilst interviews can be time consuming requiring face to face discussion, the emerging themes were able to be established and tabulated for evaluation and consideration. This was considered useful in developing a knowledge of current thinking. It was noted that not all sites had an energy efficiency improvement plan in place.

From research interviews a number of significant points were noted which stood out for reflection and specific referencing. In considering the phases of thematic analysis suggested (Braun & Clarke, 2006) the role of internal practitioner enabled the research to be very familiar with the data from both written and verbal responses, as well as the data sources for the question design.

In evaluating the responses a detailed approach to coding is put forward based on the work (Braun & Clarke, 2006). The responses were considered from a personal 'feeling' perspective through to a 'factual' continuum and coded accordingly against areas of energy efficiency, supply, reduction and activity. These responses were collated and evaluated against factual site energy consumption data in relation to specific interviewees.

The key themes that were derived from the data and considered in line with specific research questions. The research conducted through the interview approach is referenced to the specific research questions shown in Table 4.6 described in detail in Chapter 1.

No	Specific research question	Research Objective
3	What gaps are there in relation to corrugated manufacturing industry?	1,2,3
4	What is the current best practice applicable within the corrugated industry?	1,2
5	How can energy load be identified, evaluated and potentially reduced within the corrugated industry?	1,2,3,4,5

Table 4.6 Interview research

A number of key statements from the interviews are listed below for reference.

'*We are sometimes busy fools, trying to implement energy savings but not being sure where to start or what to do, as a result we often don't bother*.'

Key theme: Knowledge & Understanding Engineering Manager, Site C, April 2016

'*Our stated group wide objective is to save carbon. However we struggle to appropriate capital for improvement as there are always many questions we cannot answer on projected return and payback*.'

Key theme: Energy Efficiency approach General Manager, Site F, November 2015

'*Generally we become aware of energy technologies when the latest salesman suggests that he/she can deliver savings with the latest technology. Who knows if they can be trusted to deliver?*

Key theme: Delivery of energy efficiency Operations Director, Site K, January 2016

Responses from semi structured interviews are contained within Table 4.7. These have been listed by specific research topic and also clustered within areas of responsibility and functional position. These areas have helped to inform the technology approach detailed further in Chapter 5

There was a consistent and clear message coming back from the survey and interviews that everyone involved was committed to energy efficiency and carbon reduction as a key strategic objective. There were many ideas on what to do and thoughts around what could be delivered. It is put forward by this research that these ideas and thoughts need to be supported by a factual process and a framework for delivery.

In concluding the research interviews it is argued by this research that there is a lack of understanding of what technologies can be adopted in corrugated operations for energy efficiency. Additionally it can be stated that there is confusion around what to do and in which order of priority.

The insight into the personal views of those interviewed demonstrates an opportunity for energy efficiency improvement. In order to facilitate this it is proposed that the technology must be known and understood, the return determined and payback justified so that the structure and process of deployment be easily understandable.

No	Interview question	General Managers	Operations Director	Engineering Manager
Q1	How is the energy consumption measured and evaluated on site	Most responses discussed financial cost as a main driver with a lack of knowledge of where energy is used and what to do to improve efficiency	Majority of responses provided an understanding of energy consumption across the plant without understanding consumption users	Responses varied from a good knowledge of site usage to responses suggesting the use of data loggers to estimate usage required on site.
Q2	What energy efficiency technology is used on site	Interview responses included opportunities such as lighting improvements without providing detail of what or how to improve efficiency	An awareness of what to do was evident, such as motors and drives and lighting. However there was a limited response to the impact of a varied set of technologies.	Suggestions included lagging and steam leaks to reduce thermal losses. Saving energy was often given as the overriding impact achieved with a gap in understanding what to prioritise.
Q3	What energy efficiency technology has been considered before on site	Responses gave a clear commitment to delivering carbon reduction and suggested more work was generally required to understand future potential savings across the sites.	A good understanding of previous technologies adopted was provided along with an awareness of the impact derived. Key issued raised was focus and availability of investement.	Most responses included motors, thermal losses and air leaks with a lack of investement and conflicting priorities given as reasons for a lack of action in energy efficiency.
Q4	With regards to electrical motors what is your approach to energy efficiency	There was a lack of understanding on motor control and replacement, with purchase seen as a revenue cost which was needed for production and no life cycle cost analysis carried out.	Responses varied from suggesting motor rewinds as the best energy efficiency measure, to implementing inverter control and DC replacement as most appropriate.	Focus appeared to be on uptime for production, lack of focus evident on energy efficiency in cost and service discussions. A number of responses were not clear on what to do.
Q5	Has your site invested in a lighting improvement upgrade project in the last five years	Response was generally that from a safety and quality perspective light levels needed to be improved, however this was stated as being difficult to justify.	Typically lighting would be upgraded as when required and would be considered as a result of local supplier deals and availability. Diffult to justify due to conflicting priorities.	Lighting replacement considered as a revenue cost carried out on an as needs basis. Responses stated LED as the preference but unsure of specification or impact / saving.
Q6	How do you manage compressed air across the manufacturing operations on site	Responses given suggested use of a dedicated air compressor which was adequately maintained and operated to supply site air demand.	Air controlled at the required pressure and flow as needed by the equipment. Little opportunity to improve energy effieciency stated and kit well maintained and managed.	Focus of responses on maintaining plant operation,little focus on energy efficiency and resistant to change pressure due to requirements. Leaks stated as not being an issue.
Q7	How energy efficient is your boiler operation and how do you measure it	Weakest area of responses given, lack of awareness of energy efficiency although leaks and lagging stated as areas of opportunity. Gap in knowledge in this area apparent.	Responses to both questions and prompts produced a gap in awareness with little understanding of opportunities for energy efficiency or key controls.	Maintenance focus given as the main response for boiler operation/control. Responses included leaks and losses through lagging but no quantifcation of potential energy efficiency gain.
Q8	How effective is your baseload management in supporting energy efficiency	Generally responses suggested a good control of baseload was in place without a knowledge of the actual figures. A belief was apparent that plant was turned off when not in use.	Responses suggsted boiler operation was run for steam supply for production, little consideration given to energy efficiency, no awareness of what to do to achieve improvement.	Suggested that most of plant was left on by production afetr use losing energy effieicny opportunities and this was accepted this was an area for improvement.

Table 4.7 Interview Responses

4.5 Summary

In determining the research implements for this study the environment and situation were considered, together with the purpose of the research in informing the research objective. The chosen implements of survey, interview and observation provide the flexibility in time, approach and location needed during the research study.

The elements of quantitative and qualitative research conducted have extended the literature research and provided a solid foundation for the action research within the research organisation. This area of study itself provides new knowledge and information, previously unestablished across the industry.

The following research sets out to define the current situation, evaluate opportunities and finally deliver a solution which can currently be defined as contributing to new knowledge in the industry. The proposed findings of all three research implements will be proposed to be the justification for this research study and the foundation for action research detailed in Chapter 6.

Chapter 5 Framework Development

5.1 Introduction

The chapter describes the phases of framework development. In establishing this approach modelling theory and current energy models are considered. The phases of development for the energy framework are summarised, together with models of energy technology and process approach adopted when carrying out Action Research at sites. Energy applications at sites are evaluated and considered with regards to developing energy efficiency. These are summarised before their dynamic application and evaluation in Chapter 6.

5.2 Energy Models

5.2.1 Theory of a modelling approach

The idea of a model has been suggested (Oakshott, 1997) to have existed since the time man developed the ability to think and attempt to change and therefore control his surroundings. Modelling can show where energy is being used and what energy is being consumed over time.

In order to provide a clear understanding of both the total energy consumption of a facility it has been proven (Knopf, 2012) that it is important to understand the interaction between its elements. Knopf goes onto to suggest that it is possible to then change the environment by forecasting and modelling potential energy reduction opportunities to establish a best practice modelling solution.

In research (Knopf, 2012) it shows a complex approach whereby computer aided solutions are applied to energy balances with detailed calculations and formulaic calculations adopted to provide solutions. Whilst such an approach may provide a valuable insight into the process world of manufacturing, it is not considered appropriate for the proposed framework development within this research due to the dynamic nature of the corrugating operating conditions.

Modelling is considered (Pidd, 2009) as understanding, changing, managing and controlling reality. In this work Pidd places emphasis on simplification without over complication and sophisticated software modelling. There are three basic types of model put forward by Pidd as the iconic, the analogue and the symbolic models. The difference being that physical models look like the real thing and mathematical models represent an aspect of reality.

There are two types of symbolic models stated (Dennis & Dennis, 1991) as being those providing a descriptive and normative approach. Descriptive models represent the relationships, identifying the outcomes, whilst not indicating the actions to be taken to achieve the solution. Normative models are more complex and used to optimise a situation, they are prescriptive and define actions to be taken to achieve a specific goal.

These models were reviewed to provide insight into the requirement for modelling carried out in Stage 2 of the Factory Process Model. A simplistic modelling approach subsequently was designed to forecast potential savings from energy efficiency technologies. This proposed research intends to adopt a descriptive approach as the modelling will provide the answer to the factory energy solution and will in doing so recommend the appropriate technologies to explain an energy efficiency solution for the factory.

A bottom up modelling approach (Talaei et al, 2021) is considered within the Canadian Iron and Steel industry to enable the implementation of long term energy efficiency improvements using a system referred to as the 'Leap System'. This details the approach of an energy policy analysis and mitigation framework. An Energy Demand Tree identifies the main energy consumers across multiple sites in the steel industry. In the work (Talaei et al, 2021) suggest potential energy efficiency measures that could be adopted to improve performance. In as far as the work goes this provides an overview and description of measures, such as automation and process control and heat recovery and VSD's. Of the 28 potential measures described, three are potentially suitable for application within the corrugated operations.

Energy system optimisation models (ESOMs) are reported to be widely used (DeCarolis, 2017), however the work recognises that such systems have become 'a magnet for increasing complexity'. The work suggest that features have been adopted to improve the realism associated with internal model dynamics. DeCarolis suggest that ESOM's have a long track record of use within academic and policy use in the UK. Such high level systems are not suited to delivering the aim of this research.

5.2.2 Established energy models

In developing the framework a number of alternative published energy specific models were considered in terms of 'fit' and 'content.' It is important that this research brought new knowledge to the subject matter and that it could therefore be classed as original. A review of current challenges and trends in energy systems modelling is presented (Lopien, 2018). The paper presents a very detailed review of model selection for governments with strategic decisions in relation to energy supply. The paper by Lopien also presents a summary of work (Bhattacharyya & Timilsina, 2010) and (Hall & Buckley, 2016). The works all cover in depth calculation and analysis of energy usage.

From reviewing the approaches within the paper presented by Lopien it is suggested the missing gap is providing a framework to deliver energy efficiency, as opposed to measuring the usage. It is recognised that every model is developed with different purposes and that the referenced models deliver within their selected objectives.

In work presented (Woo Jean et al, 2014) modelling and analysis of energy footprint of manufacturing systems is reported. It is suggested that this model is 'practical' in its approach as it considers how product, machine, plant and industry levels are connected for energy footprint evaluation. Having utilised a number of complex calculations the work considers design of experiments to address energy efficiency benchmarking.

The work (Woo Jean et al, 2014) is recognised by the writers as being hypothetical and probabilistic in its approach, however the suggested model does enable manufacturing plants to calculate the overall energy consumption. The model provides no indication of measures to adopt to improve energy efficiency.

A framework for modelling energy consumption within manufacturing systems is provided (Seow & Rahimifard, 2011). The review of relevant research presented in this work suggests that the focus on energy modelling is targeted towards understanding consumption. In the same way that a meter will measure usage, current models measure where energy usage occurs. The paper provides evidence of a taxonomy of processes used and considers the embodied energy product energy.

The work (Seow & Rahimifard, 2011) does provide a method of estimating and calculating the energy use right back to the design process so that the total energy required to manufacture a unit of product can be derived. The research reviewed shows no evidence of a framework to deliver energy efficiency. It is proposed in the paper that the energy use in a factory will vary across work areas and that energy consumption used by various processes is not well understood.

The concepts of linking ISO 50001:2018 to domestic practices within an energy management maturity model for China (Jin et al, 2021) is considered. The paper discusses an overall approach to energy management and systems development and puts forward levels of maturity in an approach. The work of Jin et al provides a long term meta-approach considering the knowledge base and process model that could be adopted to advance maturity. What the paper concludes is that there is more need for industrial energy standards and a requirement to develop industry specific practices. It is suggested that for the UK and for the research company this is exactly what this research is aiming to achieve.

An energy modelling approach based on a framework construction is reported (van Wyk, 2021). In this a framework adopts an algorithmic to enable a decision that designs a quantitative measure to evaluating energy saving. What comes across clearly in the review is the need to identify the highest energy consuming elements within a plant. The work covers potential opportunities such as sequencing of machinery, technology improvement and replacement, and carbon offsetting. The framework established reported a 57% reduction in energy use. The work shows the benefits of such an approach whilst leaving a gap with respect to the linkage of technology application, implementation and derived savings opportunities within the corrugated sector.

5.2.3 Measuring systems for modelling

Research identified a number of commercially available models used to measure and calculate energy usage. In a paper (Bramstoft et al, 2018) it recognises that energy system models are powerful tools. It goes onto review and critique one energy scenario tool, ‘Stream,’ in considering its strengths, limitations and potential developments.

The work of Bramstoft recognises that on many occasions simple spreadsheets can provide transparency and insight into a wide range of energy usage. The suggested approach is used to conduct a quick analysis to explore plausible scenarios. In this way it concentrates more on energy use and apportionment than delivering energy efficiency.

In work (Fleiter et al, 2012) the ‘IS Industry’ system model is reviewed in evaluating energy use in German pulp and paper mills. The complex system follows a philosophy of technology specific bottom up modelling. The work references ‘Technology Diffusion’ across many paper making processes, providing detailed calculations of usage by specific process.

The concept of ‘Technology Diffusion’ is an interesting aspect of the Fleiter work for this research. It suggests that each level of technology should be implemented first to avoid any confusion or overlap of technology. In this way aspects of certain energy improvement can be easily understood, applied and implemented in a structured manner.

There is some alignment with this research in that the work of Fleiter et al considers energy efficient technologies, whilst recognising the limitation being this only references paper making processes.

5.3 Phases of development

This research set out to design and develop a framework. This is constructed from a detailed energy review with a simple modelling approach for data evaluation. Whilst the framework proposed will evaluate and measure energy based on detailed data collection, its overall application will be through a strategic validated approach. The development of the framework is considered in four phases which include:

- Initial Design Considerations
- Energy Technology Wheel
- Factory Process Model
- Energy Efficiency Framework

The purpose of the Energy Technology Wheel (ETW) is to outline areas of energy usage within corrugated operations previously described in Chapter 1. The Factory Process Model (FPM) provides structure for Action Research in Chapter 6. The final research proposal will be refined and developed into the Energy Efficiency Framework (EEF) in Chapter 7. In this way the research provides a structured clear process to inform the desired outcome.

5.3.1 Phase 1 - Initial design

The initial design was considered at the outset of the research study and for such a model to be effective within the research organisation the following points were considered important;

- The research outcome requires to be easily visible, informing users of the appropriate approach in a simple and easily understandable way.
- The proposed solution is required to identify the level of technology on a scale from 'low' such as compressed air leaks to 'high' such as renewable solar power.
- Project costs will be accurately determined, but forecast initially based on previous projects and experience. Once energy efficiency projects are delivered a library referencing typical project costs will be established during research.
- To gain engagement and support at a later stage it is accepted that any proposed solution should provide an indication of return on investment with regards to specific chosen applications.

A requirement of the framework is to provide a logical process for implementation of energy efficiency technology. This needs to be based on a number of key considerations shown in Figure 5.1. These being listed as ease of implementation of technology, implementation cost and return on investment.

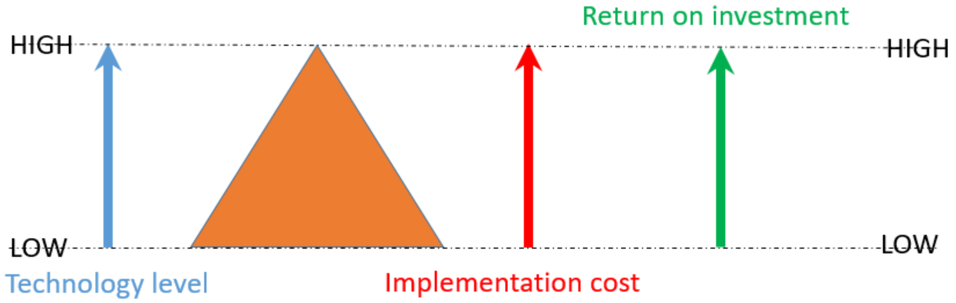

Figure 5.1: Initial framework considerations

5.3.2 Phase 2 - Energy Technology Wheel (ETW)

In order that site energy, equipment energy consumption, energy efficiency and technology savings can be considered at a site level a factory model is proposed. This provides linkage between theory and application, ultimately informing the framework development. The initial concept is shown in Figure 5.2, further developed following action research to populate the different layers of the model.

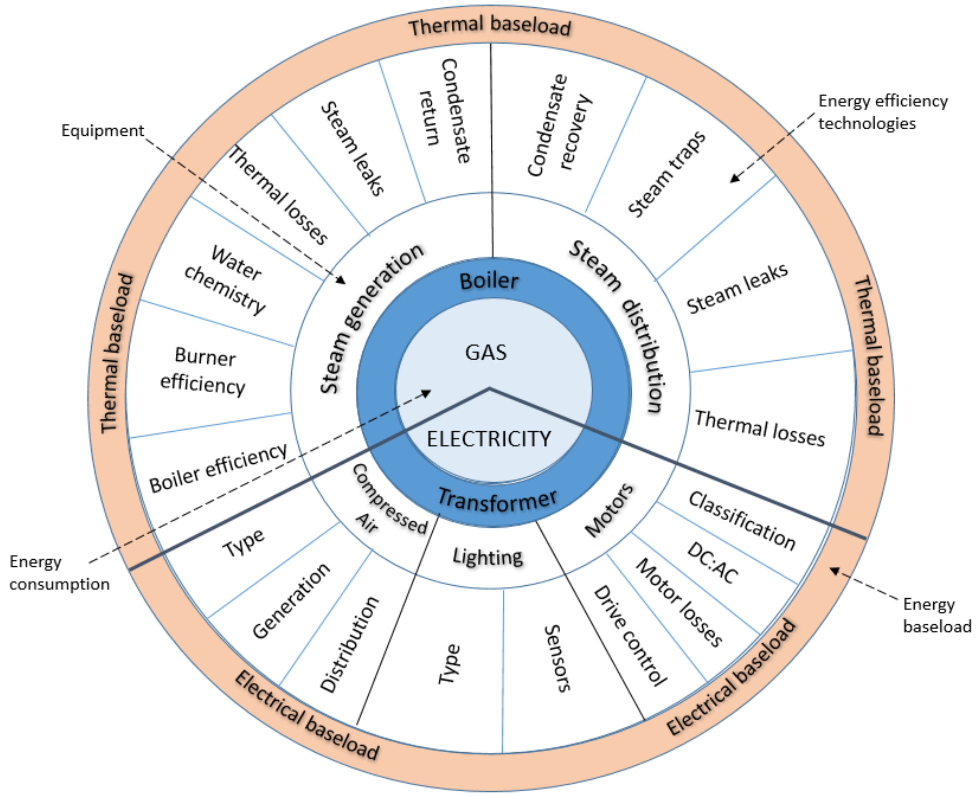

Figure 5.2: Energy Technology Wheel

The centre of the wheel represents the total site energy consumption that is anticipated will be made up in the majority of cases by gas and electricity. As the wheel radiates outward the next sector represents equipment such as boilers, motors etc. These are equipment that consume energy in the site. The next sector shows relevant energy efficiency technologies that would be adopted. Whilst the final sector represents an overall energy baseload consumed by the site when not in production.

Specific technical detail relating to the individual technology and equipment contained within the wheel segments is provided within section 5.4 of this chapter.

5.3.3 Phase 3 - Factory Process Model (FPM)

To consider the opportunities identified in the ETW a model for evaluating the energy efficiency with relevance to corrugated operations was developed. This Factory Process Model shown in Figure 5.3 provides a way of evaluating the ETW against plant operations within this research.

The FPM consists of four stages. Stage 1 provides an overview and determination of energy usage at site and equipment. Stage 2 considers the Energy Technology Wheel and potential opportunities for energy efficiency. Within Stage 3 the energy efficiency project is delivered at site and evaluated before Stage 4 provides reflection and evaluation of results and a sense check on the any model refinement.

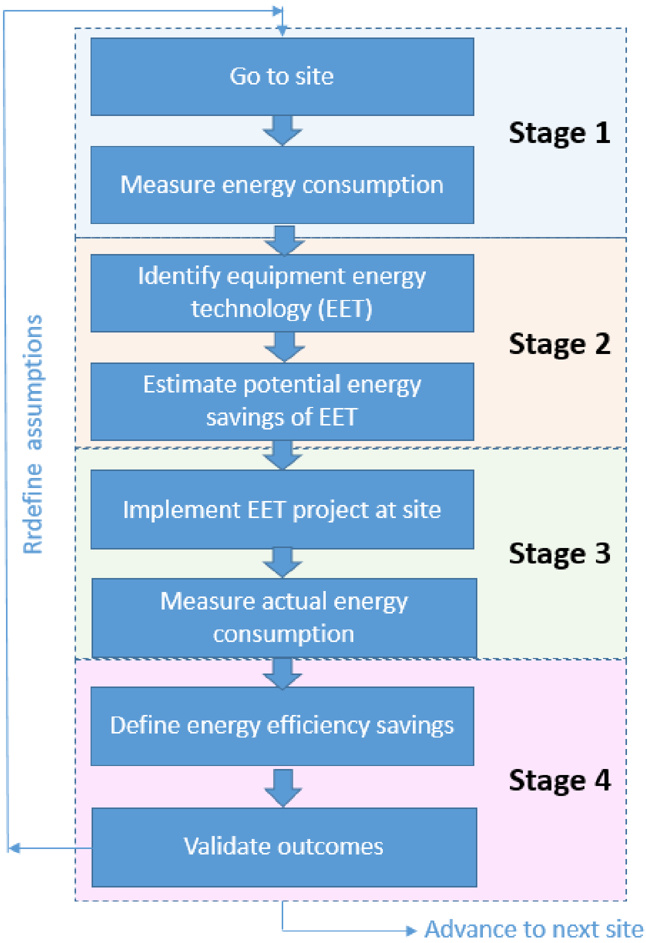

Figure 5.3 Factory Process Model (FPM)

Stage 1 of the Factory Process Model enables site energy evaluation and data collection to initially identify the sites total site energy consumption across a given time period. As defined in the methodology in chapter 3 this is cross sectional to establish actual energy consumption based on a snapshot and longitudinal basis to review and evaluate longer term trends. Data collection is employed with regards to energy usage of gas and electricity across equipment and manufacturing areas.

In stage 2 having established the energy demand energy efficiency technologies are considered and forecasts made of the potential savings based on iterative data collection and analysis. The researcher adopts a role of Project Manager evaluating energy efficiency technology against currently installed equipment. A simple example of this being to replace metal halide lighting with a high efficiency lighting solution.

In doing this site research defines and measures current energy and forecast potential savings based on previously acquired knowledge from this research. To enable project management this requires the definition of specifications, obtaining detailed project costs a proposed implementation programme. Specific energy efficiency projects are then proposed for capital approval by the research company based on this research.

Within Stage 3 of the FPM the researcher adopts an active participation of the project installation and commissioning on site. Following completion a full and through evaluation of the project impact and savings is contained with this stage. This is conducted through detailed data collection from on line automated data capture and manual readings of energy usage.

Stage 4 of the FPM allows further evaluation of results and reflection with regards to any forecast accuracy deviation. The project is evaluated based on unit savings (kWh) and payback, with calculated carbon (Tonnes) savings identified. At this stage there is an opportunity for reflection of results and evaluation with a feedback loop to Stage 1. This enables any changes to be considered for the following site within the research study to improve the research accuracy.

The output of the Factory Process Model is detailed for each research site contained within Chapter 6 Action Research.

5.3.4 Phase 4 - Energy Efficiency Framework (EEF)

Energy can be evaluated in many different ways for many different reasons (Knopf, 2012), this can include reporting, legal, improvement and financial. Energy can be evaluated against usage and determined over time. In this way the concept of usage can be defined. However this research proposes a framework that looks at reducing usage in the future based on current energy consumption.

An energy hierarchy (Wolfe, 2013) shown in Figure 5.4 which suggests that energy saving is the first place to start where industry applies simple rules of switch off, eliminate and reduce the need. The work goes on to suggest that having worked through this first stage industry then looks towards energy efficiency whereby losses are minimised and technology is improved to deliver energy efficiency improvements.

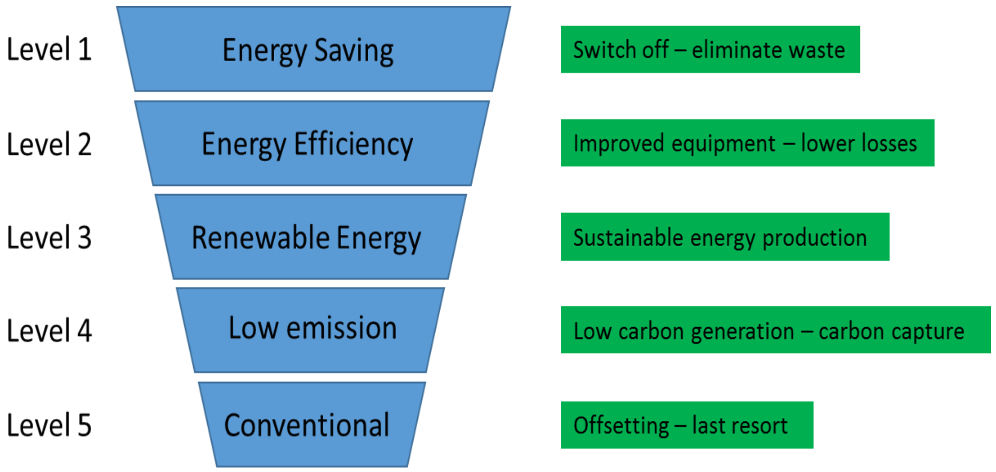

Figure 5.4: Energy Hierarchy (Wolfe, 2013)

In considering such an approach as put forward by Wolfe it may suggest that energy efficiency needs to be implemented fully before level two can be adopted. The detailed order of such efficiency measures being implemented will be considered in this research. The work (Wolfe, 2013) is more strategic and holistic and may have been more insightful in its application if it had been referenced with specific case study examples. A deeper depth of research and coverage of the levels within the hierarchy would have been more insightful.

It is clear in reviewing the Wolfe work that it is important to ensure there is a strong energy strategy in place to ensure trends and the latest new approach aren't implemented based on the wrong information. In research (Oung, 2013) an approach of an energy efficiency maturity model is put forward whereby the same principles of the energy hierarchy are adopted in general terms. Neither model reviewed proposed how to achieve energy efficiency, only describing the direction of approach.

In other work (Wolfe, 2017), the concept of the energy hierarchy is developed to consider the energy opportunities to make energy usage more sustainable. In this book publication Wolfe goes onto consider using energy smarter, and enters into the subject of using greener energy and generating sustainable heat. It can be recognised in the work that the hierarchal approach starts with saving energy and moves onto energy efficiency. This continues to support the research aim that the focus starts with a structured approach contained within a technology specific framework applicable for specific industry applications.

The illustration in Figure 5.5 for the Energy Efficiency Framework was considered by this research as appropriate with regards to visual representation, in that it is simple to assimilate and easily understood.

The final EEF will need to consider the stages of efficiency improvements and a concept of levels has been considered from the Wolfe (2013) work. This is also required to help ascertain a logical flow and process, which established stages of what was referred to by Fleiter et al (2012) as 'Technology Diffusion.' In the work Fleiter explained the need for one approach to be completed before moving on to the next in a hap hazard manner.

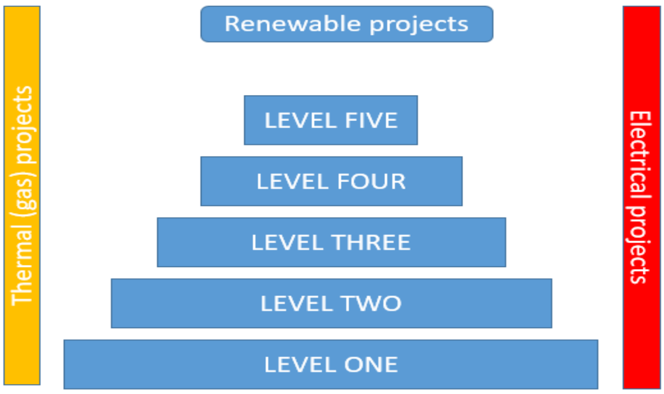

Figure 5.5: Considered levels of project implementation

To represent a full energy balance would be excessively time consuming as the time to collect data and model every aspect of the factory system would provide a significant challenge in terms of resourcing and time. As a result the final EEF proposed in Chapter 7 was emergent, being refined and validated from the action research findings.

5.4 Technology considerations

At the core of the Energy Technology Wheel is the main source of energy, gas and electricity, utilised in corrugated manufacturing operations. In considering the actual technologies related to gas and electrical energy considered for implementation within the Factory Process Model section 5.4.1 Gas and Electricity 5.4.2 provide an overview of the energy technology considerations.

5.4.1 Boiler efficiency

In corrugated factories gas fired boilers are utilised to provide energy for the corrugating process in the form of high pressure steam. From a review of boilers installed at sites it was established that most of the population were aged between 10-20 years old with a rated capacity of 7 tonne of steam per hour operating at 14 bar pressure.

A boiler is a device that simply converts the chemical energy of a fuel, natural gas, into a useful heat output used for the process, steam. Inside a boiler the fuel source is combusted by burners which produce flames and the hot combustion gases created transfer the heat to water which has been fed into the boiler. An efficient boiler is recognised (Ganapathy, 2002) as having a significant influence on heating related energy savings.

The operational efficiency of a boiler can be measured by the percentage of the fuel input energy that is eventually delivered as useful heat output. Not all of the heat released when the fuel is combusted can be used and some potential heat is lost due to incomplete combustion. The main sources of heat loss from steam boilers are suggested (Gupta et al, 2011) to be through the flue gas, blowdown and radiation to the boiler's surroundings, shown in Figure 5.6.

It is proposed (Barma et al, 2017) that the efficiency of a boiler can be related to a number of factors. These include ‘Combustion efficiency’ which relates to the effectiveness of release of heat from fuel. Secondly ‘Heat Transfer efficiency’ which is the effectiveness of transfer of heat from the combustion gases to the heat transfer medium. Thirdly ‘Thermal integrity, which considers the effectiveness of the boiler at retaining the heat introduced into it by the burner.

In a review of the energy efficiency of the steam boiler (Camaraza-Medina et al, 2021) energy efficiency indicators were considered. The paper provides a detailed and statistical approach to reviewing energy efficiency. In the paper is shows an actual calculated representation of the Sankey diagram shown in Figure 5.6 applied to the plant in Cuba. The work discusses the interpretation of results and concludes that implementing effective maintenance has a positive impact on boiler efficiency

A common method of evaluating thermal losses is shown in Figure 5.6 and is represented by the Sankey Diagram. This was referred to (Soundararajan et al, 2014) as a useful tool, developed to trace energy flows in steam engines. The application of such a Sankey diagram considers the heat input and generated heat to the process and enables calculations of efficiency to be determined.

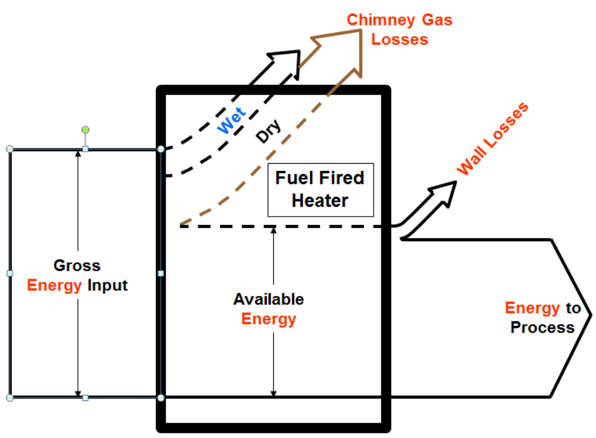

Figure 5.6 Boiler efficiency – Sankey Loss Diagram

In the ‘Manufacturing Sector Guide’ (Carbon Trust, 2018) it is suggested that the following losses are experienced in boiler systems:

- *Radiation and convection wall heat losses* *4%*
- *Heat losses in chimney flue gas* *18%*
- *Heat loss in blowdown* *3%*

The action research will evaluate the heat loss from radiation and convection as well as considering boiler efficiency and combustion. These are shown on the ETW and will be further evaluated.

5.4.2 Boiler burner efficiency

Fuel is combusted by a burner located in the boiler. The burner controls will deviate from their original settings and mechanical components become worn. If this occurs it will adversely affect combustion efficiency. For combustion to be carried out efficiently it is recognised (Barma et al, 2017) that the correct amount of combustion air is required to be mixed with the fuel in the burner. Too little air will result in incomplete combustion whereas too much excess air will lead to heat being unnecessarily lost to the flue-gases.

Excess air required within the burner system is typically 15-25%, but the exact amount depends on factors such as the fuel, burner make and type, and firing rate. Incorrect air-to-fuel ratio can lead to excessive fuel consumption, poor combustion and possibly illegal emissions. From the chart, shown in Figure 5.7, it can be seen that the relationship between the combustion gases changes as Excess Air changes. Efficiency drops as excess air increases. Boiler burners are ‘tuned’ by adjusting the volume of O_2 that will achieve maximum CO_2 volume and zero CO, referred to as trimming the boiler (Agency, 2001).

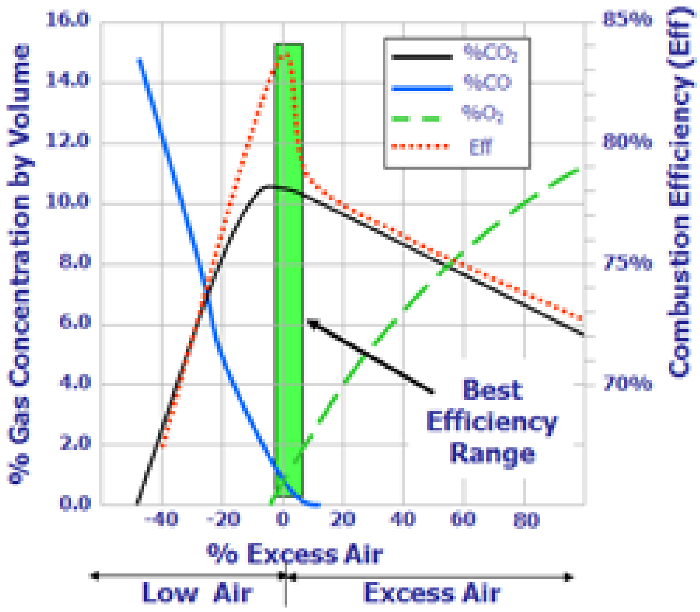

Figure 5.7: Combustion Efficiency

From Figure 5.7 it can be seen that the CO, CO_2, O_2 as well as the Efficiency change as the amount of excess air increases on the bottom axis of the graph. At 100% air, the fuel has exactly the right amount of air to burn all the fuel, so theoretically the burner should have the highest efficiency at this point.

In reality an amount of excess air must be present for there to be enough molecules of oxygen to combine with the fuel before it is exhausted out of the furnace. The green box on the graph shows the range where the most efficient combustion occurs. This is normally between 10% and 20% excess air (equating to 3% to 4% excess oxygen).

It is shown (Kaya et al, 2010) that analysis of the flue gas can highlight if there is incomplete combustion in a boiler. The analysis checks the amount of oxygen and carbon monoxide in the flue gas to determine whether combustion is being carried out in an optimum manner. Typically a boiler in good repair and running at steady-state should have an oxygen value in the region of 8%. Any value from 4 to 10% is an acceptable number for a boiler operation. There should be no CO which means the fuel is completely burned. A measure of efficiency should ideally be above 80% which would mean the boiler is running well.

During the action research the area of burner efficiency is validated to confirm the ETW approach for gas fired boiler operations. Air levels will be measured directly through observation and gas analysis will help determine overall performance and effectiveness.

5.4.3 Boiler water chemistry

Water chemistry plays an important part in ensuring the effective operation of the boiler from both an efficiency perspective and also integrity and length of service as discussed in BG04 'Boiler Water Treatment Guidance for Shell Boilers' (Combustion Engineering Association, 2019).

Water is known to be an excellent solvent in which many compounds will readily dissolve. It is also an excellent medium for transporting suspended materials. The presence of these impurities and contaminants makes appropriate water treatment and conditioning regimes essential to provide water of a suitable quality for the effective operation of steam boiler plant and systems.

An issue that can affect efficiency is carryover, whereby water entrained in the steam leaving the boiler contains impurities, called total dissolved solids (TDS) from the boiler water and water-treatment chemicals. Carryover is known to be caused by chemical or mechanical means and it is recommended by the CEA that this should be avoided or reduced to a practical minimum as it can cause potentially dangerous corrosion, reduced heat transfer, damage to the steam distribution system and water hammer.

Water treatment can be found to be generally divided into two forms, firstly external treatment which is applied before the water enters the boiler to remove or modify problem mineral salts. Secondly internal treatment (sometimes referred to as boiler water conditioning) whereby chemicals are added directly to the feed or boiler water to prevent scale formation and corrosion.

The impact of any scale deposits is determined by the composition and thickness of the scale. Scale will lead to a rise in the flue-gas temperature and, as a guide it is suggested

(Hasanbeigi, 2010) that for each 5ºC rise in flue-gas temperature, the efficiency will fall by 0.25% of fuel input. Loss of efficiency will also occur as a result of carryover and corrosion, but this is less quantifiable. This is supported (Dockrill, 2001) who reported that a 1mm build-up of scale in water tube boilers can increase fuel consumption by 2%.

When water is converted to steam in the boiler it leaves behind suspended solids and dissolved salts. This has the effect of increasing the solid and salt concentration in the remaining water and, if left unchecked, will eventually lead to crystallisation of these salts on any surface.

This may lead to the fouling of heat transfer surfaces and a general build-up of solids in the base of the boiler. The total quantity of mineral salts that can be tolerated in a boiler depends on the boiler design. Controlling the quantity of TDS is an integral part of boiler water treatment, a diagram of a typical control system is shown in Figure 5.8.

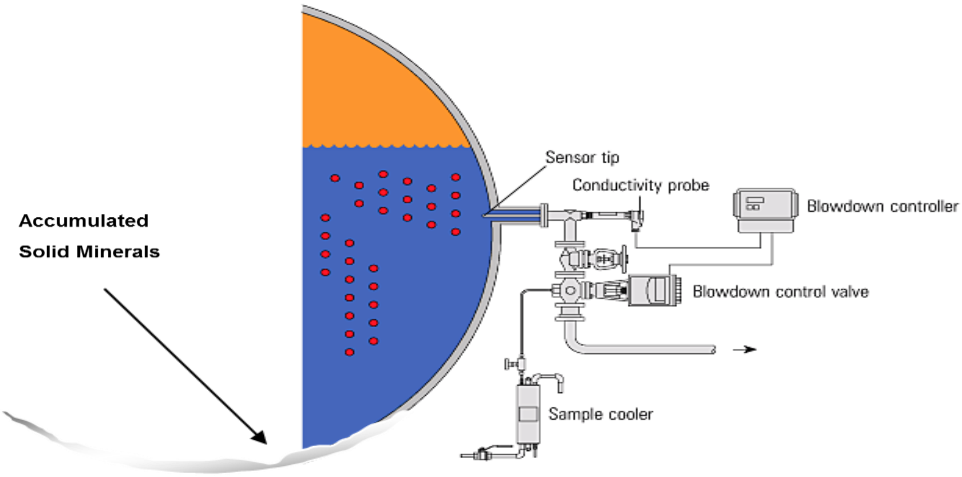

Figure 5.8: Boiler blowdown control

Figure 5.8 shows how control of the system is maintained through a conductivity probe which analyses the build-up of solids and allows the blowdown controller to automatically control the blowdown valve to maintain the desired level of total dissolved solids by removal of an amount of water. The residual boiler water can then be checked for further chemical analysis through the sample cooler to maintain boiler performance.

In all boilers there will be a targeted level of TDS (ppm). Too low and the boiler may be very clean with high chemical costs, too high and the boiler may become dirty with resulting fouling facilitating potential carryover and loss of efficiency.

To maintain the TDS concentration below the maximum recommended level (Bhatt, 2000) described that a portion of the boiler water at steam temperature is removed, referred to as 'blow down', from the boiler and then replaced with cooler make-up water, which has been treated and has a lower TDS content than the old boiler water. The process reduces the overall suspended and dissolved solids content in the boiler water and, therefore, reduces the likelihood of scaling inside the boiler.

During action research water chemistry across manufacturing sites will be reviewed and determined to establish the validity of its position on the ETW and clarify relevant savings and impact on corrugated manufacturing operations.

5.4.4 Thermal losses

Radiation heat is considered to be losses noted from the surface of the boiler through a combination of convection and radiation heat transfer. In a modern, efficient system, it is suggested (Gupta et al, 2011) that the radiation loss from the boiler should be less than 1% of the heat input rating. It may be considerably higher on older boilers and could be more than 2% of fuel input on plant with poor or damaged insulation.

Radiation losses, shown in thermal images in Figure 5.9, will depend on boiler temperature and not output. Running the boiler at a high load rather than a low load will be proportionally be more efficient. To minimise radiation losses, the boiler insulation should be kept in good condition. It is suggested that all pipework, valves, flanges and fittings in the boiler house should be adequately insulated and valve mats/covers should be replaced after maintenance work. Research (Caffal, 1993) has shown that improved insulation can save 6-26% of radiation losses.

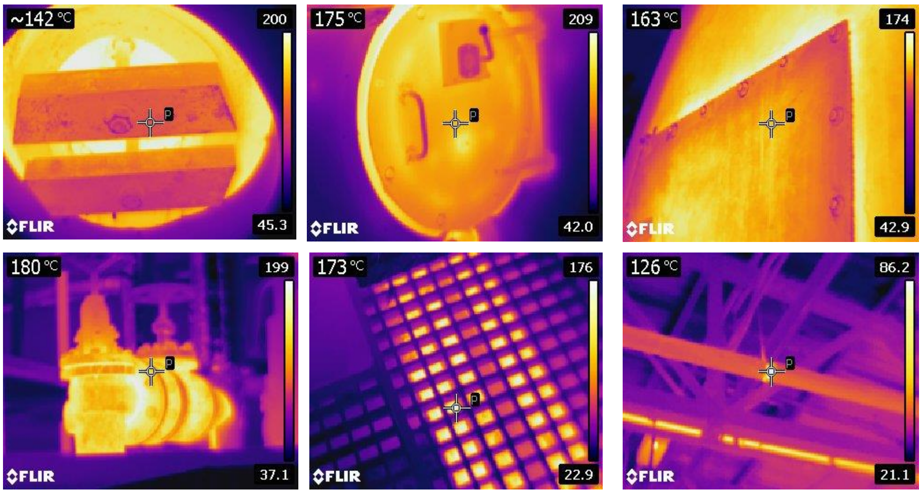

Figure 5.9: Thermal Losses

5.4.5 Steam leaks

Steam can be considered an expensive utility that is difficult to contain. Any processes that use steam or any steam distribution systems are likely to have steam leaks, which reduce system efficiency and also present a safety hazard. The wastage caused by even a small leak can be significant (Jayamaha, 2006).The amount of steam leaking from various openings depends on the size of opening and working pressure.

In a study (McKay et al, 1981) it was concluded that the major part of a boiler system total loss could be attributed a small number of large steam leaks or condensate leaks. Steam leaks shown in Figure 5.10 can adversely impact energy efficiency and also represent a safety risk.

Figure 5.10 Steam leaks

During action research steam leaks will be identified through observation across the manufacturing operations and their consequential loss calculated to determine positioning on the ETW and the potential ranking within the EEF.

5.4.6 Steam Traps

It is suggested (Radle, 2007) that it is inevitable that some steam will condense in the distribution network. Steam traps, if working correctly, remove this condensate from the system without significant losses of steam. A source of steam loss can be through sticking steam traps, although with condensate recovery systems this may be recovered. Steam traps can be evaluated through ultrasonic analysis or thermal review as shown in Figure 5.11.

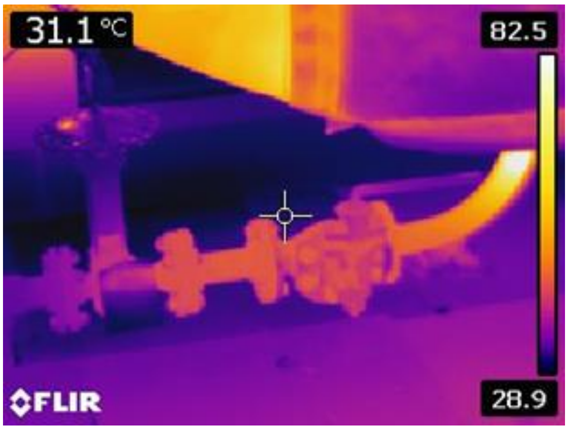

Figure 5.11: Steam traps-thermal image

If steam traps are not effective they may not remove air at start up times and additionally may create water hammer due to entrained air which can damage the plant and also increase energy losses (Risko, 2011) in ‘A Guide to Understanding Steam Traps.’

Steam losses will be reviewed across research sites and their losses calculated. This will enable positioning on the ETW to be confirmed and help to establish the positioning of steam leaks within the EEF.

5.4.7 Condensate recovery

It is reported (Saidur et al, 2010) that a significant amount of energy can be lost through boiler exhaust or flue gases, reported at 10-20% of input energy. A common way of recovering heat from the exhaust flue gas is pre heating the feed water and combustion air using a heat exchanger

Condensate contains around 25% of the heat used to produce steam, and if not recovered the latent heat energy contained within the condensate will be lost. This is recognised in work (Collier et al, 1994) who also discussed that condensate recovery helps to reduce water consumption (cost) and water treatment costs.

To pre-heat the boiler water in corrugated plants the adoption of a steam heat pump systems for ensuring collection and re-use of the condensate recovery has been implemented in many cases as shown in Figure 5.12.

Figure 5.12 Steam condensate collection and recovery

The system provides in principle a closed loop system and is a highly effective technology which recovers 95% of condensate. The heat pump steam system for corrugators delivers at the same time, energy efficiency and production flexibility. Condensates are recovered with high pressure and temperature, and pumped back directly to the boiler.

5.4.8 Compressed air generation

Compressed air energy efficiency is reported (Schmidt et al, 2005) to be affected by the age and condition of the compressed air generation equipment. Within the research organisation compressor age varied between 2 and 10 years old. The majority of installed equipment has the application of inverter technology as standard which improves energy efficiency.

It is suggested (Dindorf, 2012) that compressors are inefficient at partial loads. A variable speed drive compressor can save energy by reducing the input power to match the running load. Typically it is proposed (Saidur et al, 2009) that almost 85% of the power input will be converted into heat and the heat dissipated before air is used, therefore creating significant wasted energy.

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Figure 5.13: Typical air compressor installed in corrugated sites

Typical compressed air systems, shown in Figure 5.13, consist of a positive displacement screw compressor (s), storage tank, and drier with in line filtration systems. The sizing of a compressor system needs to be suited to the required pressure and flow requirements of plant and equipment operated by the compressor.

Operational use of compressor systems, an example shown in Figure 5.14, will require the use and optimisation of a drier to ensure that the air is water free when running normally. Filtration is designed to remove solid materials from the air stream. These materials may be rust, scale, oil or other solids. Filtration can be dependent upon the air quality required and can be carried out in the main line or at point of use.

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Figure 5.14: Installation and distribution of a compressed air system.

It is suggested (Radgen, 2006) that compressed air use accounts for as much as 10% of industrial electrical energy consumption in the European Union. This will be evaluated and reviewed within the research organisation manufacturing sites and determined through action research. Control of air compressors, operation and efficiency will be reviewed to determine potential EEF positioning.

5.4.9 Compressed air distribution

Distribution of compressed air will typically incur a loss in efficiency due to leaks, pressure drops and inappropriate use. It is suggested (Saidur et al, 2010) this could be as much as 20-50% of a compressors output. This is supported in work (Kaya, 2002) that suggests leaks cause an increase in compressor energy and maintenance costs. Air leaks can be measured as described (Crespo, 2009) through ultrasonic analysis that will be carried out at sites, together with structured energy audits reviewing filters, distribution pressure and flow requirements to and from the plant equipment.

Typical areas of air losses on equipment within research sites are shown in Figure 5.15 that were observed during stage 1 of the FPM noted at joints, regulators and air nozzles.

Figure 5.15 Typical air leaks on equipment

It is suggested (Kaya, 2002) that energy can be saved by reducing compressed air pressure, thereby saving energy. It is recognised in the work of Kaya that there will be some critical applications that require a specific pressure to operate effectively. It is recommended (Christina et al, 2008) that compressed air systems should operate at the lowest possible functional pressure to meet production requirements.

5.4.10 Lighting

Key aspects of lighting are considered in the 'Bright ideas for efficient illumination' guide to lighting (Carbon Trust, 2012). These are suggested to be the wattage required to power the unit, the light output given by the unit and importantly the lamp life. Additionally the ballast that drives the light unit has an impact on efficiency.

5.4.10.1 Lighting classification

In considering lighting solutions it was noted (Petrinska, 2018) that lamp life, often referred to as 'Burning Hours', should be considered. The work suggests that new tubes will give 100% of their rated output potential measured in lumens. As the lamps age or burn it is suggested that the light output degrades. Standard fluorescent tubes are recommended by manufacturers such as 'Phillips' to last for on average 20,000 hours, or 833 days.

Understanding these aspects in a detailed study of existing light levels can help in defining a new proposed solution. Action research will map current lux levels providing a relux map as shown in Figure 5.16 and also determining the height and area of the space which will be key to specifying the lighting requirements.

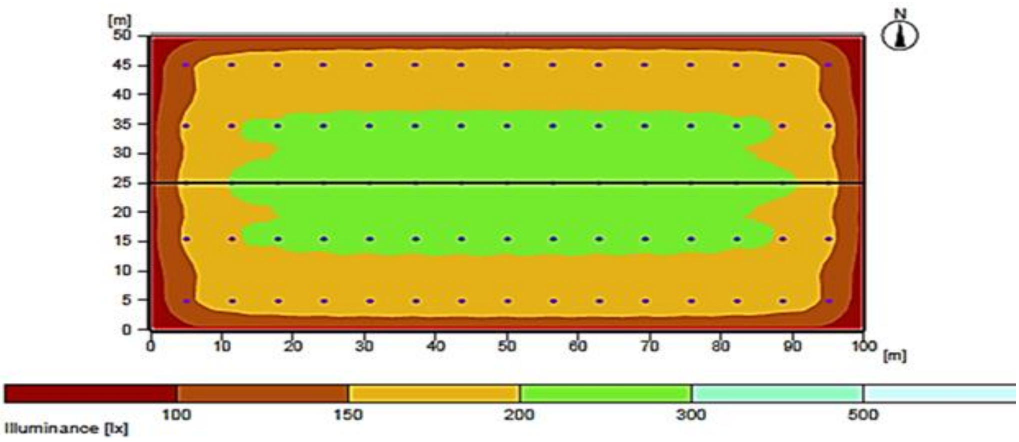

Figure 5.16: Typical site reflux map of light levels

A key consideration will be to define what standard is required and then ensure a specification that will support adoption consistently across the research organisation. Figure 5.17 shows typical factory lighting applications.

Figure 5.17 Factory lighting

5.4.10.2 Lighting sensors

A further area of consideration is suggested by this research to be occupancy and sensor control. Sensors are fitted to ensure that the full space of an area is illuminated only when people are directly working in the area. Two types of sensor commonly employed to improve energy efficiency are classed as passive infra-red (PIR) or Microwave sensors. PIR sensors operate based on temperature of an area working on the presence or absence of people. This type of sensor can have a combined PIR and light level sensor integrated within the unit which allows the sensor to detect movement and turn on lights to pre-set levels, importantly to different levels at different areas if required.

The other main type of sensor in operation was a Microwave sensor. This is claimed in an internal technology review (Clements, 2018) to have a wider detection pattern and work on physical movement. Small sensors can actually be located in individual units to give the best opportunity for occupancy control.

Lighting is suggested by this research to generate a significant electrical energy demand within corrugated manufacturing operations. This is reviewed within action research and considerations of specification, light levels and equipment type will inform the research proposals and implementation within Stage 1 and 2 of the FPM. The action research at sites will determine the proposed positioning of lighting on the EEF.

5.4.11 Electric Motors

Many mechanical moving applications in the corrugated industry have been observed to be powered by electric motors. It is suggested (Capehart et al, 2012) that globally electric motors are estimated to account for 40% of all electricity consumption. Capehart suggests that in UK industry almost two thirds of the entire industrial electricity consumption is taken by electric motors.

In a study (United Nations, 2020) a review of energy efficiency in motor systems is discussed. The work recognises suitable options such as high efficiency motors, variable speed drives and drive coupling improvements as ways to reduce electrical consumption on account of energy efficiency improvements. The work of the United Nations provides more of a methodological approach to measurement and monitoring of efficiency and does not consider the applicable benefits and resulting impacts of application.

The cost of buying an electric motor may be considered a small part of the overall life cycle cost of the equipment. It is proposed by this research that in a single year a typical running motor at a corrugator site can cost up to ten times its purchase cost in energy.

The component parts of a typical AC motor are shown in Figure 5.18. The electric motor converts electrical energy into rotating mechanical energy to drive devices such as pumps, fans or conveyors.

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Figure 5.18: Typical diagram of an AC motor

5.4.11.1 Motor Losses

In a motor driven system energy is transformed from one state to another by its component parts before it is finally able to do useful work, with some energy being lost at each stage. A motor itself will have various internal losses and these are argued in a motor application guide (Carbon Trust, 2018) to account for typically 8%.

A motor is attached to a transmission system which the Carbon Trust approximate will lose typically 10% through friction. In the publication 'Efficient Motor Management' (Carbon Trust, 2018) Figure 5.19 illustrates how only a proportion of the electrical energy supplied is ultimately transmitted and becomes useful energy with the rest being lost.

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Figure 5.19: Typical motor losses, Carbon Trust (2018)

5.4.11.2 DC to AC

The direct current (DC) motor was one of the first machines devised to convert electrical power into mechanical power. It is suggested (Hughes, 2013) that the motor is not an ideal converter, due to armature resistance and associated losses. The motor has heat losses as by-products of the energy conversion. The motor losses explained by Hughes are grouped into two sections which are load sensitive losses, dependent upon the generated torque, and the speed sensitive losses determined by rotational speed.

The AC motor is reported (Manias, 2017) to be a more reliable piece of equipment and is a standard piece of equipment with acceptable supplier stock holding times and much easier replacement. The AC motor has reduced complexity in that it has no tachometer or commutator and no brushes. Not only does an AC have lower electrical losses than DC, but from a maintenance perspective there are lower maintenance considerations.

5.4.11.3 High Efficiency motors

It was proposed by a number of equipment suppliers during research that high efficiency motors (HEMs) cost less to run than conventional motors. The savings they realise are suggested to outweigh their additional cost to purchase and ensure long term financial benefits. The business case for such motors is believed to be in that a HEM typically costs more than the motor it is replacing, but its higher purchase cost is recouped by the power savings it makes during its operational life.

Motors generally run at 65 per cent of full load. Figure 5.20 suggests how the high efficiency motor maintains efficiency across a greater load range, whereas a basic design motor would incur further losses.

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Figure 5.20: High efficiency motor performance (Carbon Trust, 2018)

All motors lose efficiency when used at reduced speed with a variable-speed drive. It is suggested (Carbon Trust, 2018) that the high efficiency motor retains much more of its efficiency across the speed range. The lower the speed, the greater the difference.

High efficiency motors can improve reliability because less of the energy is converted to heat which keeps the temperature low inside the motor. While the normal running temperature in high quality motors running at full load can be as low as 60-80 ºC, lower quality motors can run in excess of 90 ºC. Theoretically, reductions of 10-15 ºC will double the life of the windings.

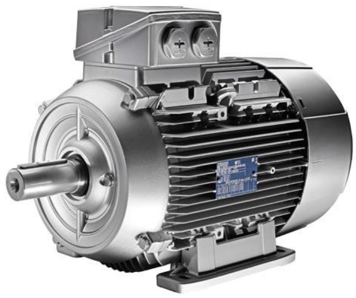

Figure 5.21: High efficiency motor

It is discussed (Ferreira et al, 2016) that improvements in motor efficiency have been made possible as a result of new materials, better design and better manufacturing. A HEM, shown in Figure 5.21, may be regarded as a motor whose efficiency class is at least one level above the mandatory minimum. In the paper by Ferreira et al it is proposed that there is a close relationship between motor efficiency and reliability and that this is an important advantage of high-efficiency motors. Additionally the work of Ferreira et al states that a HEM has lower energy losses and extended life time operation.

Motors have been labelled according to their performance. The International Electro Technical Commission introduced a standard relating to energy efficient motors. In a study (Karkkainen et al, 2017) it explains the introduction of the four International Efficiency (IE) classes for single-speed and three phase cage induction motors shown in Figure 5.22.

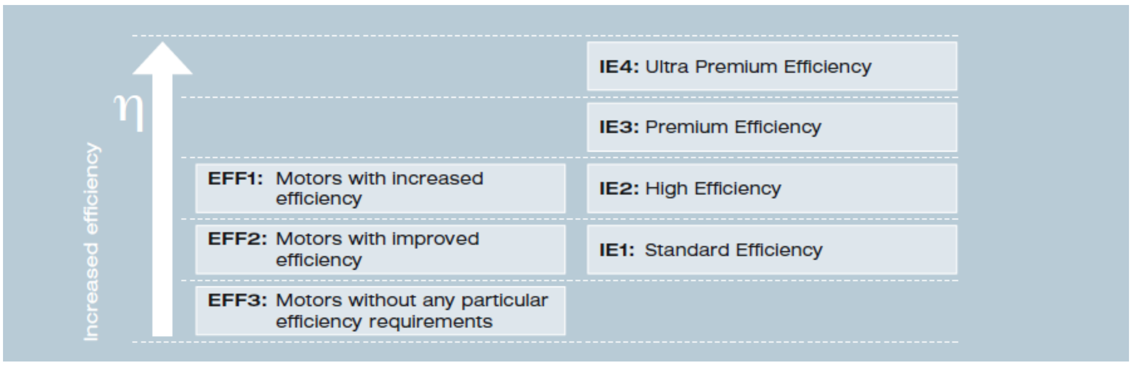

Figure 5.22: International Efficiency Standards for motors

Over time motors have improved in their method of manufacture and consequently reduced the associated energy loss. The IE standard has helped to improve performance and is moving towards a goal of removing all standard efficiency motors from manufacturing operations.

5.4.11.4 Motor drive control

Electric motors would appear to power the majority of equipment that moves in a corrugated plant operation. From a corrugator reel stand to the hydraulic power packs, from the main corrugator drive to the conversion waste fans. Each application when considered individually may not appear significant, but motors are probably one of the biggest users of electricity within industry. The use and operation of such equipment therefore should be effectively controlled.

An 'Inverter Drive' controls the current and acceleration to ensure effective control and optimisation of required energy. The basic principle of an inverter is to isolate the fixed mains frequency from the motor and generate an artificial sinusoidal current waveform.

This then allows the frequency (Hertz) to be adjusted to vary the speed. In a study (Leonowicz, 2012) findings showed that the digital control and regulation of the drive speed can be controlled quickly allowing the drive to adjust the required process parameters. Establishing control of the motor through the inverter the technology can control many variables such as flow, pressure and temperature.

There are many different applications for motors, two of which mainly concern the corrugated industry being constant torque and variable torque. The majority of the corrugated operational plants noted through observation during stage 1 of the FPM were found to mainly operate variable torque motors for equipment such as fans and hydraulic power packs, shown in Figure 5.23. A smaller number of constant torque applications were noted such as conveyors.

Figure 5.23 Inverter drive application on a hydraulic motor

Variable torque motor applications operate with varying torque (varying current). Voltage also varies in proportion to speed therefore by varying the speed of the motor the power reduces proportionally. The energy saving comes as a result of reducing the speed by a certain percentage that results in the power reducing by the cube of the speed change.

In a paper (Liu et al, 2007) simulation results of a frequency test based on the Cube Law which confirm the validity of the theoretical analysis. The proposed cube law circuit is suggested to be useful in the design of frequency controller and modulation. This principle for energy is significantly important as 80% of the speed requires 50% of the power.

The use, control, operation and energy requirement of electric motors across corrugated operations will be evaluated and determined through action research contained in Chapter 6. The evaluation will support the proposed EEF in establishing energy efficiency improvements deliverable through electric motors.

5.4.12 Electrical Transformers

A transformer is referred to (Winders, 2002) as a static device consisting of a winding, or two or more coupled windings with or without a magnetic core, for inducing mutual coupling between circuits. Transformers are used in electrical power distribution systems to transform power from high voltage grid supply to lower voltage industry supply. A diagrammatic representation of the power supply is shown in Figure 5.24.

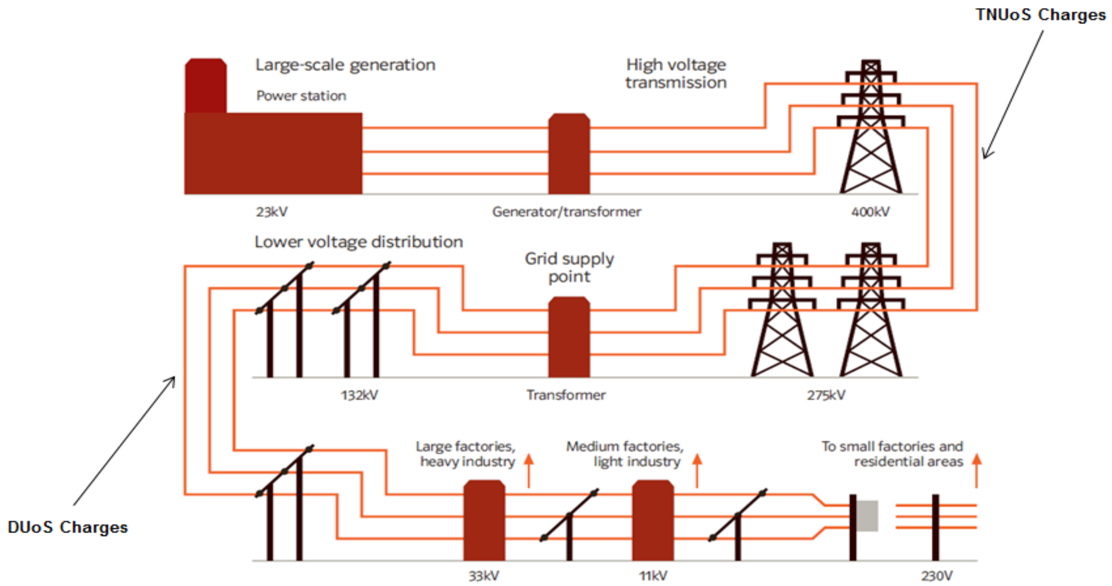

Figure 5.24: Power distribution and transformers

Voltage is normally generated in the grid at 23kV and then transformed down at local sites to 380-440V for manufacturing operations and safe usage. This is further reduced (wound down) to 240V for light industrial/domestic application and use.

Voltage supplied to most manufacturing sites is controlled and managed by a district network operator (DNO). It is noted in the British Electrotechnical and Allied Manufacturers Association Guide (BEAMA, 2015) that primary voltage is kept high to reduce transmission losses while keeping the voltage within statutory limits for all customers on the network. Most sites have a voltage of 240V or higher which may give rise to equipment running at inappropriate levels resulting in additional costs.

It has been reported (Bakshi & Bakshi, 2009) the maximum efficiency of a transformer is between 60 and 70% of its rated load. Reducing and maintaining the voltage at the most favorable level is an established way to significantly reduce energy consumption and costs whilst having the additional benefits of reduced maintenance and increased equipment life.

Transformers consume energy over 24 hours a day, seven days a week, literally every hour of every year. The transformer has a level of equipment loss which can directly affected by efficiency. A transformer will provide the benefits of voltage control and optimisation helping to reduce site voltage down to the required level and improve energy efficiency.

Energy saving by voltage optimisation is driven through the relationship between power consumption and voltage for a given resistance. This relationship determines that the higher the supply voltage, the higher the energy consumption. It is suggested (BEAMA, 2015) that a one per cent increase in supply voltage will cause a 2% increase in power demand.

There are different types of electrical load, some are manufactured to give a fixed output regardless of the supply voltage. These can be classified as voltage independent. A voltage independent load is an electrical device whose power demand, within its designed operating range, is independent of supply voltage.

Alternatively, other loads such as electric motors are partially voltage dependent, some of the motor losses which will result from a higher voltage result in performance being dependent upon supplied voltage. A voltage dependent load is an electrical device whose power consumption varies with the voltage being supplied to it.

In order to understand if operations can save based on voltage optimisation it is necessary to understand what proportion of electrical load is voltage independent. Electrical equipment is designed to operate within an electrical range, variation outside this range may result in damage to equipment or incorrect operation.

The second area of potential savings through replacement of older technology transformers is the actual losses within the transformer itself. The design of the transformer has developed over many years and recently super low loss amorphous transformers have entered the market. These have an amorphous metal core and are suggested to have the lowest combined transformer losses. It has been suggested that replacement of aged technology with such a system can provide savings of up to 10%.

The evaluation of transformer technology can be theoretically deduced and calculated. During action research the adoption/replacement of the technology will be reviewed in practice and assessed to help define positioning with the proposed EEF.

5.4.13 Baseload

In all areas of manufacturing operation there will be an energy load associated with the processes adopted within the specific application. When the manufacturing demand has ceased an energy load may still exist for non-production activities can be referred to as the 'baseload'. It is suggested by this research that this can be an area for significant losses to occur. No actual production or factory requirement present whilst energy is still consumed. This is identified as an energy loss and is shown for both gas and electricity in the ETW in Figure 5.2.

It is proposed by this research that energy baseload is a factor of cultural engagement and behaviour. It has been suggested (Springer, 2017) that very little research has been done to understand the barriers to influence behaviour of production workers. In the published case study by Springer it was suggested that a 10 percentage reduction in energy was achieved by implementing a strategy of changing everyday behaviour.

People aspects of engagement and culture are not considered within this research, levels of baseload energy consumption are evaluated. The people aspect of energy efficiency is considered an extensive subject to assess and measure and as such it is considered to be an area for future research.

It has been proposed (Steg et al, 2015) that the challenge for industry is that individuals are all different and their corresponding motivating factors are dependent on their intrinsic values and beliefs. Further work (Zierler et al, 2017) suggests that benefit, stated intentions, goals and awareness are all considered key enablers of managing energy engagement, which in turn is proposed by this research to influence baseload.

Baseload will be evaluated and action research determined that will establish the validity and impact of baseload and understand the potential positioning within a proposed EEF in Chapter 7.

5.4.14 Combined Heat and Power

Combined heat and power (CHP) for many industrial users is reported in a guide (Carbon Trust, 2010) as providing a significant opportunity to improve energy efficiency, control energy costs and reduce primary fuel usage on site. CHP is suggested by the Carbon Trust to be a highly efficient process that by design integrates the production of useable heat with the generation of electricity in one process. Importantly this single process is located at the point of use which reduces potential distribution losses and provides flexibility to meet site demands also providing energy security.

It has been quoted by the Department for Business Energy and Industrial Strategy (BEIS, 2020) that CHP reduces the primary fuel use by up to 30% compared to separate means of conventional generation via a boiler and power station. This, if suitable and applicable to the corrugated industry, may outweigh other energy saving opportunities identified from the ETW and will be reviewed within the action research.

5.4.14.1 CHP operation

There are many available sources that explains the operation of such technology. In reviewing the work (BEIS, 2020) it establishes three basic elements of a CHP unit, the engine which provides the motive force, the electrical generator and the heat recovery system. The engine will predominantly be one of three types with varying degrees of electrical efficiency. The three types are (i) reciprocating with an electrical efficiency of

37% (ii) Steam with an efficiency of 40% (iii) Gas with an efficiency of 30%.

The key difference when compared to a grid supply is that CHP losses are fundamentally reduced by recovering many of the traditional losses and using this heat to provide a low temperature hot water (LTHW) source.

5.4.14.2 Potential CHP Benefits

CHP is suggested from publications reviewed by this research to represent a potential significant opportunity for the corrugated manufacturing operation. A CHP operation must justify commercial objectives and provide the necessary requirements for plant operation. Benefits may include reduced site energy costs, meeting Climate Change obligations and avoidance of Climate Change Levy (CCL) payments.

CHP is most commonly operated with natural gas in the UK. This is reported by the Department for Energy and Climate Change (DECC, 2016), to be widely available and is distributed through mains gas network with natural gas providing 33% of electricity generation by the major power producers. Gas is a significant energy fuel within corrugated manufacturing used primarily for the raising of steam for heat treatment.
It is suggested by this research that the most important factor when considering the potential for CHP would therefore be the reduction of site energy costs. This is not a technology that could be deemed to be improving energy efficiency.

One factor considered by major power suppliers is the cost efficacy of generation in what is referred to as the 'Spark Spread'. This is defined (Smith et al, 2011) as the theoretical gross margin of a gas-fired power plant from selling a unit of electricity, having bought the fuel required to produce this unit of electricity.

A high gas price will determine that fuel used to generate electricity will similarly be high. In an energy market where the price is suppressed the difference between gas price and supplied electricity price will become closer which is suggested may make the application of CHP a more commercially attractive proposition.

Under Government legislation and taxation within the Combined Heat and Power Quality Assurance standards there is a quality assurance scheme for CHP (BEIS, 2016). Where CHP provides good quality systems and you can use a sufficient amount of the steam and LTHW in site applications then Climate Change Levy payments are not implemented on gas. However where corrugated sites are already a part of a CCL scheme they will currently attract a 65% discount on the gas Levy payment as long as the compliance targets are met.

CHP will be evaluated through Action Research. It is recognised that within this research this will be from theory and calculation and not through the implementation of the technology due to its scale, implementation cost and level of technology. The impact of CHP will be determined to establish the potential positioning of CHP and the resulting proposal presented in Chapter 7.

5.5 Validating energy efficiency savings

This research will ensure that the research outcome provides a validated approach to energy efficiency that will ensure the EEF acceptance suggested in Chapter 7. The ETW identifies potential opportunities and during the action research in Chapter 6 these will be evaluated, implemented and reviewed as a result of the research company's financial investment support for this research.

It is proposed by this research that for energy efficiency and investment to be given support within business the justification needs to be based on a predicted model of savings. However such savings can be based on unit usage (kWh), consumption based metrics such as kWh per tonne, or carbon emissions reduction.

In considering research ethics and confidentiality results will be presented from this research based on unit savings (kWh), simple payback and carbon emissions. The overall carbon emissions reported for a site are a direct reflection of the energy consumed. This takes into account unit consumption, site activity and is an overall representative measure. It is also a key measure that aligns itself with the research ethics and the research organisations key aspects of sustainability.

Whilst financial consideration will be given through the research to energy efficiency projects the results will not be directly reported. The research company employ a simple pay back model to justify and validate strategic capital investment. This considers the number of years required to pay back the initial investment, but says little about the overall value of the investment. There is a danger that such an approach focusses on the short term whilst ignoring longer term factors such as unit price trends. Payback is a key energy driver and will be adopted by this study.

In the Energy Savings Opportunities Scheme (ESOS), (Environment Agency, 2019) it is suggested that using a life cycle cost analysis provides a more complete financial picture when considering larger financial investments. This allows the evaluation of costs and usage over time along a far greater time horizon. However, for the purpose of this research is not considered a key driver for the research organisation.

It is reported in a guide to implementing energy efficiency (Carbon Trust, 2015) and acknowledged that not all energy efficiency improvements require financial investment. Implementing no cost and low cost opportunities is suggested to typically be the first priority for companies to establish quick wins. It is proposed that the proposed EEF will be a combination of quick wins and medium term investments.

5.6 Summary

In considering a number of different energy models it can be suggested that none are of specific relevance to the corrugating industry and are not helpful in determining a framework for applied efficiency improvement. To an extent the Wolf Hierarchy (Wolfe, 2013) provides a strategic context for further development.

This research has defined a framework to achieving its objective in the creation of the Energy Technology Wheel and the Factory Process Model. It is recognised that the established ETW will not cover all energy technologies, however it contains key aspects that relate directly the corrugating industry.

The FPM provides a pathway for carrying out action research at sites. The staged approach will provide structure and process to ensure the wide scope of the research across all corrugated manufacturing sites provides the necessary insight, data collection and results to inform the Energy Efficiency Framework.

The concepts of the Energy Efficiency Framework will make it visual and easy to interpret. The structure will be informed by the ETW and FPM process and its definition will be constructed during action research in Chapter 6.

Building on the work of Fleiter (Fleiter et al,2012) the concept of energy 'Technology Diffusion' will be clearly defined and represented within this research as a specific approach new to the industry that brings new knowledge and thinking driving energy efficiency.

Chapter 6 Action Research

6.1 Action Research Cycle

The adoption of an AR strategy enabled a structured process to be developed that provides consistency of approach and ensured quality of research and data collection. The main six steps of action research (Coughlan & Coughlan, 2020) are described below relevant to this research and the research organisation studied.

'Data gathering' has been described in Chapter 4, together with the approach and research instruments that were selected to ensure that the AR process was enabling accurate and timely data collection techniques to provide information from actual corrugated operating sites and process during the AR cycle.

'Data feedback' site generated information was collected and reviewed to enable ongoing analysis of emerging theory to be developed and analysed within the research.

'Data analysis' was carried out as part of the research and discussions held to develop a consensus of understanding with those key stakeholders within the organisation to test theory and proposed solutions in a collaborative way as going forward the EEF is proposed as the way of implementing energy efficiency.

'Action planning' was established initially to create a time phased plan as the complexity of delivering an AR process across 22 sites provided a number of challenges. During the planning process the research considered which types of equipment and sites would be covered, what support was needed and how to build commitment to the finalised proposed solution.

‘Implementation’ of the planned actions was conducted throughout the research organisation in a circular approach which built first on action research cycles at one site to establish data and information, which then informed the following action research cycle at the next site in the planned process.

‘Evaluation’ involved reflecting on each AR process and cycle at each site and evaluating the success and challenges associated with the developing theory. This process helped to ensure that the next cycle of planning and action informed the following cycle and that the action benefitted from the learnings of the last completed cycle.

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Figure 6.1: Action Research Cycles, (Saunders et al, 2016)

The main steps of the AR process which relate first to data and then to action have been mapped and integrated into the FPM process to enable an effective research strategy to deliver the aims and objectives of the research.

6.2 Introduction to research organisation AR activity

In delivering the research three key objectives of the research study set out in Chapter 1 and shown below are delivered.

Research Objective No2

Develop an initial understanding of energy consumption by equipment within operational sites and carry out primary research to review opportunities for the application of energy efficiency technology.

Research Objective No3

Following resulting outcomes of objective two carry out a specific energy review across key factory sites to establish predictive improvements and implement identified improvement opportunities.

Research Objective No 4

Having considered, predicted and implemented specific energy efficiency technology to reduce consumption within plants, evaluate the potential impact of these approaches.

In describing the phases of framework development in Chapter 5 this chapter goes on to provide details of the research carried out at sites across the research organisation. The 'Energy Technology Wheel' (ETW) Figure 6.1 will be considered through the application of the 'Factory Process Model' (FPM) Figure 6.2 evaluated at corrugating sites. For ease of reference both models are provided.

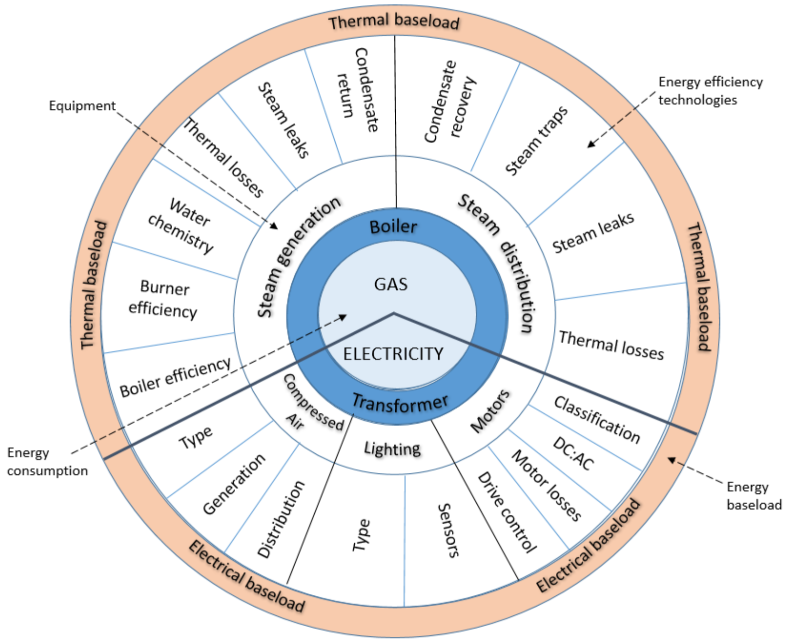

Figure 6.2 Energy Technology Wheel

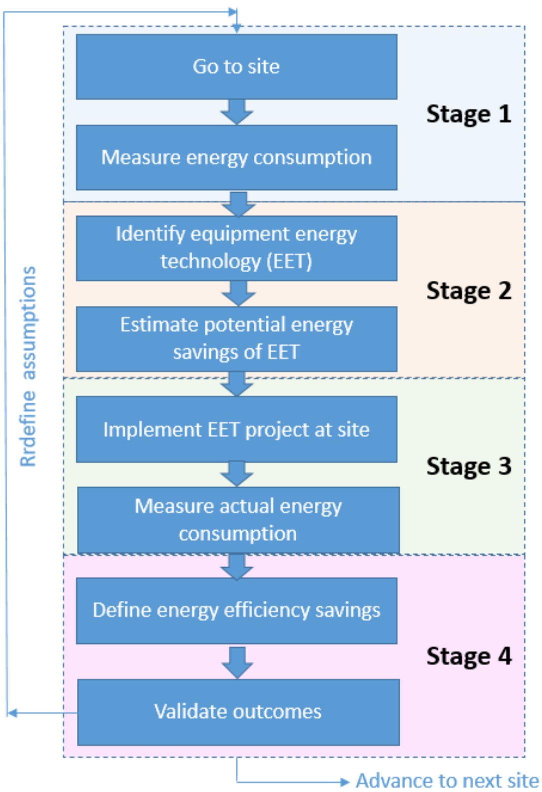

Figure 6.3 Factory Process Model

The research was initially conducted at a number of pilot sites to establish the basis of the study. Having confirmed the applicability of the model this research then progressed into the further twenty two research organisation sites. This provided a much wider research study taking in three sheet feeding sites, nine integrated sites and thirteen converting sites.

In order to enable this research to be informative and to recognise the depth and breadth of the research detailed research feedback is presented for nine of the sites where 85% of the total energy is consumed. A summary of the research data and findings is presented for the other sixteen sites.

This section documents the application of Action research across the research organisation sites. It explains the step by step approach at each site which was formulated from the FPM developed in Chapter 5. In summary Stage 1 provides data gathering and evaluation of data. Stage 2 provides further data analysis and action planning. Whilst Stage 3 of the FPM provides implementation and associated data collection for validation purposes. Stage 4 of the FPM provides the opportunity for reflection, evaluation and further action planning from key lessons learnt and identified from the FPM process at each site.

There are 4 tables contained within each FPM cycle and one figure. These are standard throughout this chapter and provide a way of demonstrating the AR cycles effectiveness in developing emergent theory.

The first figure from Stage 1 of the FPM process, example Figure 6.3, provides the resulting energy balance obtained from data collection and analysis at each site. This is shown in the format of a pie diagram to identify areas for energy efficiency improvement based on the consumed energy type.

The first table for Stage 1 of each FPM, example Table 6.1, provides an analysis of collected energy power consumption for the specific research site. This is shown in the top two rows as total kWh consumed for gas and electricity from data collection activities at the site. Below the total kWh figures the electrical energy consumption is further broken down into specific key energy users, for example energy consumed across the compressed air system or kWh consumed in lighting the facility.

The second table shown in each FPM cycle at Stage 2 at research sites identifies, example Table 6.2, identifies potential applicable energy efficiency technologies that have been considered for the specific research site. These are selected from the ETW for the associated plant and equipment contained within the corrugated manufacturing process at the selected plant. This also details the anticipated savings, evaluated and analysis as part of the previous AR cycle.

The third table within FPM Stage 3 provides an evaluation post implementation of the selected energy efficiency technologies delivered, example 6.3 at site A. This shows the resulting application of selected ETW technologies along with the benefits derived from follow up data collection to establish further the theory of the model development.

The final table within FPM Stage 4, example 6.13, shows by percentage efficiency improvement the maximum savings delivered from data collection by each ETW application. It also shows the minimum recorded savings percentage by ETW technology and the corresponding range for each. This table helps to formulate the overall emerging accuracy of savings delivered on plant and equipment at research sites.

6.3 Measurement and data collection

This research recognises that reducing energy usage does not necessarily improve energy efficiency. Many process factors can influence and affect energy usage such as volume throughput, corrugated board thickness, packaging format and manufacturing time. Therefore to ensure actual measurement of efficiency energy usage must be measured in direct correlation to output.

When considering the application and usage of energy it is suggested by this research that it is important to establish exactly what is being measured. During the research measurements were taken directly from plant and equipment with automated metering equipment upon evaluation of each project and technology applied.

Where necessary data was recorded through additional strap on meters if suitable on line equipment was not already installed. In this way pre and post measurement was available, with all results recorded representing a percentage reduction in energy usage for the same output observed. Each measurement informed subsequent analysis and improved the accuracy of forecast and also the absolute delivered efficiency improvement.

6.3.1. Electrical energy consumption

For areas of electrical energy usage these were mostly measured with data collection instruments recording the actual kilowatt hour (kWh) units of electricity pre and post the technology implementation. This included ETW technologies covered by motors, lighting and compressed air.

In this way savings were assessed by the implementation of the specific energy efficiency technology. Observed readings for electrical consumption were taken or recorded on plant during research and the subsequent measurement of the same technologies at later sites increased the level of accuracy used to formulate the EEF.

Savings relating to the following categories were measured for electrical consumption in the above way and percentage savings delivered calculated accordingly.

- The application of high efficiency motors
- Replacement of DC motors with AC alternatives
- Application of inverter drives
- Lighting type and sensors
- Compressed air generation
- Compressed air distribution

Each application was forecasted and then evaluated post-delivery at those sites researched in Chapter 6.

6.3.2 Gas energy consumption

For areas of gas consumption shown on the ETW in Figure 6.1 such as boiler, steam and thermal efficiency these were considered through data measurement and expressed in terms of kWh per unit of steam produced. In this way measurement could record thermal input to compare with steam output.

Some instances required losses of thermal energy to be recorded through the use of comparison of kWh identified through a temperature loss measured through the use of a thermal imaging camera. Additionally thermal recorders for items such as flue gas analysis were used.

In this way savings were assessed by the implementation of the specific energy efficiency technology. Observed readings for gas consumption were taken or recorded on plant during research and the subsequent measurement of the same technologies at later sites increased the level of accuracy used to formulate the EEF.

Savings relating to the following categories were measured for gas consumption in the above way and percentage savings delivered calculated accordingly.

- Boiler efficiency was measured and recorded through a Testo Gas Analyser
- Burner efficiency was measured pre and post projects by kWh/T analysis
- Thermal losses were measured through an internal loss calculator
- Condensate return was measured through make up water addition
- Steam traps were measured through use of ‘Trap Mate’ testing equipment

Each application was forecasted and then evaluated post-delivery at those sites researched in Chapter 6.

6.4 Sheet Feeding Site A

The production for Site A was typical of the sheet feeding process and the flow was observed as paper reels being taken onto site with corrugated board manufactured on the corrugating machine. The plant consisted of materials intake, corrugator and materials handling equipment, together with associated utilities and despatch operation. The site operated five days a week twenty four hours a day.

6.4.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.3.

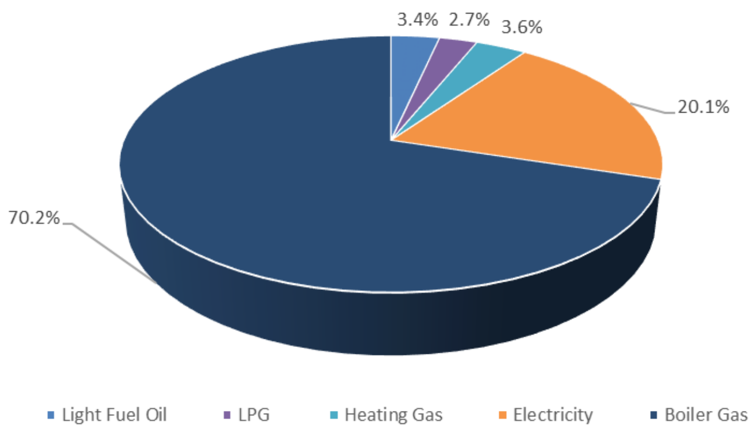

Figure 6.4 Site energy consumption % Site 'A' - Sheet feeding

From site data it was established that the site energy consumption was driven by boiler gas usage at 70% and electricity distribution at 20%. The remaining energy was consumed by LPG for fork lift trucks and factory heating. A detailed energy review identified usage by individual areas of site and equipment. The apportionment of electrical energy down to specific plant and equipment was measured through observation and data collection.

This was conducted over a period of 5 days and a snapshot taken representing the average kWh consumption of gas and electricity measured during production. Baseload during non-production hours was also measured to determine potential savings. Table 6.1 shows the breakdown of energy across site. Being a sheet feeding site there were no conversion energy requirements. Research provided a 91% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	1,980	670
Elec	497	234
Corrugator	295	
Conversion	0	
Compressed Air	54	
Lighting	65	
Waste System	36	

Table 6.1: Sheet Feeding site A - Site energy usage

From data in Table 6.1 the initial review showed that 60% of all the electrical energy was consumed on the corrugator, which had a considerable amount of electrical motors. Of the remaining energy 13% was consumed on lighting, 11% on compressed air and 7% on the waste system. All of gas consumed was used for steam generation. Additionally the site had a high electrical baseload at 47% out of production with a thermal baseload of 34%.

6.4.2 Stage 2

The FPM process at Stage 2 provides a list of potential projects for consideration. Being the first site potential projects were based on previously researched applications and technology, with no observations from action research data to as yet use for comparison. Through carrying out a detailed site survey and energy review the applicable technologies were identified by energy type. The projects identified from the ETW were identified and forecasted savings are shown in Table 6.2.

	Site : A	ETW Opportunities									
Source	Plant Area	Boiler Efficiency	Burner Efficiency	Water Chemistry	Thermal Losses	Steam Leaks	Condensate Return	Condensate Recovery	Steam Traps	Steam Leaks	Thermal losses
Boiler	Steam Generation	N/A	5%	4%	5%	3%	N/A				
	Steam Distribution							N/A	1%	2%	1%
Transformer	Plant Area	Classification	DC:AC	Motor Losses	Drive control	Type	Sensors	Type	Generation	Distribution	
	Motors		10%		55%						
	Lighting					50%	15%				
	Compressed Air							N/A	8%	15%	

Table 6.2: ETW opportunities – FPM Stage 2

6.4.3 Stage 3

During Stage 3 projects identified were implemented and reviewed with respect to the impact on energy kWh against forecasted data. This took place over a period of three months following project justification and approval. Having completed this a further two day study at site enabled actual savings to be evaluated and reviewed. These potential opportunities are shown in Table 6.3.

	Site : A	ETW Delivered efficiency savings									
Source	Plant Area	Boiler Efficiency	Burner Efficiency	Water Chemistry	Thermal Losses	Steam Leaks	Condensate Return	Condensate Recovery	Steam Traps	Steam Leaks	Thermal losses
Boiler	Steam Generation	N/A	3%	Not defined	8%	1%	N/A				
	Steam Distribution							N/A	Not defined	0.5%	1%
Transformer	Plant Area	Classification	DC:AC	Motor Losses	Drive control	Type	Sensors	Type	Generation	Distribution	
	Motors		Not defined		43%						
	Lighting					51%	10%				
	Compressed Air							N/A	6%	12%	

Table 6.3 Delivered efficiency savings – FPM Stage 3

Being the first site researched data provided the first actual baseline for potential savings at factory level. There were no steam traps passing through the steam distribution system and no DC: AC conversion projects undertaken. Condensate recovery had a full Baviera recovery system fitted and efficiency improvement results could not be established.

6.4.4 Stage 4

Whilst minor variations in results versus forecasts were noted these were not considered representative at this stage. The FPM model was successful in its application and there were no energy efficiency technologies missing from the ETW.

6.5 Integrated Site E

The production for Site E was typical of an integrated plant operation where the flow combined corrugating board manufacture and converting operations. The site operated five days a week twenty four hours a day.

6.5.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.4.

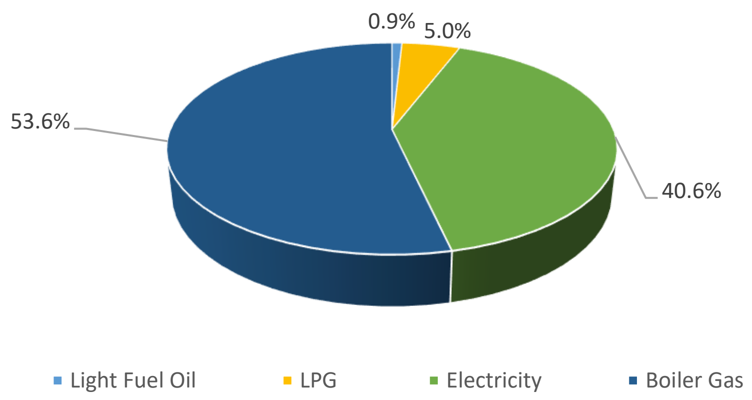

Figure 6.5: Site energy consumption % Site 'E' - Integrated

From site data evaluated it was established that the site energy consumption was driven by boiler gas usage at 54% and electricity distribution at 40%. The remaining energy was consumed by fork lift trucks and factory heating. A detailed energy review identified usage by individual areas of site and equipment. The apportionment of electrical energy down to specific plant and equipment was measured through observation and data collection.

This was conducted over a period of 5 days and a snapshot taken representing the average kWh consumption of gas and electricity measured during production. Baseload during non-production hours was also measured to determine potential savings.

Table 6.4 shows the breakdown of energy across site. Research provided a 91% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	1,456	569
Elec	795	214
Corrugator	315	
Conversion	215	
Compressed Air	76	
Lighting	78	
Waste System	41	

Table 6.4: Integrated Site E - Site energy usage

From the data in Table 6.4 the review showed that 40% of all the electrical energy was consumed on the corrugator, with 27% of energy consumed on converting equipment. Of the remaining energy 10% was consumed on lighting, 10% on compressed air and 5% on the waste system. All gas consumed was used for steam generation. Additionally the site had an electrical baseload at 39% out of production with a thermal baseload of 27%.

6.5.2 Stage 2

The FPM process at Stage 2 provides a list of potential projects for consideration. Being the second site potential projects were based on previously researched applications and technology, with inadequate action research data as yet to use for comparison. Through carrying out a detailed site survey the applicable technologies were identified. The projects identified from the ETW and forecasted savings are shown in Table 6.5.

	Site E	ETW Opportunities									
Source	*Plant Area*	*Boiler Efficiency*	*Burner Efficiency*	*Water Chemistry*	*Thermal Losses*	*Steam Leaks*	*Condensate Return*	*Condensate Recovery*	*Steam Traps*	*Steam Leaks*	*Thermal losses*
Boiler	Steam Generation	2%	3%	4%	5%	3%					
	Steam Distribution								1%	2%	1%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		10%		55%						
	Lighting					50%	10%				
	Compressed Air							15%	8%	15%	

Table 6.5: ETW opportunities – FPM Stage 2

6.5.3 Stage 3

During Stage 3 projects identified were implemented and reviewed with respect to the impact on energy kWh against forecasted data. This took place over a period of six months following project justification and approval. Having completed this a further three day study at site enabled actual savings to be evaluated and reviewed.

	Site E	ETW Delivered efficiency savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation	Not defined	6%	Not defined	12%	0%					
	Steam Distribution								1%	2%	1%
Transformer	Plant Area	***Classification***	***DC:AC***	***Motor Losses***	***Drive control***	***Type***	***Sensors***	***Type***	***Generation***	***Distribution***	
	Motors		10%		55%						
	Lighting					50%	10%				
	Compressed Air							10%	7%	15%	

Table 6.6: Delivered efficiency savings – FPM Stage 3

From review the boiler could be seen to be operating below where an expected performance would be. However there was no means of calculating the efficiency of the actual operational savings following calibration and service overhaul. Burner efficiency savings were recorded through data collection based on gas usage per tonne of steam generated. Thermal losses were derived from thermal imaging measurement on both steam generation and distribution systems.

The research showed a 10% saving in delivered efficiency improvement based on kWh consumed following the replacement of aged DC electrical motors. The biggest area of efficiency improvement was following the application of inverter control to electrical motors across conversion and waste handling equipment. Additionally lighting improvements yielded a reduction in electrical energy requirements of 60%.

Compressed air was a key area of focus with the installation of a new compressor generation system improving efficiency by 10%, a reduction in generation pressure providing 7% saving and elimination of air leaks resulting in savings of 15% of the consumed electricity required for compressed air on site.

6.5.4 Stage 4

Following the review of sites A and E variation in the results recorded was noted. This is understandable as each application has a number of different variables such as equipment type, loading, age and service condition.

6.6 Integrated Site F

The production for Site F was typical of an integrated plant operation were the flow combined corrugating board manufacture and converting operations. The site operated seven days a week twenty four hours a day.

6.6.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.5.

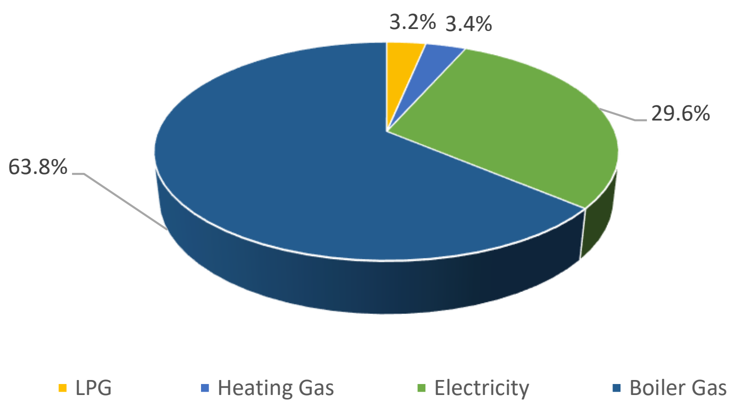

Figure 6.6: Site energy consumption % Site 'F' - Integrated

From the site data evaluated it was established that the site energy consumption was driven by boiler gas usage at 64% and electricity distribution at 30%. The remaining energy was consumed by fork lift trucks and factory heating. A detailed energy review identified usage by individual areas of site and equipment. The apportionment of electrical energy down to specific plant and equipment was measured through observation and data collection.

This was conducted over a period of 5 days and a snapshot taken representing the average kWh consumption of gas and electricity measured during production. Baseload during non-production hours was also measured to determine potential savings.

Figure 6.5 shows the breakdown of energy across site. Research provided a 96% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	1,732	826
Elec	1,095	869
Corrugator	414	
Conversion	294	
Compressed Air	112	
Lighting	172	
Waste System	56	

Table 6.7: Integrated site F - Site energy usage

Table 6.7 shows that 38% of all the electrical energy was consumed on the corrugator, with 27% of energy consumed on converting equipment. Of the remaining energy 16% was consumed on lighting, 10% on compressed air and 5% on the waste system. The majority of the thermal energy consumed was used for steam generation. The site had a high electrical baseload at 79% with a thermal baseload of 48%. This was due to the site mostly being a 24/7 site with baseload measured only at midnight on Saturday when most of energy consumption was lower but in standby mode.

6.6.2 Stage 2

The FPM process provides a list of potential projects for consideration at Stage 2. The projects identified from the ETW along with forecasted savings are shown in Table 6.8.

	Site F	ETW Opportunities									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation		5%	3%							
	Steam Distribution										5%
Transformer	Plant Area	***Classification***	***DC:AC***	***Motor Losses***	***Drive control***	***Type***	***Sensors***	***Type***	***Generation***	***Distribution***	
	Motors				30%						
	Lighting					45%	15%				
	Compressed Air								7%	15	

Table 6.8: ETW opportunities – FPM Stage 2

Generally the boiler operation was well controlled, although opportunities in burner upgrade and water chemistry were noted due to age of technology and control. Electrical motors had improvements in efficiency noted due to the need for application of inverter control. The site had a significant opportunity to improve the energy loading due to lighting efficiency and efficiency improvements regarding compressed air generation and distribution were observed and measured.

In terms of compressed air the site was consuming 112 kWh in its use of compressed air. The research was able to collect data showing that the twelve specific areas of leakage on the distribution system equated to a loss of 10% in efficiency. The site was also generating air at an excessively high pressure. A reduction in the pressure of 1.0b down to 6 bar operating pressure resulted in an efficiency improvement of 5%.

6.6.3 Stage 3

During Stage 3 projects identified and shown in Table 6.9 were implemented and reviewed with respect to the impact on energy kWh against forecasted data. This took place over a period of three months following project justification and approval. Having completed this a further five day study at site.

	Site F	ETW Delivered efficiency savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation		8%	3%	1%						
	Steam Distribution										3%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors				47%						
	Lighting					55%	5%				
	Compressed Air								5%	10	

Table 6.9 Delivered efficiency savings – FPM Stage 3

The research was able to establish the improvement in burner efficiency through data collection and measurement of gas usage compared with steam production on the boiler. The application of inverter drives, mainly to waste fan motors, together with improvements in compressed air management were measured on plant.

6.6.4 Stage 4

Following a review of the three sites it was evident that savings in the four main areas of Steam, Motors, Lighting, and Compressed Air were developing statistical analysis that could be compared across sites. Table 6.10 provides an insight into the developing themes at this stage.

	Max	***Min***	***Range***
Burner Efficiency	8	3	5
Thermal losses	12	8	4
Drive control	55	43	12
Lighting	65	55	10
CA Generation	7	5	2
CA Distribution	15	10	5

Table 6.10: Levels of energy efficiency improvement – FPM Stage 4

There was variation across the maximum and minimum values noted as can be seen in Table 6.10. There is good correlation in the range of results considering the variables associated with site manufacturing operations. The resulting figures where consequently used for comparison when comparing further sites energy efficiency.

6.7 Integrated Site G

The production for Site G was typical of an integrated plant operation were the flow combined corrugating board manufacture and converting operations. The site operated five days a week twenty four hours a day, with reduced manufacturing operations over the Saturday and Sunday periods.

6.7.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.7.

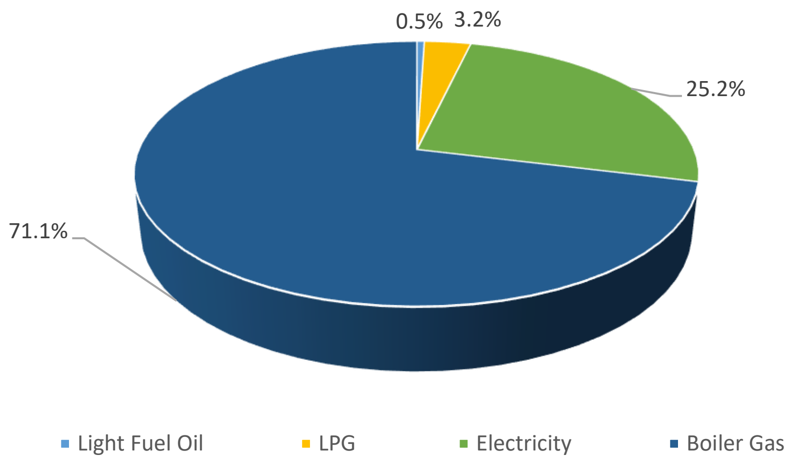

Figure 6.7: Site energy consumption % Site 'G' - Integrated

From the site data evaluated site energy consumption was driven by boiler gas usage at 71% and electricity distribution at 25%. The remaining energy was consumed by fork lift trucks and factory heating.

Table 6.11 shows the breakdown of energy across site. Research provided a 96% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	kWh	Baseload
Gas	2,234	658
Elec	919	657
Corrugator	325	
Conversion	279	
Compressed Air	61	
Lighting	122	
Waste System	47	

Table 6.11: Integrated Site G - Site energy usage

Table 6.11 shows that 30% of all the electrical energy was consumed on the corrugator, with 25% of energy consumed on converting equipment. Of the remaining energy 11% was consumed on lighting, 6% on compressed air and 4% on the waste system. The majority of the thermal energy consumed was used for steam generation. The site had a high electrical baseload at 71% with a thermal baseload of 29%. This was due to the site operating over the weekend period during the days, with baseload measured only at midnight on Saturday when most of energy consumption was lower but in standby mode.

6.7.2 Stage 2

The FPM process provides a list of potential projects for consideration at Stage 2. The projects identified from the ETW along with forecasted savings are shown in Table 6.12.

	Site G	ETW Opportunities									
Source	Plant Area	Boiler Efficiency	Burner Efficiency	Water Chemistry	Thermal Losses	Steam Leaks	Condensate Return	Condensate Recovery	Steam Traps	Steam Leaks	Thermal losses
Boiler	Steam Generation		5%		7%						
	Steam Distribution										3%
Transformer	Plant Area	Classification	DC:AC	Motor Losses	Drive control	Type	Sensors	Type	Generation	Distribution	
	Motors		10%		49%						
	Lighting					50%	10%				
	Compressed Air								6%	12.50%	

Table 6.12: ETW opportunities – FPM Stage 2

Measuring the total gas usage against the production throughput the boiler kWh/T ratio showed a high requirement of gas for every tonne of production. The data suggested a poor boiler efficiency. Plans were established to service the boiler, review the condensate recovery system and review thermal losses across generation and distribution systems. Electrical motor drive control was identified as an area of opportunity, along with lighting and compressed air.

6.7.3 Stage 3

Stage 3 delivered project implementation and reviewed energy efficiency improvements with respect to the impact on energy kWh against forecasted data, shown in Table 6.13. This took place over a period of three months following project justification and approval. Having completed this a further three day study at site was conducted to enable actual savings to be evaluated and reviewed.

	Site G	ETW Delivered efficiency savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation	10%	10%	Not defined	15%	5					
	Steam Distribution							Not defined	1%	1%	5%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors				43%						
	Lighting					65%	0%				
	Compressed Air								10%	15.00%	

Table 6.13: Delivered efficiency savings – FPM Stage 3

The site showed a significant improvement of energy efficiency technologies related to gas usage on the ETW, mainly associated with steam generation, although distribution improvements were also noted. The application of electrical motor drive control, along with lighting and compressed air efficiency technologies all resulted in significant improvements being recorded.

6.7.4 Stage 4

In reviewing the progress to date at this stage of the action research the common themes continue to provide a direction which shows the relevant associated technology level of savings shown in Table 6.14.

	Max	Min	Range
Burner Efficiency	10%	3%	7%
Thermal losses	15%	8%	7%
Drive control	55%	43%	12%
Lighting	65%	50%	15%
CA Generation	10%	5%	5%
CA Distribution	15%	10%	5%

Table 6.14: Levels of energy efficiency improvement

There were a number of areas of concerns established from this FPM review. These were noted as motor classification, motor losses, and condensate boiler efficiency. In considering motor losses Figure 5.19 gives an indication of typical losses. The specific loss associated with motor drive was measured and recorded. In the area of motor classification (type) the research had not been able to be demonstrate that high efficiency motors gave an improvement in efficiency over standard type motors. Transmission and fan losses were not directly measurable on plant. Boiler efficiency was measured through kilowatts of gas required to produce one tonne of steam if the required metering equipment was fitted.

These areas continue to feature as part of ongoing research but it is recognised that motor classification along with transmission and fan losses may not form a significant part of energy efficiency improvements based on current data.

6.8 Integrated Site H

The production for Site H was higher than that of a typical integrated plant operation with the flow combining corrugating board manufacture and converting operations. The site operated five days a week twenty four hours a day, with no scheduled manufacturing operation over the Saturday and Sunday periods.

6.8.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.9.

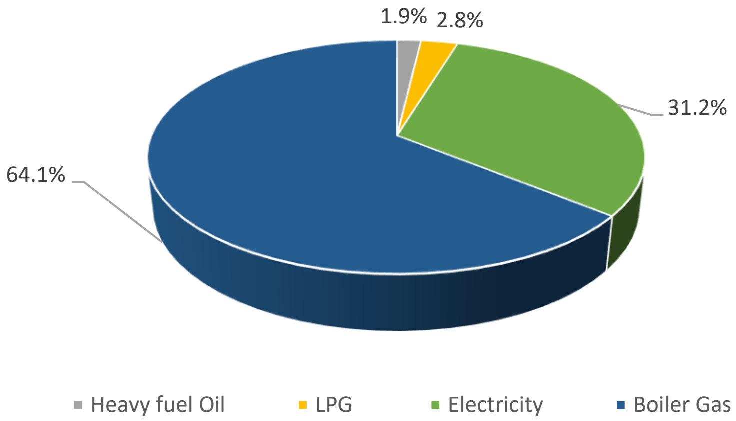

Figure 6.8: Site energy consumption % Site 'H' - Integrated

From the site data evaluated site energy consumption was driven by boiler gas usage at 64% and electricity distribution at 31%. The remaining energy was consumed by fork lift trucks with some heavy fuel oil used as a source of energy back up on site.

Table 6.15 shows the breakdown of energy across site. Research provided a 96% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	2,234	346
Elec	1,176	115
Corrugator	414	
Conversion	364	
Compressed Air	99	
Lighting	132	
Waste System	87	

Table 6.15: Integrated site H- Site energy usage

Table 6.15 shows that 38% of all the electrical energy was consumed on the corrugator, with 33% of energy consumed on converting equipment. The converting area had more machines than some other sites reviewed. Of the remaining energy 12% was consumed on lighting, 9% on compressed air and 8% on the waste system. The majority of the thermal energy consumed was used for steam generation. The site had a low electrical baseload at 10% with a thermal baseload of 15%. Baseload will be considered further in this chapter, the readings taken at Site H suggested good control in shutdown procedures and control.

6.8.2 Stage 2

The FPM process provides a list of potential projects for consideration at Stage 2. The projects identified from the ETW along with forecasted savings are shown in Table 6.16.

	Site H	ETW Opportunities									
Source	*Plant Area*	*Boiler Efficiency*	*Burner Efficiency*	*Water Chemistry*	*Thermal Losses*	*Steam Leaks*	*Condensate Return*	*Condensate Recovery*	*Steam Traps*	*Steam Leaks*	*Thermal losses*
Boiler	Steam Generation		10	5	10	2					
	Steam Distribution								1	5	10
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		10%		45						
	Lighting					50	10				
	Compressed Air							15	10	15	

Table 6.16: ETW opportunities – FPM Stage 2

The site operated a mechanical aged obsolete boiler burner. This suggested direct efficiency improvements would be deliverable. Additionally water chemistry was identified as an opportunity, along with thermal losses on the boiler section of the ETW. The site provided opportunities for the replacement of DC motors with AC, along with motor drive control opportunities. The lighting was identified as an efficiency opportunity together with areas of compressed air generation and usage across site.

6.8.3 Stage 3

Stage 3 delivered project implementation and reviewed energy efficiency with respect to the impact on energy kWh against forecasted data. This took place over a period of five months following project justification and approval. Having completed this a further five day study at site was conducted to enable actual savings to be evaluated and reviewed in line with results shown in Table 6.17.

	Site H	ETW Delivered efficiency savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation		6%	3%	5%	1%					
	Steam Distribution								1%	1%	5%
Transformer	Plant Area	***Classification***	***DC:AC***	***Motor Losses***	***Drive control***	***Type***	***Sensors***	***Type***	***Generation***	***Distribution***	
	Motors		12%		52%						
	Lighting					50%	8%				
	Compressed Air							15%	10%	10%	

Table 6.17 Delivered efficiency savings – FPM Stage 3

The site showed a significant improvement of energy efficiency technologies related to gas usage on the ETW, mainly associated with steam generation, although distribution improvements were also noted. Burner efficiency was measured over a six month period post burner upgrade. Water chemistry savings were calculated from consumption related to direct gas usage. A significant number of thermal losses were noted in leaks, traps and exposed mains allowing radiant losses to occur as a result.

The application of electrical motor drive control showed significant energy efficiency savings which were delivered mostly across conversion and waste fan systems. Lighting and compressed air efficiency technologies all resulted in significant improvements being recorded from data collected and observed on plant.

6.8.4 Stage 4

Following this action research at site H there is adequate data to include Water Chemistry, DC: AC motor conversion and Compressed Air Generation. These have been included in subsequent data for analysis and shown in Table 6.18.

	Max	*Min*	*Range*
Burner Efficiency	10%	3%	7%
Thermal losses	15%	5%	10%
Water Chemistry	5%	3%	2%
Drive control	55%	43%	12%
DC:AC Motors	12%	10%	2%
Lighting	65%	50%	15%
CA Type	15%	10%	5%
CA Generation	10%	5%	5%
CA Distribution	15%	10%	5%

Table 6.18: Levels of energy efficiency improvement

At this stage of this research thermal loss efficiency improvements have reduced slightly as a result of projects associated with the lagging of joints, mains and surfaces to prevent radiant losses. Steam leaks and traps can be classed as insignificant.

Lighting efficiency measured by electrical kWh input versus light output is difficult to accurately measure without the use of calculation of occupancy and ambient light levels. Therefore lighting will be classed as total kWh saving in percentage energy to achieve the required and measured light output. This provides a more accurate reflection of actual efficiency as measured and not partly calculated.

6.9 Integrated Site I

The production for Site I was typical of an integrated plant operation with the process flow combining corrugating board manufacture and converting operations. The site operated five days a week twenty four hours a day, with a 12 hour dayshift manufacturing operation over the Saturday and Sunday periods.

6.9.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.8.

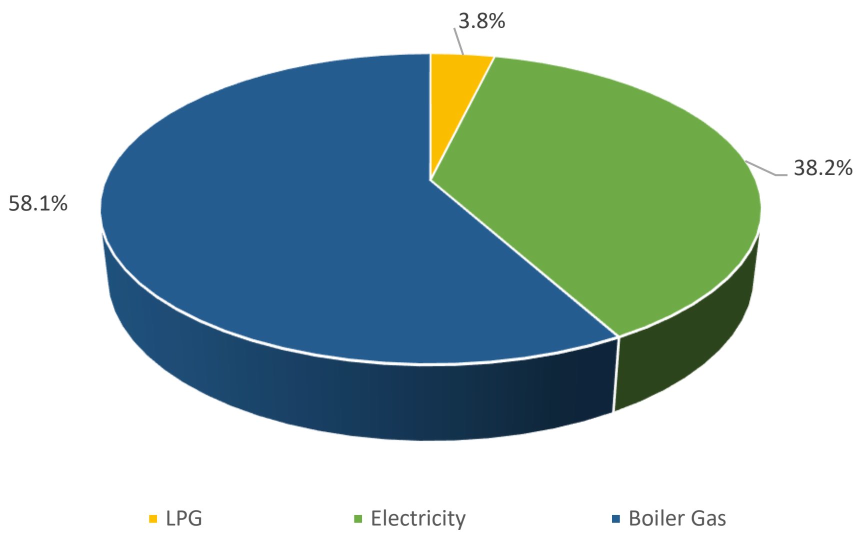

Figure 6.9: Site energy consumption % Site 'I' - Integrated

From the site data evaluated site energy consumption was driven by boiler gas usage at 58% and electricity distribution at 38%. The remaining energy, LPG, was consumed by fork lift trucks.

Table 6.19 shows the breakdown of energy across site. Research provided a 93% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	1,567	212
Elec	895	102
Corrugator	365	
Conversion	227	
Compressed Air	76	
Lighting	102	
Waste System	62	

Table 6.19: Integrated site I - Site energy usage

Table 6.19 shows that 33% of all the electrical energy was consumed on the corrugator, with 21% of energy consumed on converting equipment. Of the remaining energy 9% was consumed on lighting, 7% on compressed air and 6% on the waste system. The majority of the thermal energy consumed was used for steam generation. The site had a low electrical baseload at 11% with a thermal baseload of 14%. The readings taken at

Site I suggested good control in shutdown procedures and control on plant with baseload taken at midnight on a Saturday out of the normal production window.

6.9.2 Stage 2

The FPM process provides a list of potential projects for consideration at Stage 2. The projects identified from the ETW along with forecasted savings are shown in Table 6.20.

	Site I	ETW Opportunities									
Source	*Plant Area*	*Boiler Efficiency*	*Burner Efficiency*	*Water Chemistry*	*Thermal Losses*	*Steam Leaks*	*Condensate Return*	*Condensate Recovery*	*Steam Traps*	*Steam Leaks*	*Thermal losses*
Boiler	Steam Generation	2%	5%	5%	8%						
	Steam Distribution							10%			8%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		12%		40%						
	Lighting					60%					
	Compressed Air								10%	10%	

Table 6.20: ETW opportunities – FPM Stage 2

Boiler efficiency was defined as an area of efficiency in terms of oxygen control whilst the boiler burner was an aged mechanical linkage type. Improvements in control of blowdown and water chemistry provided thermal efficiency improvement. Opportunities for replacement high efficiency lighting were identified along with compressed air improvements. All forecasted saving levels were noted and projects submitted for approval.

6.9.3 Stage 3

Stage 3 delivered project implementation and reviewed energy efficiency with respect to the impact on energy kWh against forecasted data. This took place over a period of four months following project justification and approval. Having completed this a further four day study at site was conducted to enable actual savings to be evaluated and reviewed shown in Table 6.21.

	Site I	ETW Delivered efficiency savings									
Source	Plant Area	Boiler Efficiency	Burner Efficiency	Water Chemistry	Thermal Losses	Steam Leaks	Condensate Return	Condensate Recovery	Steam Traps	Steam Leaks	Thermal losses
Boiler	Steam Generation	2%	3%	2%	6%						
	Steam Distribution							10%			5%
Transformer	Plant Area	Classification	DC:AC	Motor Losses	Drive control	Type	Sensors	Type	Generation	Distribution	
	Motors		10%		40%						
	Lighting					60%					
	Compressed Air								7%	12%	

Table 6.21: Delivered efficiency savings – FPM Stage 3

Thermal efficiency improvement was made through oxygen control, burner upgrade, improved control of water chemistry and lagging upgrade. A lighting project was implemented improving the light level through a more efficient light solution. Compressed air pressure control was regulated and the air distribution system improved through leak reduction and air regulator control.

6.9.4 Stage 4

Following this action research at site I it is proposed that the results are within a very similar value in comparing the maximum efficiency improvement delivered alongside the minimum value recorded. Additional the range of the results appears to be consistent and there is an improvement in the standard deviation across the range of results which is proposed provides higher confidence in the resulting efficiency defined, shown in Table 6.22.

	Max	Min	Range
Burner Efficiency	10%	3%	7%
Thermal losses	15%	5%	10%
Water Chemistry	5%	2%	3%
Drive control	55%	40%	15%
DC:AC Motors	12%	10%	2%
Lighting	65%	50%	15%
CA Type	15%	10%	5%
CA Generation	10%	5%	5%
CA Distribution	15%	10%	5%

Table 6.22: Levels of energy efficiency improvement

The research set out to identify the potential application of technologies within the ETW, applied to areas of the corrugated manufacturing operation, and to validate the associated efficiency improvements. The final three sites are reviewed to finalise the data findings from the main energy users. Having completed this research will then include all further research sites to finally validate the study and inform the Energy Efficiency Framework.

6.10 Integrated Site J

The production for Site J was typical of an integrated plant operation. The site operated five days a week twenty four hours a day, with a 12 hour dayshift manufacturing operation over the Saturday and Sunday periods.

6.10.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.10.

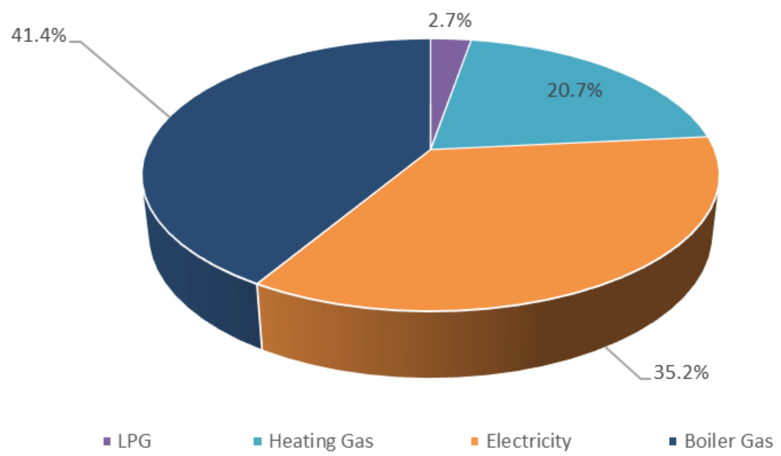

Figure 6.10: Site energy consumption % Site 'J' - Integrated

From the site data evaluated site energy consumption was driven by boiler gas usage at 41% and electricity distribution at 35%. There was a significant usage of gas at 20% used for factory heating with the remaining LPG consumed by fork lift trucks activity on site.

Table 6.23 shows the breakdown of energy across site. Research provided a 94% collection of electrical data from measurements taken, with all gas data recorded from automatic meter collection.

Data Collection	***kWh***	***Baseload***
Gas	2,122	799
Elec	1,122	564
Corrugator	403	
Conversion	299	
Compressed Air	138	
Lighting	124	
Waste System	88	

Table 6.23: Integrated site J - Site energy usage

Table 6.23 shows that 37% of all the electrical energy was consumed on the corrugator, with 27% of energy consumed on converting equipment. Of the remaining energy 13% was consumed on compressed air, with 11% on lighting and 8% on compressed air and 8% on the waste system. There was a significant use of thermal energy supplied from gas heating of the factory. .

6.10.2 Stage 2

The FPM process provides a list of potential projects for consideration at Stage 2. The projects identified from the ETW along with forecasted savings are shown in Table 6.24.

	Site J	ETW Opportunities									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation	2%	5%	5%	8%						
	Steam Distribution										8%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		12%		40%						
	Lighting					60%					
	Compressed Air								10%	10%	

Table 6.24: ETW opportunities – FPM Stage 2

6.10.3 Stage 3

Stage 3 delivered project implementation and reviewed energy efficiency with respect to the impact on energy kWh against forecasted data. This took place over a period of three months following project justification and approval. Having completed this a further five day study at site was conducted to enable actual savings to be evaluated and reviewed, results of which are shown in Table 6.25.

	Site J	ETW Delivered efficiency savings									
Source	*Plant Area*	*Boiler Efficiency*	*Burner Efficiency*	*Water Chemistry*	*Thermal Losses*	*Steam Leaks*	*Condensate Return*	*Condensate Recovery*	*Steam Traps*	*Steam Leaks*	*Thermal losses*
Boiler	Steam Generation	3%	3%	3.5%	5%						
	Steam Distribution										5%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		14%		44%						
	Lighting					58%					
	Compressed Air							15	10%	14%	

Table 6.25: Delivered efficiency savings – FPM Stage 3

6.10.4 Stage 4

Following this action research at site no significant changes were noted to the FPM process or corresponding results associated with ETW technology or application.

6.11 Integrated Site K

The production for Site K was typical of an integrated plant operation. The site operated five days a week twenty four hours a day with no weekend operations.

6.11.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.11.

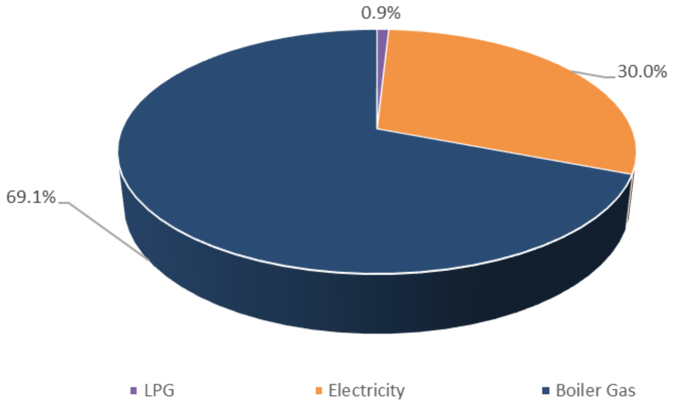

Figure 6.11: Site energy consumption % Site 'K' - Integrated

Table 6.26 shows the breakdown of energy across site.

Data Collection	***kWh***	***Baseload***
Gas	1,920	143
Elec	795	202
Corrugator	342	
Conversion	206	
Compressed Air	61	
Lighting	95	
Waste System	45	

Table 6.26: Integrated site K - Site energy usage

6.11.2 Stage 2

Projects identified from the ETW along with forecasted savings are shown in Table 6.27. These are based on previous action research findings which have seen accuracy and forecasting improvement over previously reviewed sites.

	Site K	ETW Opportunities									
Source	*Plant Area*	*Boiler Efficiency*	*Burner Efficiency*	*Water Chemistry*	*Thermal Losses*	*Steam Leaks*	*Condensate Return*	*Condensate Recovery*	*Steam Traps*	*Steam Leaks*	*Thermal losses*
Boiler	Steam Generation	2%	5%	5%	8%						
	Steam Distribution										8%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		12%		40%						
	Lighting					60%					
	Compressed Air							15%	10%	10%	

Table 6.27: ETW opportunities – FPM Stage 2

6.11.3 Stage 3

Stage 3 delivered project implementation and reviewed energy efficiency with respect to the impact on energy kWh against forecasted data, shown in Table 6.28.

	Site K	ETW Delivered effieicny savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation	3%	3%	4%	7%						
	Steam Distribution										8%
Transformer	Plant Area	*Classification*	*DC:AC*	*Motor Losses*	*Drive control*	*Type*	*Sensors*	*Type*	*Generation*	*Distribution*	
	Motors		11%		45%						
	Lighting					62%					
	Compressed Air							17%	12%	13%	

Table 6.28 Delivered efficiency savings – FPM Stage 3

6.11.4 Stage 4

Following this action research at site no significant changes were noted to the FPM process or corresponding results associated with ETW technology or application.

6.12 Integrated Site L

The production for Site L was that of a smaller integrated plant operation with a reduced conversion capability. The site operated five days a week twenty four hours a day with no weekend operations.

6.12.1 Stage 1

The FPM involved establishing a detailed energy balance on site of actual energy consumption which was measured and is shown in Figure 6.12.

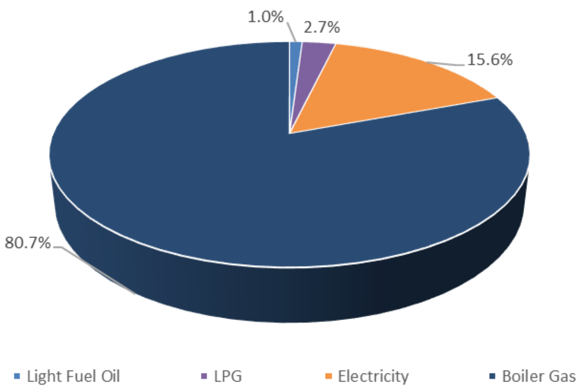

Figure 6.12: Site energy consumption % Site 'L' - Integrated

Table 6.29 shows the breakdown of energy across site. Against previous research data the corrugated appeared to have a high electrical energy load at 49% of the site usage.

Data Collection	***kWh***	***Baseload***
Gas	2,887	261
Elec	818	202
Corrugator	398	
Conversion	144	
Compressed Air	84	
Lighting	99	
Waste System	47	

Table 6.29: Integrated site L - Site energy usage

6.12.2 Stage 2

Projects identified from the ETW and previous action research are shown in Table 6.30 along with forecasted savings based on research findings to date.

	Site L	ETW Opportunities									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation		5%	5%	8%						
	Steam Distribution										8%
Transformer	Plant Area	***Classification***	***DC:AC***	***Motor Losses***	***Drive control***	***Type***	***Sensors***	***Type***	***Generation***	***Distribution***	
	Motors				40%						
	Lighting					60%					
	Compressed Air								10%	10%	

Table 6.30: ETW opportunities – FPM Stage 2

6.12.3 Stage 3

Stage 3, as with the defined research process at sites, delivered project implementation and reviewed energy efficiency with respect to the impact on energy kWh against forecasted data. The results are shown in Table 6.31.

	Site L	ETW Delivered efficiency savings									
Source	***Plant Area***	***Boiler Efficiency***	***Burner Efficiency***	***Water Chemistry***	***Thermal Losses***	***Steam Leaks***	***Condensate Return***	***Condensate Recovery***	***Steam Traps***	***Steam Leaks***	***Thermal losses***
Boiler	Steam Generation		2%	1%	7.5%						
	Steam Distribution										8%
Transformer	Plant Area	***Classification***	***DC:AC***	***Motor Losses***	***Drive control***	***Type***	***Sensors***	***Type***	***Generation***	***Distribution***	
	Motors				44%						
	Lighting					57%					
	Compressed Air								8%	12%	

Table 6.31: Delivered efficiency savings – FPM Stage 3

6.12.4 Stage 4

Following this action research at site L no significant changes were noted to the FPM process or corresponding results associated with ETW technology or application. The following efficiency assumptions, shown in Table 6.32, were recorded and taken forward into research across all other manufacturing sites.

	Max	***Min***	***Range***
Boiler Efficiency	10%	2%	8%
Burner Efficiency	10%	2%	8%
Thermal losses	15%	5%	10%
Water Chemistry	5%	1%	4%
Drive control	55%	40%	15%
DC:AC Motors	14%	10%	4%
Lighting	65%	50%	15%
CA Type	17%	10%	7%
CA Generation	12%	5%	7%
CA Distribution	15%	10%	5%

Table 6.32: Levels of energy efficiency improvement – FPM Stage 4

6.13 Wider research study

Research was carried out across the corrugated manufacturing sites with the application of the FPM model at all other sites shown in Table 6.33. These were converting sites and had no gas usage. Specific electrical efficiency technologies were evaluated.

		Potential Energy Efficiency Technology Application									
		GAS						ELECTRICITY			
Site	**Area of Business**	**Boiler Efficiency**	**Burner Efficiency**	**Boiler Water Chemistry**	**Thermal Losses**	**Steam Leaks & Traps**	**Condensate Return & Recovery**	**DC: AC conversion**	**Inverter drive control**	**Lighting**	**Compressed Air**
Site M	Converting							X		X	X
Site N	Converting							X		X	X
Site O	Converting									X	X
Site P	Converting							X	X	X	X
Site Q	Converting								X	X	X
Site R	Converting									X	X
Site S	Converting							X		X	X
Site T	Converting							X	X	X	X
Site U	Converting							X	X	X	X
Site V	Converting								X	X	X
Site W	Converting									X	X
Site X	Converting									X	X
Site Y	Converting								X	X	X

Table 6.33: Action research – wider study area

The majority of potential ETW applications were evaluated, and forecasted assumptions compared to actual delivered savings. The FPM was adopted at all smaller plants and ETW technologies evaluated prior to project implementation. Savings in the wider study showed plants to have a lower level of potential saving, however the research findings supported the data and information derived from the main study.

6.14 Key specific projects

During the research timeline a number of events at factory level provided further research opportunities. These were carefully considered and where the inclusion of study was aligned to the objectives and within the ETW, the technology was considered in further detail. The areas of power supplied through transformers or combined heat and power were considered, along with site baseload.

In considering the supply of energy to sites the centre of the ETW shows the linkage between fuel and supply. Electrical power supplied to sites is transmitted through a transformer. A specific piece of research was conducted in this area and is explained in Chapter 6.12.1.

In considering alternatives for gas and electricity supply there is a potential option considered as an alternative to gas supply in the form of combined heat and power. This is an established technology but not currently implemented within the corrugated industry. A research study into the viability of such a direction as carried out at a research site and is reported in Chapter 6.12.2.

Reference has been made throughout the research to baseload data and readings taken at sites. This relates to the effectiveness of shutdown procedures and conserving energy when not required. In this baseload is not directly an energy efficiency technology but was researched due to the findings of the action research at sites. The conclusions of the action research into this area are reported in Chapter 6.12.3.

6.14.1 Transformer corrugated plant application

From annual oil analysis during the research the transformer at Site G had started to show signs of a potential breakdown internally. Whilst this was acceptable to continue to use it gave rise to future reliability concerns and at some point further breakdown and failure.

Two forms of energy efficiency savings were reviewed in terms of equipment efficiency and voltage reduction. The simple reduction (with new equipment) to Tap 3 (11000/417V Transformer) showed a saving of 3.5% equating to 99,176kWh per annum. This reduced the voltage supplied to site equipment from 244V to 230V

The equipment savings from the introduction of a super low loss amorphous transformer were suggested to be a 3.5% reduction from the manufacturers' specified data. This could not be measured independently from the overall data at the point of transition from the old transformer to the new.

The project was implemented and gave rise to a number of significant considerations, none more so than the impact of shutting down the power supply to the entire operating site. However, this was minimised with the utilisation of a backup portable power supply transformer. The change in power can be seen in Figure 6.13.

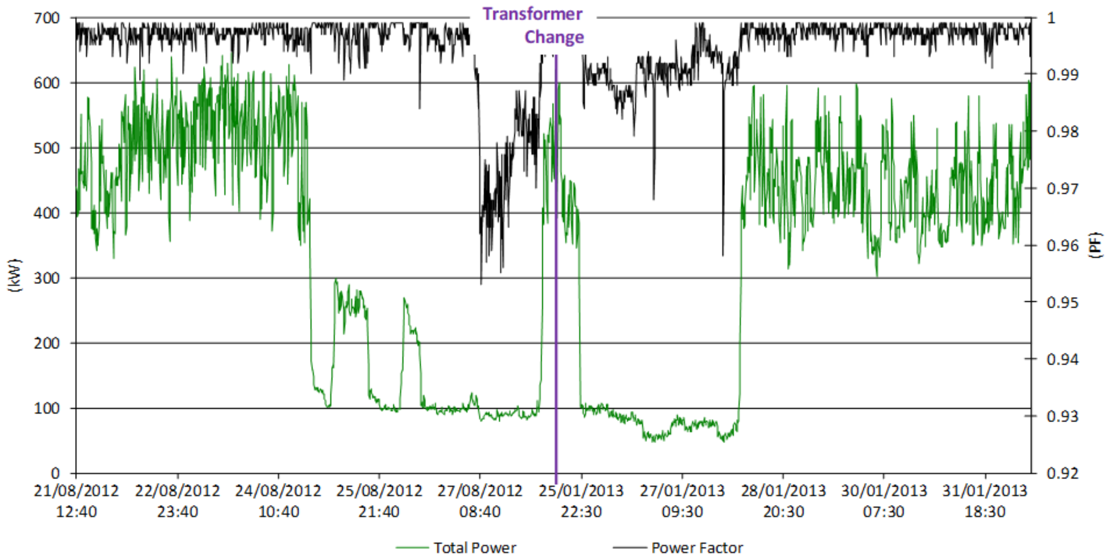

Figure 6.13: Transformer electrical savings delivered

Overall the technology application delivered a reduction in electrical usage of 3.5%. This was later validated a further site with a corresponding 4.0% saving validated. It must be noted however that the majority of savings of such an application come from voltage optimisation and reduction. These savings could be delivered with a change of tap settings on current transformers if suitable.

6.14.2 CHP Corrugated plant application

The chosen integrated site for the review had an average 950kWh electrical load which was assumed for a 24 hour 5 day a week operation for 50 weeks a year. This was taken from HH supplied electricity and an average and baseload calculated for the review period. This was evaluated against full year seasonality and a reference data set used for evaluation. The site operating hours are key to determining payback potential. A site not operating 24/7 will immediately lose 29% of the potential savings due to reduced CHP operating windows.

The site has a spark spread of 4.6 and the evaluation has used generally available commodity pricing for gas and electricity at the time of the review.

In terms of the study the site dynamics were considered along with operating hours, gas supply, site steam demand and potential use for LTHW. Based on this initial review a packaged CHP unit of 770kW engine was chosen for the potential application. Sizing of the CHP engine is critical to ensure the correct alignment of the CHP capacity with a sufficient site requirement for electrical and thermal energy.

Another practical consideration of CHP application is that if the unit is generating below 50% of the packaged output then the unit will switch off. This is to safeguard the engine against thermal damage due to overheating. Therefore correct sizing of the unit is essential as is the baseload determination. In the case of the review conducted, 20% of the operating time the CHP unit would have been turned off automatically during the full year under review as the site was not above the baseload.

Following a site review and application assessment a suitably sized 770 kW CHP unit was considered for introduction at the integrated site and the fundamental calculations were processed and validated utilising a desk top modelling application. The table below provides a simplified set of data produced from the study. The assumption made for all data is that the generated steam is utilised 100% by the site, with corresponding usages of LTHW shown;

Application on site	*Cost saving*	*Payback yrs.*
100% use of all LTHW	£175k	5
75% use of all LTHW	£165k	5
50% use of all LTHW	£152k	5.5
25% use of all LTHW	£141k	6.5
0% use of all LTHW	£130k	7

Specific calculations will vary dependent upon site operating characteristics. Where the production window is different, where weekend working is considered, based on scheduled periods of shutdown and based on utility pricing and cost of CHP equipment. An assumption has been taken that the site will only utilise 50% of the available thermal energy supplied in LTHW. This would be used for heating during the winter months only as no other suitable applications have as yet been targeted.

The reviewed integrated corrugated plant, utilising 100% of the steam and 50% of the LTHW provides a cost saving of around £152k per annum at current utility prices and a financial payback on investment of 5.5 years. The reviewed sheet feeding site, utilising 100% of the steam and 50% of the LTHW provides a cost saving of around £65k per annum at current utility prices and a financial payback on investment of 8 years.

Where sites operate production on 24 hours a day 7 days a week corresponding investment and running costs will improve the payback calculations significantly. In the calculations conducted within the review if sites were to operate 24/7 the integrated payback would improve to 4 years from 5.5. The sheet feeding site if working 24/7 would see an improved payback from 8 years to 6 years.

The utilisation of LTHW at each site was not able to be optimised and therefore potential payback opportunities are extended compared to utilising 50% of the LTHW shown.

For CHP to be a viable opportunity at the two sites utilised for the study, a virtually constant demand for steam would be essential along with a suitable identified use for LTHW. Neither of these criteria could be sufficiently met and a very low use of LTHW would be realised.

Importantly the application of CHP does not provide a carbon reduction when calculated as the conversion factors used for kWh to carbon are not favourable for the technology approach as it is not considered a green alternative for power supply by the government.

As a result the payback criteria would suggest that an ongoing energy reduction programme focussed on reducing and implementing energy efficient technology at this point is more suitable than CHP application.

6.14.3 Baseload

When manufacturing is not actively producing output the energy being consumed is in effect wasted. This energy can be considered in terms of kWh consumed to manufacture one tonne of output. The more wasted energy the lower the efficiency of production. In this way its consumption reduces the performance of the operation.

This energy consumption is required when the plant is left idle, without manpower to produce often where long periods of time of 8 hours or more occur. The energy consumed at these times can be considered as the baseload. This is the energy required to maintain the site infrastructure, plus the additional wasted energy consumed unnecessarily by plant and equipment.

It can be seen from this research shown in Table 6.34 that plants have different levels of baseload at times of zero manufacturing activity. In order to be able to compare and contrast this baseload a decision was made to always review the energy consumption on a Saturday at midnight, when all plants had no manufacturing activity.

Site	*Gas*	*Electric*	*% Gas*	*% Electric*
Site A	670	234	34	47
Site E	569	214	39	27
Site F	826	869	48	79
Site G	658	657	29	71
Site H	346	115	15	10
Site I	212	102	14	11
Site J	799	564	38	50
Site K	143	202	7	25
Site L	261	202	9	25
kWh				
MAX	826	869		
MIN	143	102		
AVG	498	351		

Table 6.34: Baseload energy figures

The data shows a high degree of variation due to a number of variables that include shutdown procedures, focus and engagement, culture and operational approach. From work of Krushna et al (2018) it was shown that a 10% reduction was achieved in energy consumed during idle time during a three month trial. This improvement was suggested by Krushan was due to reflective behaviour and a greater awareness of energy usage.

Within the duration of this research study an engagement approach was developed to heighten the awareness of the energy within the organisation at all levels. Research has shown (Steg et al, 2013) that awareness, interest and engagement across all areas is essential to changing behaviour. Additionally shutdown procedures were introduced to either automatically or manually power down plant and equipment when not in use. The approach combined both technological methods with cultural engagement to reduce baseload energy.

Following the action research and implementation of the chosen methods a follow up study was conducted three years after the initial data was recorded. The resulting energy could be seen to have reduced by an average 57% reduction in gas and 50% reduction in electricity as shown in Table 6.35.

Site	***Gas***	***Electric***
Site A	265	165
Site E	296	102
Site F	453	324
Site G	312	298
Site H	298	94
Site I	247	87
Site J	365	244
Site K	122	132
Site L	199	121
kWh		
MAX	453	324
MIN	122	87
AVG	284	174
% Redtn	57%	50%

Table 6.35: Baseload Reduction Study – Results

From evaluation the improvement is suggested to be as a result of effective shutdown procedures, changing the practices of manufacturing that consume energy over periods of non-production and also cultural engagement.

A specific review of Site H shows that with such engagement, process control and procedural adoption can significantly reduce baseload over time. The kWh consumed was measured on Christmas Day at midnight (zero site energy requirement) from 2013 and previous figures established from recorded data for electricity usage shown in Figure 6.14.

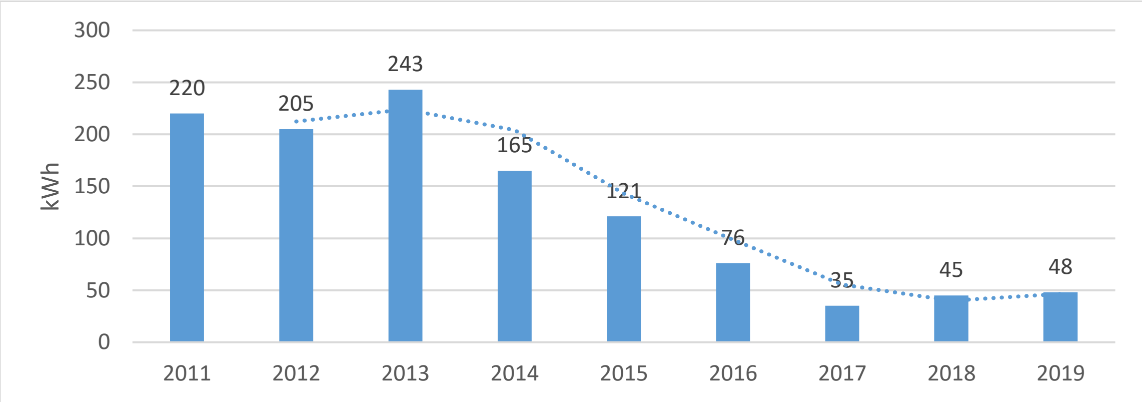

Figure 6.14: Baseload improvement Site H

The data shows the start of the action research in 2014 with a corresponding improvement year on year down to a base figure of around 50kWh. This can be established as the true baseload of the factory requiring energy to power infrastructure.

6.15 Evaluation of results

The results reflect a significant research study across 22 sites over a period of 4 years. Energy efficiency technologies from the Energy Technology Wheel were considered, implemented and reviewed at sites where forecasted savings were recorded. As a consequence of this it is considered that the resulting improvements provide validation to the research, having being acknowledged by the research organisation as factual.

The research recognises that manufacturing sites can vary in their capacity, design and energy requirements. This has been compensated for with the wide ranging research study encompassing sites with differing characteristics and energy requirements.

The efficiency improvements shown in Table 6.36 have been established through detailed action research carried out at manufacturing sites. This data is used to inform the development of the Energy Efficiency Framework. The research results have been proven through active implementation and verification to be an accurate representation of improvements delivered during research activity at sites.

Technology	***Maximum Efficiency Improvement***	***Minimum Efficiency Improvement***	***Range of Improvement***
Boiler Efficiency	10%	2%	8%
Burner Efficiency	10%	2%	8%
Thermal losses	15%	5%	10%
Water Chemistry	5%	1%	4%
Drive control	55%	40%	15%
DC:AC Motors	14%	10%	4%
Lighting	65%	50%	15%
CA Type	17%	10%	7%
CA Generation	12%	5%	7%
CA Distribution	15%	10%	5%

Table 6.36: Overall efficiency improvement derived from research

In considering the results and summarising the key points it can be proposed that boilers have different capacities, age and condition to impact efficiency. However this research has defined that the adoption of good servicing conditions to control oxygen and also improved burner control will deliver savings in the range of 2-10%. The range of results is distorted due to three sites having very inefficient boiler operations. A maximum of 5% savings may be considered more representative but this obviously depends on condition.

In relation to thermal losses it is proposed that culture and engagement play a big part in this aspect of efficiency. A number of the losses noted had previously been lagged and following maintenance had not had the lagging replaced. However this research has raised the understanding of the scale of potential benefits accruing from thermal losses in the order of 5-15% improvement.

It is suggested by this research that boiler water chemistry and its understanding is one of the potential biggest areas for knowledge improvement. Whilst savings of between 1-5% are not considered significant, the boiler condition will be seriously impacted by inappropriate chemistry leading to corrosion and damage to the boiler. Additional poor water chemistry has also been noted to present poor quality steam affecting process heat transfer from steam to paper.

It can be stated that measurement of electrical energy usage and defining electrical efficiency is simpler to do in manufacturing sites. It can be easily measured with portable equipment at any time, ensuring adequate safety precautions are taken where applicable. The research shows that the highest energy savings are available from inverter control of electric motors and lighting. However whilst the technology will deliver this level of improvement, workforce culture may have an adverse effect in overriding control for other reasons other than energy efficiency.

A simple area of efficiency improvement is proposed by this research to be in the area of compressed air generation and distribution. In over 80% of sites researched compressed air pressure was in excess of the necessary operating pressure. It was also found that all sites had a level of compressed air leakage, which when corrected with minimal expense resulted in efficiency improvements of between 10-15%.

The actual consumption of energy at any one given time will also require varying amounts of energy in terms of speed, board grade and condition. This variable was accommodated within the research by measuring energy input units in kWh versus output requirements to derive efficiency improvements.

The research required a considerable amount of time on manufacturing sites collecting data, analysing requirements, forecasting improvements and delivering projects activity. Additionally the follow up studies conducted to validate this research were considerable in the depth and time consuming. The outcome provides the opportunity for the resulting framework to be implemented in a timely manner, without justification or validation. This will deliver an increased speed of energy efficiency improvement and subsequent carbon reduction.

It is proposed by this research that the adoption of the methodology and the implementation of the Factory Process Model within the action research has established verifiable data upon which to establish levels within an Energy Efficiency Framework considered in Chapter 7.

6.16 Summary

The research has provided validated action research across 22 manufacturing plants of the impact of implementing ETW projects within an FPM process. The development of these two approaches was found to be essential in the action research programme. The ETW and FPM provided structure and process for evaluation of site operations with respect to energy efficiency.

The concluding results are provided as a basis for the development of the Energy Efficiency Framework. The time taken in carrying out this study was extensive and the access to the research was made possible by the adoption of the Internal Practioner role within the organisation.

The results are reflective of the different types of sites within the corrugated manufacturing operations, sheet feeding, integrated and converting sites. The results are also taken from smaller energy consuming sites to those large sites, where within the research 85% of the energy is consumed across 9 sites.

There is a significant amount of supplementary information behind the research results, some of which is confidential. However the data presented provides an overview and conclusion of four years action research carried out at sites. Where energy efficiency projects were implemented a significant amount of investment was made by the research organisation in equipment and time to implement trial outcomes.

An opportunity was taken during the research to evaluate two emergent applications which were presented. Boundary technologies of electrical power supplied through a Transformer and source of power provided by a potential CHP application were researched. The research was able to position these within the proposed framework and in doing so provided a wider scope of the potential for technology diffusion.

The study was extensive and ran for a period of three years. During this time action research was carried out at locations across the UK to research ETW technologies. Having completed evaluation and modelling, the FPM applied the learnings to accurately deliver energy efficiency savings. During this stage a significant amount of intervention and project management was required to define specification, agree installation programmes and evaluate outcomes.

Following completion of the action research it has been established as shown in Table 6.36 the overall levels of efficiency proposed by this research against ETW technologies. This provides the basis for informing the development of the final Energy Efficiency Framework.

Chapter 7 Energy Efficiency Framework

7.1 Introduction

The chapter defines an approach to energy efficiency developed by this study through action research across UK corrugated plants within the research organisation. The framework introduced during Chapter 4 is developed and its evolution described following the action research detailed in Chapter 6. This chapter describes the development of the framework theory and applied practice, providing a validated solution for energy efficiency delivered through the applied action research findings.

7.2 Objective

This work has remained aligned to the research goal of establishing a strategic energy framework for developing energy best practice in the corrugated sector of the print and paper industry. This chapter addresses Objective 5 of the research in relation to the design and development of a strategic framework to be implemented across corrugated factories to drive energy efficiency.

The chapter provides an answer to the specific research questions in Chapter 1, referenced in Table 7.1, achieving the objective of delivering an Energy Efficiency Framework (EEF).

No	Specific research question	Research Objective
6	What energy modelling and energy efficiency techniques can be employed to establish the costs and benefits of any potential changes within the corrugated industry?	1,4,5
7	What specific range of technologies can be applied to formulate a best practice methodology for the corrugated industry?	1,2,5
8	How can these be combined into a strategic modelling framework to be used throughout the corrugated industry to drive energy reduction best practice?	3,4,5

Table 7.1 Specific Research Questions addressed

7.3 Key Deliverables

The purpose of the EEF is to provide key stakeholders with a framework for energy efficiency with defined steps and proposed target savings identified. The framework has an aim that its application will be utilised across the research organisation at all levels, requiring no further validation and justification to support effective decision making processes.

It is proposed that the EEF may be applied to other similar corrugating operating processes. There is a high degree of similarity across the corrugated industry utilising similar equipment, together with similar manufacturing processes, consuming relatively similar amounts of energy dependent upon the scale of operation. There is a potential for a further research opportunity to determine the true applicability of the proposed EEF to other organisations and corrugated operations outside the research organisation.

7.4 Energy Efficiency Framework

Chapter 5 discussed the framework development. Initial design considerations were introduced together with key principles of the proposed theory being developed. Alternative approaches were considered and the 'Energy Hierarchy' (Wolfe, 2013) was used as a base for developing further research. This together with the approach of 'Technology Diffusion' researched and presented (Fleiter et al, 2012) provided two foundation concepts.

This section of Chapter 7 considers the construction, technology levels, implementation costs, defined savings and financial justifications. Having described the stages it goes onto to consider the impact of the approach before finalising the outcomes of the study and presenting and establishing the proposed Energy Efficiency Framework.

7.4.1 Construction of the Energy Efficiency Framework

The creation of the Energy Technology Wheel (ETW) in Chapter 5, shown in Figure 7.1 for reference, provided relevant energy efficiency technologies.

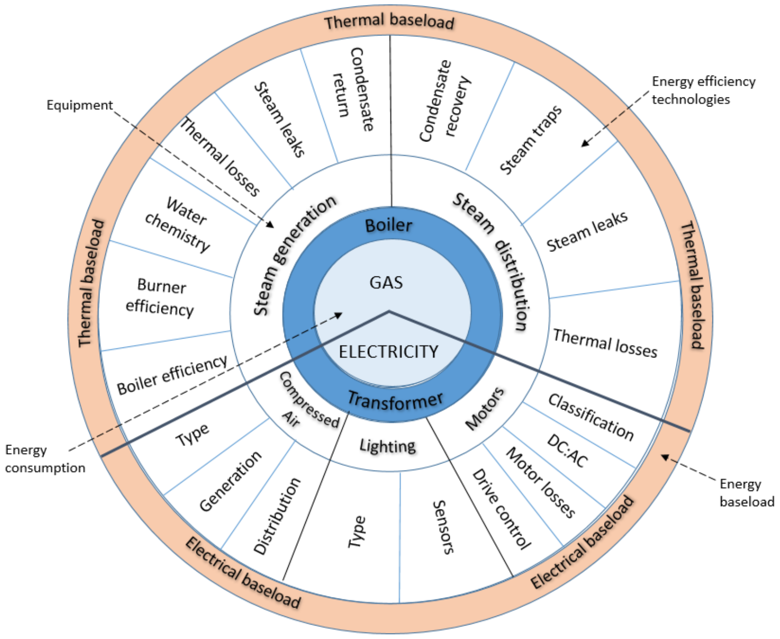

Figure 7.1: Energy Technology Wheel

To determine the levels of technology the Factory Process Model (FPM), referenced in Figure 7.2, provided a structured approach to action research.

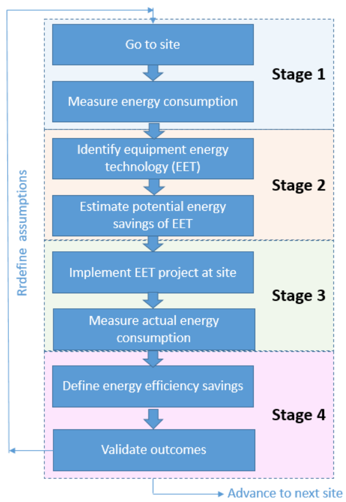

Figure 7.2: Factory Process Model

The survey and interviews, detailed in Chapter 4, provide an insight into the qualitative and quantitative feedback provided. Evaluation of this together with action research observations suggests that the three areas of consideration, shown in Figure 7.3 of Return on Investment, Implementation cost and Technology level, are relevant and justified through the research findings.

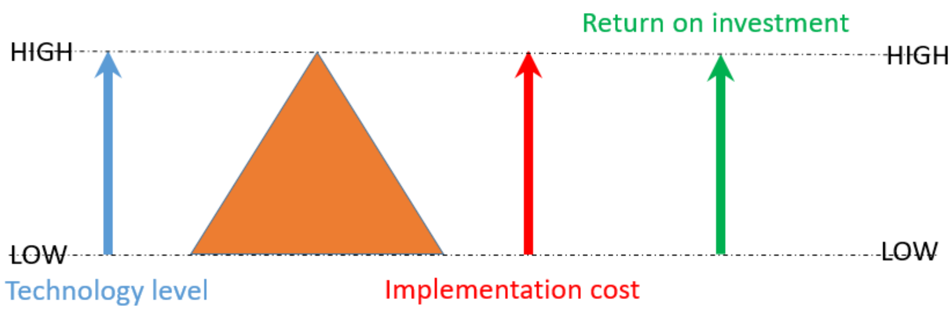

Figure 7.3 Areas of consideration

These three areas of consideration, as concepts, were defined in section 5.3.1 within the initial design and are confirmed within the EEF based on the research findings as key enablers of the implementation of energy efficiency and energy reduction measures.

Technology Level	The complexity of technology and its lifecycle position
Implementation cost	Detailed project costs
Return on Investment	Simple return on investment calculation

Initially the level of engagement to sustain the change was considered as a fourth factor. However this area in itself was found to represent a potential area for further research due to its breadth and depth and as a result the area of engagement was not considered within the action research study.

For the framework to be practically applied in meeting the research objectives it had to deliver a realisable purpose within the organisation. This was provided by considering the theory of application together with the resulting practical implications established through action research. The technology level was considered together with the return on investment and implementation costs.

7.4.2 Technology Levels

The technology level established is based on the complexity of the approach, the level of control required and the scale of change required within the plant to deliver the required technological change. For example, controlling compressed air requires a low level of technology, whilst implementing CHP requires complex control and modification to the existing operations. The data presented in Table7.2 is taken from the action research findings detailed within Chapter 6.

	Technology level
Baseload reduction	VERY LOW
Compressed air pressure	VERY LOW
Compressed air usage	LOW
Boiler water chemistry	LOW
Steam lagging	LOW
Steam leaks & traps	LOW
Boiler burner control	MEDIUM
Factory lighting	MEDIUM
Compressed air generation	MEDIUM
Motor drive control	MEDIUM
DC:AC motor conversion	MEDIUM
Low loss transformers	HIGH
Condensate recovery	HIGH
Combined heat & power	VERY HIGH
Renewable technology	VERY HIGH

Table 7.2: Technology Levels

7.4.3 Implementation Costs

Implementation costs were established within Stage 2 of the FPM following tender specification and project cost submissions from approved suppliers. This enabled the research to accurately evaluate the results and determine levels of payback.

The implementation costs were categorised, shown in Table 7.3. These ranged from simple manual interventions requiring 'ZERO' associated costs, to technology applications such as combined heat and power which required in the region of one million pounds investment and was consequently ranked as 'Very High'.

	Implementation cost
Baseload reduction	ZERO
Compressed air pressure	ZERO
Compressed air usage	VERY LOW
Boiler water chemistry	ZERO
Steam lagging	LOW
Steam leaks & traps	LOW
Boiler burner control	MODERATE
Factory lighting	MODERATE
Compressed air generation	MODERATE
Motor drive control	MODERATE
DC:AC motor conversion	HIGH
Low loss transformers	HIGH
Condensate recovery	HIGH
Combined heat & power	VERY HIGH
Renewable technology	VERY HIGH

Table 7.3: Implementation cost

7.4.4 Defined savings

From the research detailed in Chapter 6 the following listing of technologies is shown with the corresponding level of energy efficiency savings. These were determined from kWh recorded from observations pre and post project implementation.

Energy efficiency approach	**Applicable % savings**
Baseload reduction	40-50%
Compressed air pressure	5-12%
Compressed air usage	10-15%
Boiler water chemistry	1-5%
Steam lagging	5-15%
Steam traps & leaks	1-2%
Boiler burner control	2-5%
Factory lighting	50-65%
Compressed air generation	5-12%
Motor drive control	40-55%
Power transformers	3-5%
Condensate recovery	10%
DC:AC Conversion	5-12%

Table 7.4: Defined savings level

The level of savings was reviewed against an archived document published by the Department of the Environment (1988) in a specific energy efficiency best practice guide for the UK Corrugated Packaging Industry. This is the most relevant piece of published material noted during the study as it specifically relates to the subject matter.

The publication by the DoE discusses the concepts of calculating energy use and improving energy efficiency in the corrugated sector. This research suggests that the guide is light in detail and content. In less than 500 words the guide attempts to provide a simple strategy for management practices which will reduce energy consumption. In reviewing the work it is recognised that the data is considerably out of date and no later updates or publications have been made of the document in the last thirty two years.

The work of the DoE provides a table of suggested energy practices and potential savings. In reviewing this work Table 7.5 shows the position in 1988 compared to the researched view presented in 2020 by this research.

Energy efficiency area	1988	2020
Efficient use of steam	5-20%	15%
Variable speed drives	5-10%	45%
Lighting	30-50%	60%
Compressed air efficiency	5-10%	10-15%
Waste transfer systems	2-3%	35%
Baseload reduction	2-5%	10%

Table 7.5 Potential savings comparison

It is recognised by this research that since the publication of the best practice guide technology and time has moved on. In 1988 the technological approach would have been very different from that of today. Energy efficiency would have been considered an early adoption for many equipment manufacturers and suppliers. By delivering this research it is suggested that future publications will bring renewed life and focus to the area of energy efficiency within the corrugated sector.

7.4.5 Financial justification

During the study it was established that the longest financial payback delivered within the Energy Technology Wheel (ETW) was currently seven years. This was the level of return for the Combined Heat and Power (CHP) application for a corrugated plant. Obviously this will need to be recalculated on a regular basis due to long term energy commodity prices and also technology costs.

Research into renewable technologies during the research showed these to be in excess of seven years return on investment. A brief summary of these in contained later in this chapter. This was still considered high by the research organisation. Financial payback in excess of five years suggested an extended time horizon and a diminishing rate of return. Typically a two year payback was anticipated on capital investment which is considered realistic for cost take out recovery projects.

The boundary for the EEF was therefore established at a seven year return on investment in line with the technology reviewed. Within this it is proposed there is a significant opportunity to improve energy efficiency with generated savings providing a return on investment within five years. It is recognised that renewable technologies will in the future play a larger part in the energy sector within corrugated operations. It is proposed by this research that there are many more opportunities included in the ETW to improve energy efficiency than CHP which can be more easily justified from a financial savings perspective.

Return on investment was calculated from project applications from approved supplier companies. The costs were considered in simple payback terms with no life cycle consideration or future unit pricing considered. Simple improvements to boiler water chemistry had an ‘Immediate’ return on investment, compared with combined heat and power with a projected 7 year return period as shown in Table 7.6.

	Return on Investment
Baseload reduction	Immediate
Compressed air pressure	Immediate
Compressed air usage	Immediate
Boiler water chemistry	Immediate
Steam lagging	2-3 months
Steam leaks & traps	2-3 months
Boiler burner control	2-3 years
Factory lighting	2-3 years
Compressed air generation	3-4 years
Motor drive control	3-4 years
DC:AC motor conversion	4-5 years
Low loss transformers	5 years
Condensate recovery	5 years
Combined heat & power	> 7 years
Renewable technology	> 10 years

Table 7.6: Return on Investment

7.4.6 Impact of proposed technologies

The technologies identified in the Energy Technology Wheel where evaluated in line with the research study and the corresponding analysis. The impact of the proposed technologies is brought together and shown in Table 7.7 which identifies technology level, return on investment and implementation cost based on this research.

	Technology level	***Return on Investment***	***Implementation cost***
Baseload reduction	VERY LOW	Immediate	ZERO
Compressed air pressure	VERY LOW	Immediate	ZERO
Compressed air usage	LOW	Immediate	VERY LOW
Boiler water chemistry	LOW	Immediate	ZERO
Steam lagging	LOW	2-3 months	LOW
Steam leaks & traps	LOW	2-3 months	LOW
Boiler burner control	MEDIUM	2-3 years	MODERATE
Factory lighting	MEDIUM	2-3 years	MODERATE
Compressed air generation	MEDIUM	3-4 years	MODERATE
Motor drive control	MEDIUM	3-4 years	MODERATE
DC:AC motor conversion	MEDIUM	4-5 years	HIGH
Low loss transformers	HIGH	5 years	HIGH
Condensate recovery	HIGH	5 years	HIGH
Combined heat & power	VERY HIGH	> 7 years	VERY HIGH
Renewable technology	VERY HIGH	> 10 years	VERY HIGH

Table 7.7: Impact of proposed technologies

7.5 Energy Efficiency Framework Finalisation

Having defined the impact of the proposed technologies the alignment of research findings was required. To achieve this a weighting system was utilised to enable the three areas of technology, investment cost and return on investment to be categorised, together with the applicable percentage savings level. This was established with a scale of 1-10 with 1 being low and 10 being a high relationship.

This was conducted to ensure that the framework was easily translated from theory into practice, allowing effective application to generate energy efficiency results. It can be seen from Table 7.8 that the level of technology and implementation cost, aligned with return on investment provides a weighting score. A low weighting being a technology with quick payback, low cost of entry and high returns.

Level	Energy efficiency approach	Applicable % savings	Technology Level	Return on Investment	Implementation cost	Weighting
Level 1	Baseload reduction	40-50%	1	10	1	10
Level 1	Compressed air pressure	5-12%	1	10	1	10
Level 2	Compressed air usage	10-15%	3	8	3	72
Level 2	Boiler water chemistry	1-5%	3	6	3	54
Level 2	Steam lagging	5-15%	2	9	2	36
Level 2	Steam traps & leaks	1-2%	2	7	3	42
Level 3	Boiler burner control	2-5%	5	4	5	100
Level 3	Factory lighting	50-65%	4	6	5	120
Level 4	Compressed air generation	5-12%	4	6	7	168
Level 4	Motor drive control	40-55%	5	8	5	200
Level 5	Power transformers	3-5%	7	4	8	224
Level 5	Condensate recovery	10%	7	4	8	224
Level 5	DC:AC Conversion	5-12%	7	4	8	224
	Combined Heat & Power		7	4	9	252
	Renewables		8	3	10	240

Table 7.8: Ranking of potential energy efficiency solutions

This categorisation enabled a structured level of energy efficiency to be produced that enabled the finalisation of the Energy Efficiency Framework shown in Figure 7.6.

7.6 Proposed Energy Efficiency Framework

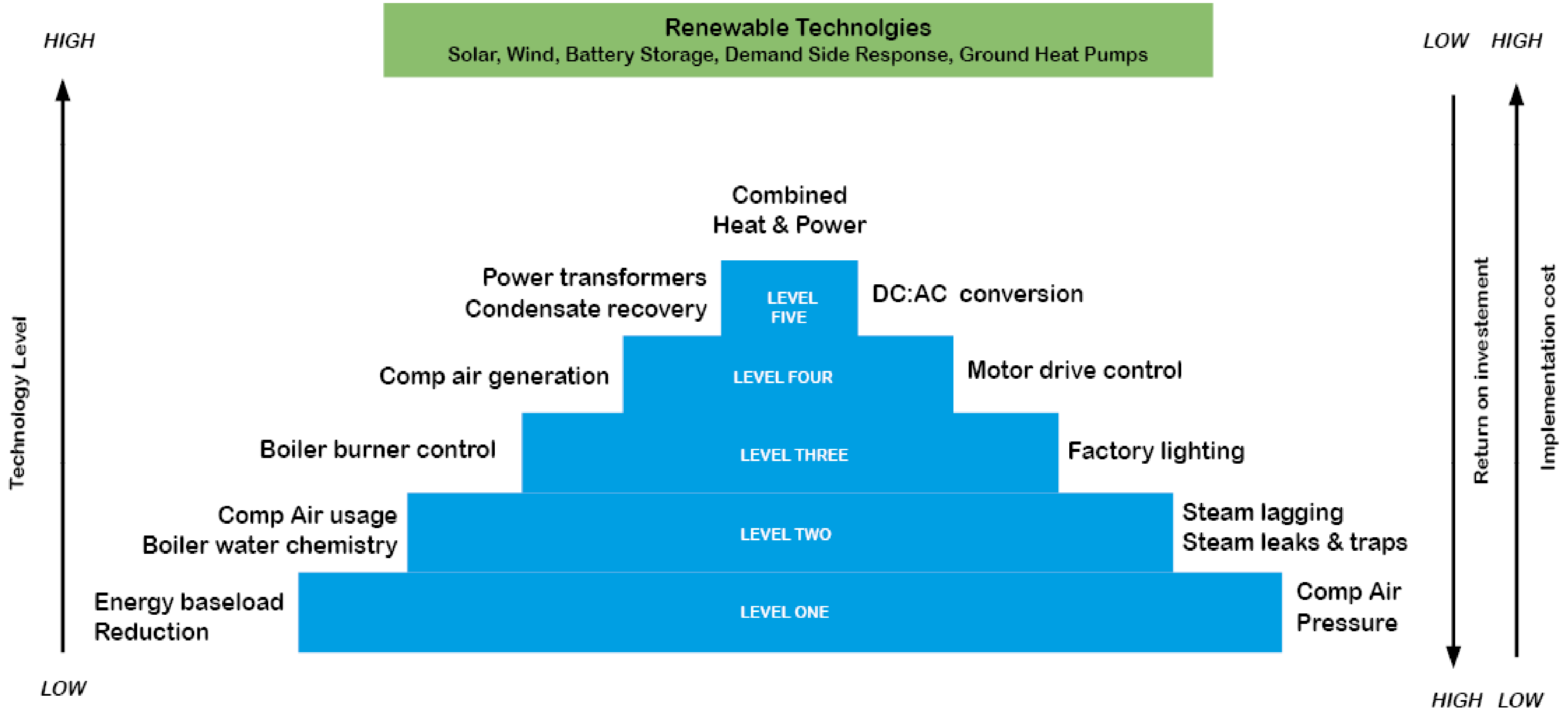

Figure 7.4: Energy Efficiency Framework

7.6.1 EEF Application

The EEF proposed in Figure 7.4 shows the elements of technology, investment cost and return on investment diagrammatically represented against levels of energy efficiency. It is proposed that dependent upon the starting point corrugating sites should focus on implementing 'Level One' activities first such as baseload reduction and compressed air pressure reduction. These provide the lowest technology level and cost of implementation.

The concept of the framework adopts a 'Technology Diffusion' approach in that energy efficiency is adopted to plant and equipment through the application of Level 1, followed by Level 2 working up to Level 5. The steps are intended to ensure a logical staged process of ETW application and to prevent jumping to technologies which may appear more beneficial or attractive.

During the first phase of action research a site proposed the implementation of a combined heat and power plant project with payback calculated at 6.5 years. In the EEF this is a Level 5 technology. Such a project has a high technology level and a high implementation cost of circa £1m. When evaluated with return on investment, which is relatively low, it can be seen from the EEF to be a relevant technology, but it is only recommended following the implementation of all other levels of the EEF.

The technologies have been validated through analysis and review within the financial teams and as such have been accepted by key stakeholders. Additionally the framework has the support of General Managers and the UK Country Operations Director as key decision makers in the energy efficiency process.

Renewable technologies are shown within the EEF as they can play a role in energy efficiency, but this research proposes that this should only be after Levels One to Five of the Energy Efficiency Framework have been exhausted. As previously presented in action research renewable technologies currently carry with them a very high technology cost and technology level with a low return on investment.

7.7 Validation of the Energy Efficiency Framework

7.7.1 Key Measures

From an academic perspective the Energy Efficiency Framework has brought new knowledge to the industry. The action research set out to measure and quantify the actual delivered benefits during the timeline of the study. To quantify the results both academically and practically within the research organisation a comparative study was conducted into energy use pre, during and post the action research.

A number of options were considered to measure the success of this applied research in its delivery of the overall objective. These included comparison of financial billing, line by line analysis of key equipment energy usage, overall site energy usage and relative measures of energy performance compared to output.

There is a recognised view (Pretorius et al, 2009) that data can represent what the user wants the reader to see. In considering this statement it is important that the research provided measures that can be seen to validate the application of the research and the EEF.

In delivering the Energy Efficiency Framework its use must be directly linked to the demonstrated improvement driven by its application. This defines a corresponding energy reduction by the framework development and application, as opposed to simple design and use of such an approach.

For a framework to be deemed effective it is proposed that it is important that key metrics are defined and stated to support the acceptance and recognised potential of delivering a best practice approach. It is suggested that without the supporting data the implementation of the framework would not be recognised, leading to delays and blockers in driving energy efficiency across an organisation.

7.7.2 Savings delivered

In developing the framework and successfully implementing the approach it was important to understand what savings were deliverable over time as a result of the EEF. Without such a consideration the framework could be considered theoretical. Whilst the design of the framework may be considered as effective its application may have not delivered the required benefits. In order to ensure this factor was addressed a clear measurement strategy was adopted.

During the research timeline detailed energy measurement was carried out across all UK Corrugated operations which were the focus of the action research. A number of key measurements were established to validate data resulting from the application of the EEF. These were chosen as

- Carbon emissions — Tonnes of CO2 emitted
- Baseload — kWh during periods of zero production
- Relative Energy — kWh consumed per Tonne of Production

7.7.2.1 Carbon Emissions

Data was recorded and approved as part of the Smurfit Kappa Sustainability Report (Smurfit Kappa, 2019). The UK data is not published separately, it was necessary to establish a detailed tracker for energy use. This was taken from the approved data, with energy activity and resulting carbon performance across all the corrugated manufacturing sites in the UK noted within the research organisation. This data shows that during the initial stages of the research little improvement was delivered. This can be aligned with the literature review, methodology and initial data gathering stages of the research approach which commenced in 2014.

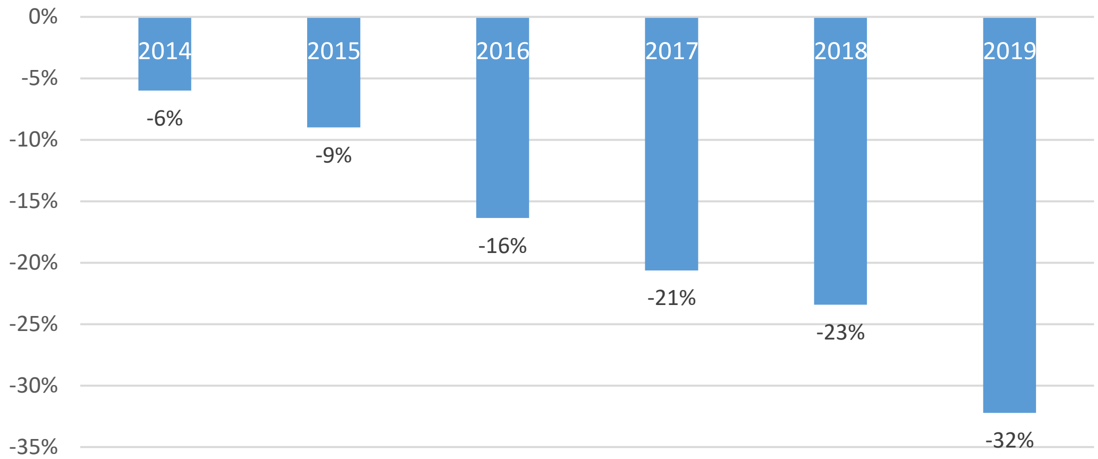

Figure 7.5: Percentage carbon reduction

Action research commenced at sites during 2015 and a series of activities were researched and implemented to start evaluating, testing and constructing the EEF. The main phase of action research was conducted at plants during 2016 through to 2018, which resulted in delivery of carbon savings, shown in percentage reduction per year in Figure 7.5.

It is proposed that the reduction in Carbon Emissions of 32% since 2014, shown in Figure 7.5, is due to the action research conducted at sites, the consequent implementation of research findings and the adoption of the EEF across the research organisation.

In order for evaluation and comparison to be made identified sites were measured consistently to enable comparison and any impact of disposals and acquisition of plants was negated. There were no large variations in volume or major changes to manufacturing operations at sites which may also have distorted the numbers.

7.7.2.2 Baseload

It was determined that consumed energy baseload was a relevant measurement to consider the aspect of culture and energy approach at sites. This was considered as a behavioural indicator of energy engagement, with low and reducing baseload in kWh suggested by this research as indicative of an improving energy culture.

All sites had baseload established as a key measure for reporting, this enabled detailed month on month comparison to be facilitated and improvement activity to be targeted. In considering both electrical and thermal baseload a number of key variables were required to be taken into account. Not all factory systems will be drawing power and dependent upon manufacturing operations and maintenance activity the site may have a varying energy demand with zero production. This when considered across multiple operations and reviewed / trended over time may not provide a consistent data set for comparison.

As a result a measurement period was established and defined as Christmas Day night, when zero activity would be taking place at operational sites. Additionally four periods during the year were nominated where plants had zero activity around bank holiday periods.

The research implemented this data collection and review across all years of the research and shared the data with all research organisation sites. The example of electrical baseload from Site F in Figure 7.6 is suggested to further validate the application of the EEF approach.

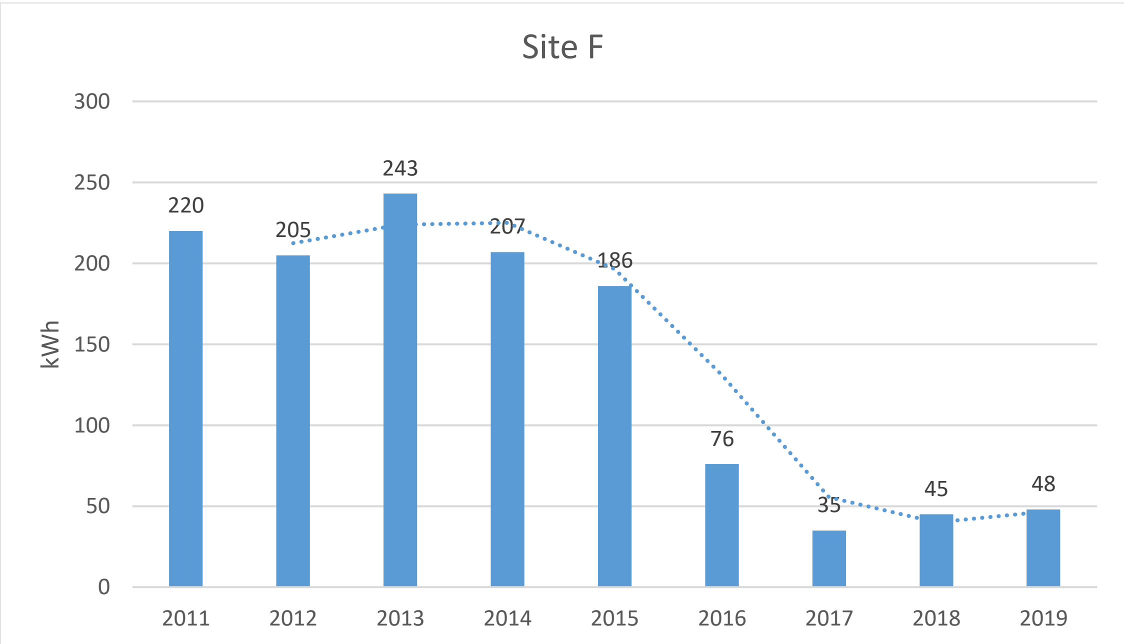

Figure 7.6: Trended Electrical Baseload

It can be seen that from the commencement of the research in 2015 there was a reduction in baseload over time of 30%. This is representative of baseload data presented across corrugated sites in the Action Research in Chapter 6. It is worth considering that this is proposed to mainly be as a result of human behaviour and cultural engagement with respect to energy efficiency. Further research is required in this area to fully understand how such an approach might influence behaviour.

Gas was determined to be the primary energy driver at site level within the action research. Site energy efficiency baseload analysis was reviewed for data evaluation of gas usage. To be consistent in ensuring control of variables during the manufacturing periods the same measuring point of Christmas Day night and four times over the year was taken.

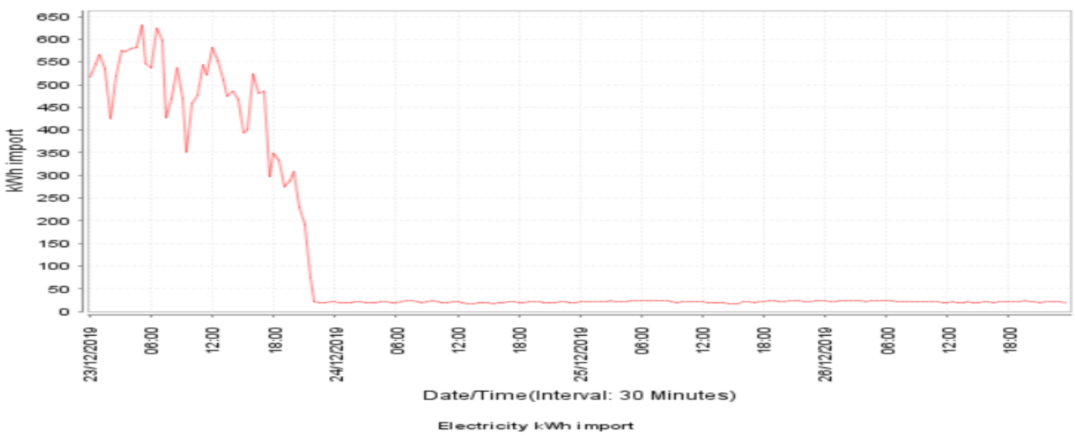

Figure 7.7: Gas baseload kWh consumed, Site F, Christmas Day night

It can be seen in Figure 7.7 that from analysis of one operating site, Site F, the Christmas gas usage was very well controlled with effective switch off procedures delivering a very low gas usage during periods of zero production.

This research proposes that the reduced baseload noted across the research study is as a result of the research outcomes delivered at sites and adoption of the EEF.

7.7.2.3 Relative Energy – kWh/Tonne

Energy was also considered in relation to production output. Changes in energy demand may be driven by increasing/reducing throughput and performance. Figure 7.8 and 7.9 shows the UK position across the research organisation showing kWh of energy consumed per tonne of production output.

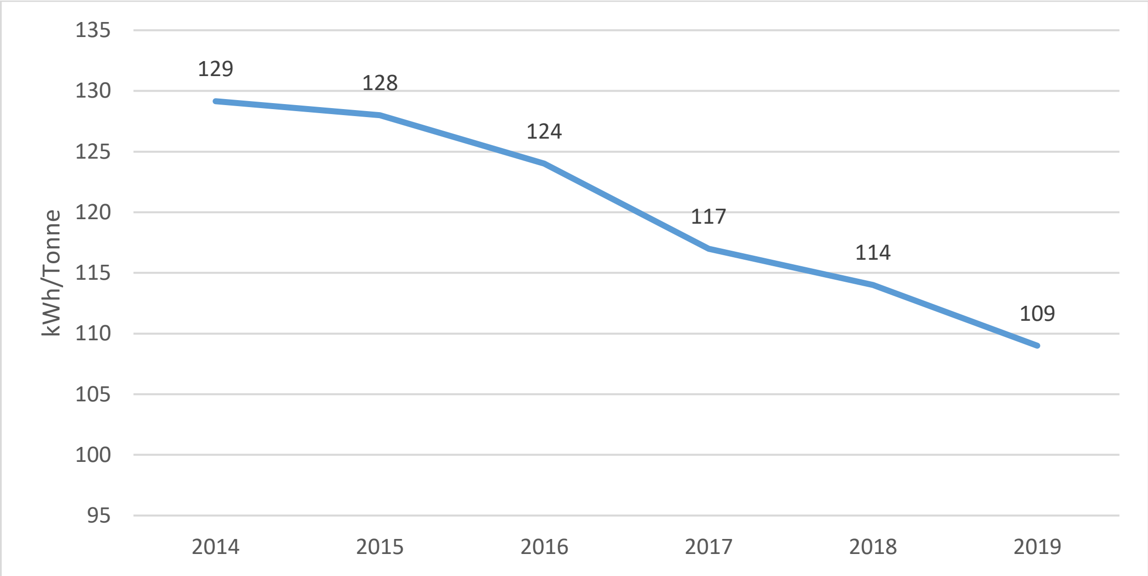

Figure 7.8 UK Relative Electrical Energy kWh/Tonne

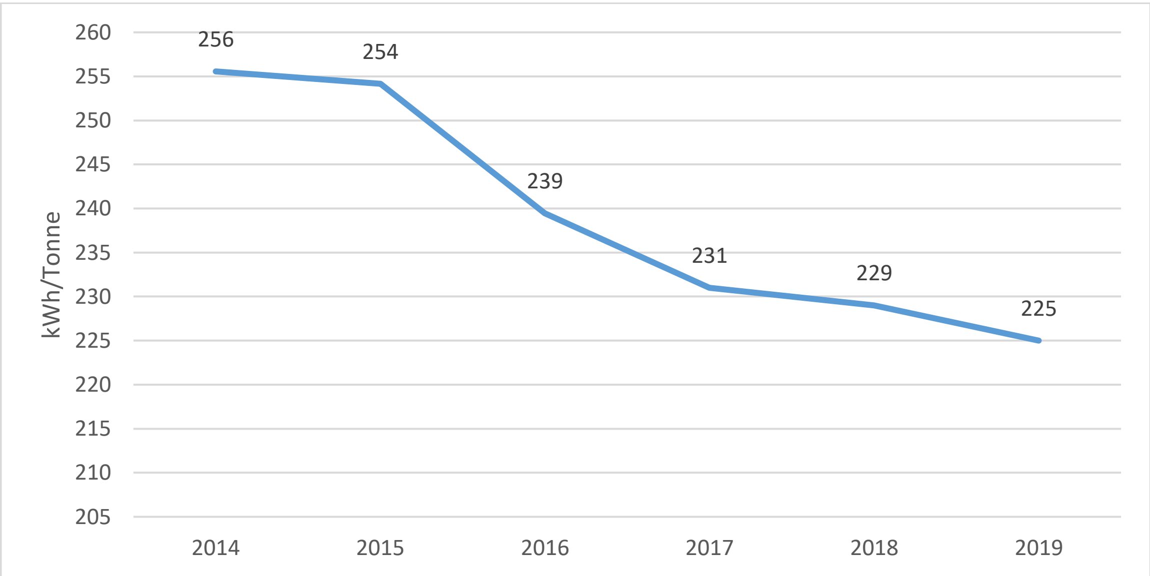

Figure 7.9 UK Relative Gas Energy kWh/Tonne

The research organisation during the period of the study had an increased production output through organic growth that was not considered significant in data analysis. It can be seen from Figures 7.8 and 7.9 that the relative energy performance has improved considerably during the research study.

The total gas and electrical energy / tonne has improved in both measures, requiring a lower kWh to manufacture a tonne of corrugated output. It is proposed this is due to the extensive research and the adoption of emerging elements of the EEF.

7.7.2.4 Absolute Energy – kWh

In relation to absolute energy consumed the data was reviewed to understand if with increasing demand the overall energy consumption of the sites was being improved through energy efficiency. Figure 7.9 shows the overall consumed MWh of electricity and gas from the start of the research study in 2014 as a base year.

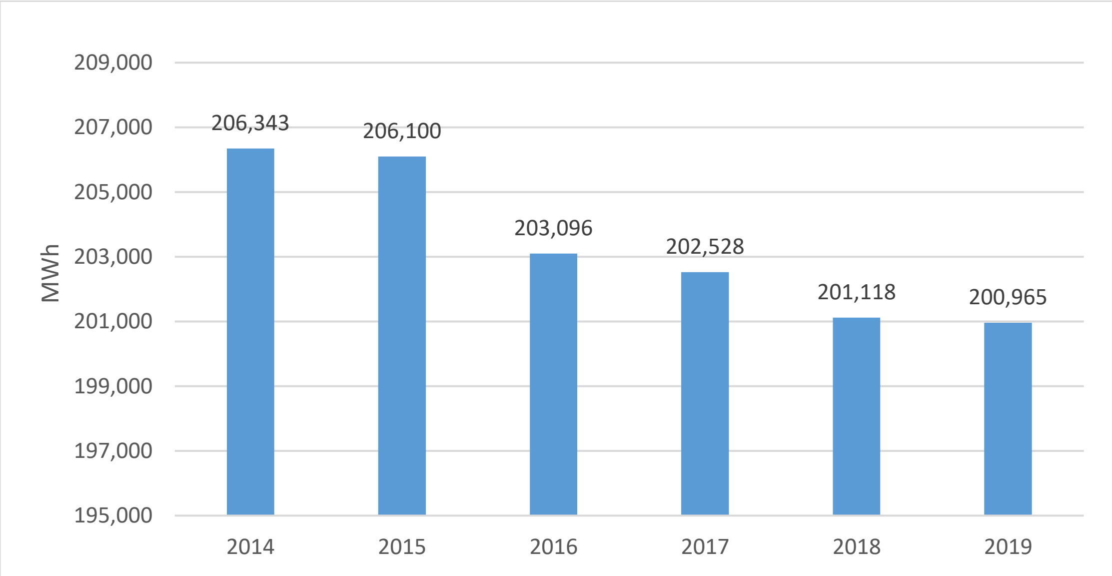

Figure 7.10: UK Absolute Total Energy MWh

The data shown in Figure 7.10 shows that whilst volume saw some organic growth the overall energy consumption at site was reducing. The research proposes increased energy efficiency is the reason for the reduction in absolute demand, with the energy efficiency improvements driven as a result of this research study.

7.8 EEF Levels - Renewable Energy

This research has provided a framework for the adoption of energy efficiency based around the Energy Technology Wheel implemented within the proposed Energy Efficiency Framework. In doing this the levels of the framework have been defined and constructed based upon observed data and findings.

One area of the EEF not covered in detail within this research is the area of Renewable Technologies. This area may be considered as more of a 'means of power supplied' as opposed to energy efficiency. It has been shown through the application of the FPM that such renewable technologies have extended payback periods. It is recognised that these calculations have limitations in that they are based on current equipment and installation costs and unit pricing.

In a report on green technology choices (United Nations Environment Programme, 2017) there are 8 demand side response technologies proposed that can support the goal of reducing global temperature increases. The findings from combined modelling show that for specific industries aspects of technology such as building insulation technologies, co-generation will play a considerable part in significantly reducing carbon emissions. This point is not in question by this research, however it would contend that the most appropriate starting point to reduce global warming is energy efficiency.

It is not currently recommended by this research that renewable technologies are implemented until all other stages of the EEF have been implemented. For completeness a short review of each technology is provided for reference. It is suggested that these areas represent future areas of further research study within the industry.

7.8.1 Solar Voltaics

The principles of solar voltaics (Solar PV) utilise semiconductors to convert solar irradiation to electricity. The output of electricity can be dependent upon a number of factors which include the amount and intensity of the sunlight, and where the plant / facility is located both geographically and in terms of south facing etc. From an initial study conducted during this research within the research organisation figures suggest that Solar PV has a headline payback period of around 9 years based on current data. This is outside the boundary period of return on investment of 7 years established as part of this research.

7.8.2 Wind Turbines

Wind turbines are dependent upon the wind velocity of the area in which the unit is sited and also the turbine technology installed. The movement of air rotates the propeller blades and in turn a generator creates electricity. In terms of efficiency wind turbines are highly reliant on wind speeds in excess of 22mph, these are not present at all times. As a result a variation in wind speed reduces the efficiency potential which was seen to be as low as 30% when the technology was considered within the research.

Consideration of the technology evaluated in the research organisation was that the turbine generates significant noise from the rotor blades and as a result is required to be sited away from local housing, often requiring advanced planning consent. Most of the research organisation sites would not accommodate the siting of such technology due to the location to nearby properties.

From comparative analysis carried out by this research it is suggested that wind has a typical return on investment of 11 years, which lies outside the boundary of the EEF.

7.8.3 Battery Storage

Battery storage can be used in conjunction with other green technologies such as Solar PV. In considering the application of battery storage a fundamental principle is that captured energy is at stored to be used at alternative times of the day. In corrugated operations there is an underlying demand for at least 16 hours a day if not 24 hours.

This means that variation in consumed energy will only enable stored energy to be utilised for a short period and to only be a part of the total site consumption. This means in reality batteries utilised would need to be very large and expensive. Typically charging losses can be in the region of 4%.

Payback for such an applied technology is suggested by this research to be above 10 years due to the high capital costs. This takes the concept of battery storage outside the five levels proposed by the EEF but still provides a future opportunity for energy efficiency.

7.8.4 Heat Pump

A heat pump utilises the principles of refrigeration in reverse. Refrigerant gas is evaporated / condensed to release heat. The technology utilises electrically driven compressors to achieve this. Efficiency is dependent upon the temperature of the water generated. Heat pumps have high capital and maintenance costs to consider and in evaluating such technology no use could be found for the generated hot water.

Due to the extended payback period and lack of usage for hot water this was not considered further. Where there is a high usage of low temperature hot water, such as in process related food manufacturing, this technology may be more applicable. Within corrugated manufacturing water is used at a low level for starch manufacture and the provision of utilities.

7.9 Summary

The EEF was constructed following many years of action research across corrugating sites. During this time and following establishment of the fundamental principles of the EEF its use was adopted across the research sites. The principles of technology, capital cost and return on investment have enabled a structured framework to evolve based on validated data.

The resulting Energy Efficiency Framework is simple in its approach, clear in terms of levels of adoption and proven from extensive research. As such its adoption will allow ease of implementation and speed of delivery in energy efficiency

The data presented by this research can be seen to be extensive, verified and current, having commenced its data collection process in 2015 and being completed in 2019. Other work reviewed in similar areas of energy reporting does not show specific corrugated reference or aligned process related energy efficiency savings.

The EEF has been validated through specific key measures which have been used for corporate reporting within the research organisation. These measures have been used to review the effectiveness of the research and the adoption of the EEF. It is clear to see the increasing levels of research activity delivering an increased energy efficiency improvement which is demonstrated overall in the reduction of carbon.

In reviewing renewable technologies it is suggested by this research that currently the technologies considered of solar, wind, battery and heat pumps are not applicable for current EEF framework adoption. These can be classed as higher level, with a high technological solution at a much higher capital cost with low payback. It may be that in delivering all proposed aspects of the EEF corrugating operations may consider a wider strategic investment around a renewable energy strategy deployment. This is suggested to be some way off due to the opportunities that exist at levels 1-5 of the EEF.

Chapter 8 Research Conclusion

8.1 Introduction

This chapter brings together and concludes the significant amount of research findings together with the objectives of the research programme. In doing this it provides justification that the aim of the research has been successfully achieved.

The chapter reviews the qualification of research objectives and demonstrates the theoretical contribution to knowledge made by the research. Finally the chapter provides evidence of the practical contribution of the research, highlighting a number of limitations and further areas of study.

8.2 Summary of research chapters

From the initial research outline through to finalised research outcome the study has provided a wealth of opportunities and research data to develop and build towards the final objective. In recapping, prior to concluding, Chapter 1 argued that climate change was a reality and Chapter 2 provided a detailed review of published literature.

Building on this Chapter 3 provided a clear methodology adopted from a philosophy of pragmatism, supported by an inductive approach based on an action research strategy. Chapter 4 provided an overview of the qualitative and quantitative approach to data collection and research.

Chapter 5 presented the development of the Energy Efficiency Framework (EEF) together with the Energy Technology Wheel (ETW). A structured approach to action research was established with the creation of the Factory Process Model (FPM). Detailed Action Research carried out across corrugated manufacturing locations was reported in

Chapter 6, with the findings of the EEF approach finalised and presented in Chapter 7. The result of the comprehensive research being the conclusion that the thesis structure and approach has delivered its overall aims and fully answered the research questions it set out to deliver.

8.3 Research aim and objectives

The research aim was to understand the application of energy efficient technology in relation to corrugated plant energy consumption. In doing this research set out to establish a validated energy framework for delivering structured improvement across the corrugated cardboard manufacturing operation within the research company.

In terms of the stated objectives the following summary provides a finalised position with regards to the progress and achievement towards the five research objectives;

8.3.1 Objective One

Review and investigate the literature on energy reduction and energy efficiency to identify gaps in knowledge to formulate and build a foundation for primary research.

The research has shown in Chapter 1, sub section 1.5.1, that a world leading manufacturer, Smurfit Kappa, has made significant progress in the area of carbon reduction and has a mature sustainability programme. This research concludes that there remain opportunities for further improvement in energy efficiency in corrugated operations. What is less clear is what to actually implement and how to do it.

It is concluded by this research that Climate change is real, affecting the world and having a detrimental impact on the planet as outlined and described clearly in Chapter 1, sub section 1.2. This is considered with regards specifically to the paper and pulp industry where energy intensive operations are considered in Chapter 2, sub section 2.3. Additionally the research argues in Chapter 2, sub section 2.4, that a lack of published work suggests there has not been any significant progress made in energy efficiency by the corrugated sector of the industry.

It is proposed from the review conducted in Chapter 2, section 2.5, that energy policies alone will not deliver carbon reduction. Whilst they provide significant focus it is suggested that they have little overall impact. Additionally energy standards provide direction but not a roadmap through the many different technologies which are described in Chapter 2, section 2.6.

It is possible therefore to conclude that if companies have a desire to drive energy and support carbon reduction that it is vitally important they understand what to do and in what order, a term that can be referred to as 'Technology Diffusion'. What has been argued through this research is that the first place to focus on is to drive energy efficiency and enable technology to assist in improving the efficiency of processes using power for manufacturing.

Objective one of the thesis was delivered through the Literature Review in Chapter 2, which defined a research gap. This was further supported by the use of a research survey and interviews conducted to better understand the key industry stakeholder perspectives. These were not easily available or published and research has added an important dimension with these perspectives. The survey was supported by the European Federation of Corrugated Manufacturers (FEFCO) and provided a significant insight into the perception and views of industry suppliers and manufacturers.

The research was able to conclude that there is a research gap within the corrugated industry, a view substantiated by the results of the FEFCO survey contained within this thesis. As a result this conclusion satisfied Objective One of the thesis enabling a clear foundation for primary research to be established.

8.3.2 Objective Two

Develop an initial understanding of energy consumption by equipment within operational sites and carry out primary research to review opportunities for the application of energy efficiency technology.

The objective of the research as proposed in Chapter 3, sub section 3.2.1, is to develop and establish a framework for energy efficiency that can easily be implemented in factory operations. To enable this a clear understanding of current state and operational activities needed to be researched. The research method applied (Saunders et al, 2015) in Chapter 3 section 3.3, enabled the research data to be obtained, evaluated and reviewed with a pragmatic approach to enable the framework development.

An understanding of the energy consumption was established which provided an action research study which enabled 'research in action', with an emergent view of potential application opportunities to be established. The research was conducted across 22 manufacturing plants in the UK and in detail within corrugating manufacturing processes. A mixed methods methodological choice outlined in Chapter 3, sub section 3.7, enabled both quantitative and qualitative data to be reviewed with a significant focus on observations and measurement of actual energy data obtained at plant level.

The research developed an understanding of energy consumption based across areas of the operation in Chapter 6. This included analysis of the equipment including the corrugator, conversion machines and utilities. Key areas of usage determined included gas energy for steam raising, electrical energy for the compressed air system and electrical energy for the waste transfer systems.

One aspect initially developed following a review of measuring models in Chapter 5, sub section 5.2.3 was the formation of a data modelling tool. Designed and developed during the research, the tool called 'Emap', was established to estimate and determine consumption and is available within the research organisation as a result of this research. Initially a simple spreadsheet system this developed into a much wider access database system, which was bespoke and specific to corrugated operations. This helped to forecast define and inform the later adoption of technologies at varying levels of application.

Different equipment was evaluated, such as motors and inverters, to determine an overall energy position forecast for equipment which could be utilised for comparative evaluation at other plants. From the review of energy consumed at sites typically the compressed air system might consume up to 15% of the site energy, with lighting up to 10% and converting equipment 30%. The research found that gas energy accounted for 40% of the energy consumed. The remaining energy was consumed on infrastructure and non-manufacturing activities.

8.3.3 Objective Three

Following resulting outcomes of objective two carry out a specific energy review across key factory sites to establish predictive improvements and implement identified improvement opportunities.

Having mapped the energy consumption at site level in fulfilling objective 2, it was then necessary for the research to go further and identify, from the technology study covered in Chapter 5, section 5.4, which specific opportunities were appropriate to be considered. The formation of the Factory Process Model (FPM), proposed in Chapter 5, sub section 5.3.3, enabled an emergent timeline to be researched where one site review of data and technology informed the next research activity in an inductive manner.

The development of this model provided a structured approach which was crucial to managing the research activity due to the complexity and divergence of material during the research study. By designing and implementing the FPM the research provided measurement of energy consumption in terms of consumed kWh on plant and equipment and identified energy saving opportunities. These were then implemented as part of the research over time and evaluated.

It can be concluded by the research that Stage 4 of the FPM, Validating Outcomes, enabled and informed a much wider research programme across multiple sites which ultimately provided the structure and development of the EEF. It cannot be understated that the active participation of the researcher in the key stages of the FPM has been acknowledged to have provided valuable research opportunities for the company and the industry. Additionally identifying further areas of study.

A significant programme of energy efficiency activity detailed by plant in Chapter 6, developed from the FPM process, was implemented during the research with the help and support of investment and forward thinking by the research organisation. Without this opportunity the definition and evaluation of potential technological solutions would have been more challenging and subject to a more theoretical research approach.

The delivery of the FPM enabled Objective 3 to be fulfilled in working towards the research goal. Having established technologies and measured the energy efficiency impact, Chapter 6 implemented the measures at site level delivering a predictive forecast and actual savings. This research shaped the EEF. It is argued by this research that the depth and detailed nature of the FPM process provided confidence to key stakeholders in enabling decision making processes, whereby investment was justified on delivered action research outcomes.

8.3.4 Objective Four

Having considered, predicted and implemented specific energy efficiency technology to reduce consumption within plants, deliver and evaluate the potential impact of these energy efficiency measures.

The considerable action research summarised in Chapter 6 provides the research evidence to substantiate delivering Objective 4. Using the ETW and FPM and applying it at individual sites projects were implemented against defined targeted savings. Each project was reviewed with a resulting improvement in forecast accuracy of energy savings. This enabled the establishment of efficiency levels and predicted savings which formed the basis for the establishment of the EEF.

In order to provide research breadth and depth corrugated sites were researched that included Sheet Feeding, Integrated and Converting plants as detailed in Chapter 1, section 1.6. This provided essential feedback to the impact of applicable technologies.

It can be concluded from the research presented in Chapter 6 that corrugated operations rely heavily on fossil fuel, natural gas, for raising steam on the boilers. This is the predominant energy consumption in terms of kWh consumed across sheet feeding and integrated sites. Whilst electrical energy consumed across all operations is lower but still considerable.

It has been proven by this research that areas of energy, with regards to gas and electricity consumption, impact carbon and cost in different ways. It is has been established that energy saving activity with regards to electrical consumption will deliver significant improvements in cost due to unit price. This research has shown that energy saving activity in gas will attract a higher carbon reduction improvement, with a much lower financial benefit due to unit price.

The research found that with regards to energy efficiency energy impacts carbon in very different ways. Whilst electrical and thermal technologies shown in the ETW improve efficiency they individually have a marked different impact on carbon due to the associated carbon conversion factors applied.

8.3.5 Objective Five

From the research design and develop a strategic framework that can be implemented across corrugated factories to drive energy efficiency.

With many varied and wide energy consuming applications within corrugated operations, the research was required to clearly develop an approach that would be impactful to deliver the research goals of energy efficiency and carbon reduction. The research identified and provided a number of technology levels that enable a prioritisation of technology, technology diffusion, to be adopted. From this items such as implementing approaches to reduce baseload are seen in Chapter 7, sub section 7.4.2, as having a very low technology level. Whilst much more complex solutions, such as renewable energy, have a very high level shown. This makes significant variation in energy efficiency approach makes technology selection a much easier process.

Additionally consideration was given during research to the implementation cost of the ETW solutions and also the defined savings derived from data validated in the FPM. These were established accurately from measured data and project costings in Section 2 of the FPM at sites. A significant amount of research data was established to define these factors in Chapter 6, however the EEF displays a simple hierarchal approach, based on levels, to articulate both cost and savings displayed in a pictorial perspective presented in Figure 7.4.

Whilst simple in its approach, the presentation of the EEF in Figure 7.4 provides the realisation of Objective 5 and in doing so delivers the overall research goal of providing a strategic framework for energy efficiency in corrugated operations.

This objective was achieved and formally recognised by the research organisation following the finalisation and presentation of the Energy Efficiency Framework to the research company Executive Committee. The EEF through detailed review and sign off procedures has provided validated savings and a justified level of return on investment. The creation of the EEF, based on the previous validated data, has been recognised by customers and by international trade bodies and its development and adoption is planned to set new standards within the corrugated industry.

In developing the EEF it has been presented that the research aim of enabling a validated energy framework for delivering structured improvement has been fulfilled. It is argued that the development, application and thesis findings provide evidence of meeting this important aspect of the research study.

8.4 Research Questions

The use of specific research questions shown in Table 1.2 were required due to the research gap reported in Section 8.3 that did not provide sufficient published referenced information. As a result the industry wide survey documented and recorded in Chapter 4 provided new knowledge and information specifically relevant to this research. Additionally the key stakeholder interviews, explained within Section 4.4.3, and summarised in Table 4.6, added to the significant creation of new knowledge within the research.

The research has provided the following answers in line with the research questions identified below;

No	Specific research question	Research Objective
1	What is current best practice in the area of energy defined from the literature review? **There is no defined best practice across the corrugated sector, however there is a significant amount of good practices suggested for the Paper Industry which do not align themselves with the corrugated manufacturing process.**	1
2	How might this defined best practice best be applied in the corrugated industry? **The process of Action Research developed suitable and applicable technologies which formulated the ETW and developed the EEF. The application of a technology diffusion approach provided clear guidance.**	1,2,3,4,5
3	What gaps are there in relation to corrugated manufacturing industry? **The research found opportunities for improvement in energy efficiency in purchasing standards and specifications. It also identified a desire for suppliers to be led by manufacturers in designing in energy efficiency. It was also noted there are no common reporting metrics across the industry.**	1,2,3
4	What is the current best practice applicable within the corrugated industry? **There was no current recognised best practice approach within the research organisation or within the corrugated industry. However the research would contest the adoption of the EEF and ETW provide good practices which are recognised as Best Practice within the research organisation.**	1,2

5	How can energy load be identified, evaluated and potentially reduced within the corrugated industry? **Whilst modelling of energy load and usage is commercially available, such systems do not provide ways to deliver energy efficiency only report what is used. Handheld equipment can easily be utilised to measure energy usage.** **The adoption of the action research cycle provides a significant number of examples whereby load has been identified, evaluated and reduced at corrugating sites within the research organisation.**	1,2,3,4,5
6	What energy modelling and energy efficiency techniques can be employed to establish the costs and benefits of any potential changes within the corrugated industry? **The research evaluated a number of modelling alternatives in Chapter 5. Many models were scientific and prescriptive focusing on usage across manufacturing. The benefits of technology adoption are proposed to be unknown until the formation of the EEF and corresponding savings shown in Table 7.4**	1,4,5
7	What specific range of technologies can be applied to formulate a best practice methodology for the corrugated industry? **From researched literature, survey and interviews the Energy Technology Wheel in Figure 7.1 prescribed applicable technologies that were tested in Action Research**	1,2,5
8	How can these be combined into a strategic modelling framework to be used throughout the corrugated industry to drive energy reduction best practice? **The ETW technologies and corresponding savings and return on investment are shown in Chapter 7 and formulated into the EEF shown in Figure 7.4.**	3,4,5

Table 8.1 Research Questions Answered

The research has been able to successfully address the research questions through its data collection approach explained in Chapter 4. The outcomes summarised in Table 8.1 provide support to the research objectives and contribute to new knowledge previously not established within the research organisation or across the industry.

8.5 Theoretical Contribution

This research provides a theoretical contribution to knowledge through the following aspects of the study:

- The development through research of a clear understanding of energy efficiency challenges across manufacturing sites and operations within the Research Company and corrugated industry.

- The development of the Energy Technology Wheel which has considered and shaped relevant energy efficiency opportunities for the specific corrugating and converting operations within the corrugated sector of the paper industry.

- The development and establishment of the Factory Process Model that has structured the process for action research that facilitated studies across 22 corrugated manufacturing operations in the UK.

- The design, development, validation and establishment of the Energy Efficiency Framework that has brought together the research and enabled a structured approach to develop best practice in the corrugated industry.

These contributions are clarified further in the sub sections that follow.

8.5.1 Industry wide

In terms of its theoretical contribution the research has established an industry wide understanding of views and opinions of key stakeholders previously unpublished or established detailed in Chapter 4. Research conducted through the research survey in this study provides the current reality in terms of industry thinking and outlook. The research survey feedback, detailed in Chapter 4, sub section 4.3.3.2, provides an understanding of the current trends and thinking of the corrugated industry. The research interviews conducted and detailed in Chapter 4, sub section 4.4.4 provide more specific insight into the level of activity and approach within organisations.

The survey responses inform a wide understanding of the industry perspective of the progress and development of energy efficiency within the industry sector. Prior to this research the views of industry bodies including, suppliers, manufacturers, customers and key stakeholders had not been presented. By researching this subject matter the degree of progress can be later measured through a follow up study. This may provide the opportunity for reflection and further evaluation of the best practice establishment and resulting change achieved from the research outcomes.

8.5.2 Energy Technology Wheel

The development of the Energy Technology Wheel (ETW), shown in Chapter 5, sub section 5.3.2, is a key contribution in delivering a theoretical approach to energy efficiency. The ETW in considering energy efficiency presents specific electrical and thermal energy efficiency technologies for deployment across corrugated operations.

These technology considerations are detailed and explained in Chapter 5, section 5.4, summarised to establish the ETW shown in Figure 5.2. This development of the ETW and FPM were reviewed and confirmed during action research in Chapter 6. There is a significant amount of equipment contained within a corrugated manufacturing operation. The ETW focuses on which technologies are appropriate and specific to corrugated operations, helping to develop an effective approach to energy efficiency.

8.5.3 Factory Process Model

In considering this research the establishment of the Factory Process Model, shown in Figure 5.3 within Chapter 5, provides a theoretical contribution to show how this research was constructed. The FPM is a step by step approach to investigation, evaluation, action and review to support research. It is proposed that the FPM is appropriate for similar organisations looking to adopt research across multiple geographic locations. The breadth and depth of the action research contained within Chapter 6 created many challenges in terms of resource utilisation, planning and organisational delivery. The FPM provides an effective approach to guide similar research and assist in ensuring an effective outcome to a potentially challenging process with multiple conflicting priorities and timelines. The four stages of the FPM and the corresponding feedback loop helped to construct a model that was delivered throughout the programme of action research. This made individual site investigations effective as they followed a structured approach, leading to the establishment of the data shown in Figure 7.8 within Chapter 7. This data and weighting classification was instrumental in establishing the finalised EEF.

8.5.4 Energy Efficiency Framework

It is proposed by this research that the most significant theoretical contribution is the establishment of the Energy Efficiency Framework, detailed in Chapter 7, Section 7.4. This provides a validated approach to the implementation of energy efficiency that can be adopted across corrugated manufacturing operations. This approach has not previously been established or published and provides a simple yet effective approach to energy efficiency based on a significant amount of research data.

The research was not able to establish through the Literature reviewed in Chapter 2, or from an industry wide survey and research interviews detailed in Chapter 4, that any previously established structured approach was in place to support the theory or implementation of energy efficiency in corrugated operations.

For organisations setting out on an energy efficiency journey the EEF prioritises the levels of technology diffusion. It is proposed by this research that it will help to drive step change improvement in a structured and effective way providing companies challenged by commercial constraints a route to improvement. For organisations already on the journey the theoretical contribution provides clear direction on when to consider longer term more complex technology application.

It is planned that following the publication of this thesis and subsequent published papers, together with conference and industry body presentations this EEF will play a large part in developing best practice across the industry. This it is proposed by this research will enable the established theoretical contribution to be applied to a more practical level shaping best development of best practice.

8.6 Practical Contribution

In terms of practical contribution of this research the first benefit derived from the study is a clear understanding of the attributable savings in energy efficiency from the technologies defined within the ETW which is shown in Table 7.7 in Chapter 7, sub section 7.4.6. The second practical contribution of this research can be demonstrated in the improvements generated and delivered in both carbon reduction and financial performance across sites demonstrated in Chapter 7, section 7.7.

8.6.1 Impact of research within the research organisation

As a result of the research presented the following resulting impact was observed within the research organisation and reflects the contribution made by this research.

- The development of the ETW, along with the validated savings shown in Table 7.8, enabled an informed discussion at research sites with key stakeholders. Whilst differing of opinions is a human factor of life, presented data removes ambiguity providing an applicable set of energy efficiency technologies depicted in the ETW.

- The research activity resulting from the application of the FPM created discussion and awareness of the use and measurement of energy consumed within manufacturing activities. It can be argued that this aspect of the research has created an interest in energy efficiency leading towards the development of a proactive energy efficiency culture that may influence human behaviour.

- The level of savings established provides validated evidence of the relative scale of potential energy efficiency improvements within corrugated manufacturing operations. These can be seen in Chapter 7, section 7.7, where validation of the research programme was delivered in establishing the EEF is demonstrated. These are directly measurable and it is clear that during the research programme key metrics of carbon emissions, baseload and relative energy have all been positively impacted.

- During the research carbon emissions dropped by 32% during the period 2014-2019 within the research organisation. It is recognised by the organisation that this is as a result of the impact of the research. Additionally relative energy, presented in Chapter 7, sub section 7.7.2.3, saw significant reductions in both electrical and gas kWh/Tonne of product. Due to confidentiality financial savings cannot be divulged, however the research organisation targeted return on investment of 3 years and below.

8.6.2 Research organisation findings

Within the research organisation the following further practical contributions were established and delivered.

- The Energy Efficiency Framework (EEF) detailed in Chapter 7 was found to be easily interpreted by those individuals and sites who were involved in the action research in Chapter 6. During the later stages of action research the framework was able to demonstrate to potential users an appropriate approach containing a simple and easily understandable solution that was seen to be quickly assimilated into action plans.

- The EEF, shown in Chapter 7, section 7.6, identifies the level of technology on a scale from ‘low’ to ‘high’ based on energy efficiency savings delivered. Behind the simple structure of the EEF are validated savings levels, shown in Chapter 7, sub section 7.4.4. These have been demonstrated and confirmed following the extensive action research in Chapter 6. The prioritisation of energy efficiency projects was found to provide practical support in terms of management time and investment prioritisation.

- Investment costs have been determined during the action research through the Factory Process Model (FPM) and validated against forecasted and delivered savings during Stage 4 of the applied FPM in action research at sites to justify return on investment. This has enabled EEF projects to be implemented without further justification as the approach has been proven to be acceptable, providing confidence in the solution and corresponding level of savings generated.

- The EEF framework proposes projects up to an including Level 5, shown in Figure 7.6. The research does not propose that the boundary technology of combined heat and power (CHP), discussed in Chapter 6, sub section 6.12.2 is applicable for the corrugated industry at this stage. It has been shown through action research the focus of the EEF provides energy efficiency projects with a payback of lower than 5 years as shown in Figure 7.4.5. In Chapter 6, sub section 6.12.2, a CHP study concluded that for corrugated operations CHP provides a payback of above 5 years. It is suggested by this research that the focus of the EEF should be at Levels 1-5 and all energy efficiency projects at this level should be implemented before longer term payback projects are considered.

Having been developed as a result of this research the EEF framework is now implemented across the research organisation. This has been presented to the Smurfit Kappa UK Executive Committee and utilised for briefing and development of awareness at all levels of the organisation. As a result the application of the EEF now requires no further validation or justification to support effective decision making processes.

8.6.3 Recognition of research findings

To further demonstrate the practical contribution of this research an objective view of key stakeholders was taken. Individuals from the research organisation and also from the wider research group, together with industry experts, professional industry bodies, suppliers, customers and industry leaders were asked for their views on the business considerations of the research. Their views have been noted within consent given for identification and inclusion within the thesis. The following individuals are acknowledged for their contributions and feedback are shown in Table 8.2.

Feedback from	*Position*	*Company*	*Role in research feedback*
Dan Moynihan	Country Technical Director	SK UK Corrugated	Key stakeholder and research sponsor
Peter Sweeney	Site Engineering Manager	SK UK Corrugated	Enabler and functional manager
Chris Sims	Site Energy Chamption	SK UK Corrugated	Supporter and potential user of EEF
Marc van Damme	Chairman - Production Committee	FEFCO	Industry Leader
Clive Bowers	UK CEO (Since Retired)	SK UK Corrugated	Strategic Leader
Graham Crowson	Site Operations Director	SK UK Corrugated	Operational Leader
Steven Stoffer	VP of Sustainability	SK Group	Strategic Leader
Walter deScmidt	VP of Operational Excellence (2019)	SK Corrugated Europe	Strategic Leader
Rob Fenwick	Chief Operating Officer	Howdens	UK Industry enabler
Ian Bailey	Managing Director	TPS Limited	UK Energy Expert
Mike Clements	Managing Director	TCS Limited	Supplier and Industry Expert
Blaise Ford	Managing Director	IDS Limited	Supplier and Industry Expert
Andy Burrows	Divisional Director - Integrated	SK UK Corrugated	Strategic Leader
Marten Dubbleboer	Energy Champion	SK Benelux	Enabler and functional manager
Frans Melisse	Country Technical Director	SK Benelux	Strategic Leader

Table 8.2: Key stakeholders involved in research feedback

The research study centred around the UK operation and in discussion with Dan Moynihan, UK Country Operations Director, he commented that '*an extensive study into energy efficiency in the UK has delivered at a strategic level, an environmental level and an industry level. Not only has the research shaped future thinking, but the knowledge provided has actively delivered significant benefits*.'

During Stage 2 of the FPM implementation it was commented upon by Graham Crowson that '*How can this approach not drive significant improvement and save time, money and effort from deciding which energy technology to apply*.'

During the development of the early stages of the framework Peter Sweeney, Site Engineering Manager at one of the research sites suggested that '*the framework will provide individuals with a clear route to energy efficiency, where everyone thinks they know what to do but can now be much better informed of really what to do to deliver energy efficiency*.'

During the research Chris Sims, Energy Champion at a local site, suggested that what we really need is a way of helping us do the right thing. Having reviewed the outcomes Chris commented that '*we can now focus on the right things, knowing that the business will accept the approach and stopping people reacting to the latest new idea just on the market.*'

In developing the research study with FEFCO Marc van Damme commented that '*Such a framework could move the industry forward, engaging suppliers and customers into a longer term energy efficiency approach.*'

During the course of the research a significant number of opportunities to present findings and discuss opportunities and research direction were provided by the research company. The UK Corrugated CEO in 2019, Clive Bowers, commented that '*the study had not only provided strategic direction, but it had actively driven significant benefits from its application already*.'

The application of this research across the wider European operational plants was evaluated by Walter de Schmidt who commented that '*with such a framework in place this provides the opportunity for a best practice approach to deliver our carbon reduction commitments across Europe*.'

The research company has a stated objective that within the corrugated operation it is committed in identifying opportunities for energy reduction at its key operational sites across Europe. The research findings were presented to Steven Stoffer Vice President of Sustainability within Smurfit Kappa Group. It was suggested by Steven Stoffer that '*such an approach will not only drive energy efficiency, it will engage others in the journey and provide a route to energy efficiency and driving carbon reduction*.'

In discussions with industry experts Ian Bailey commented that '*many companies approach energy efficiency based on what seems right at the time. This grounded approach provides a new direction that will enable a more effective approach to energy efficiency to become accepted practice*.'

Upon completion of the finalised EEF a number of conversations presented themselves with industry wide suppliers and energy experts. These proved valuable as often these individuals are faced with organisations looking to deliver energy savings.

Mike Clements from TCS Limited commented that '*The EEF provides a simple, logical and factual approach to delivering energy efficiency. It removes the uncertainty and provides focus and direction which is often lacking*.' Whilst Blaise Ford from IDS Limited said '*The approach removes any mis-understanding on energy efficiency and provides a structured approach that can't help but improve energy efficiency*.'

The EEF framework was presented to a number of the research organisations key customers who have taken the research outcome and have strongly committed to using the recommendations across their business. During the presentation, Rob Fenwick, Chief Operating Officer of Howdens Joinery Co. commented that '*I can see how the realisable benefits of the approach could deliver significant energy efficiency for our business in cost effective and timely structured manner.* '

The EEF approach was presented to a virtual meeting of UK Senior Operational Leaders in October 2020 and was recognised as a key enabler in supporting future energy efficiency by all those on the call. It was commented upon by Andy Burrows '*the EEF could potentially be developed to help General Managers with a simple prioritised self-assessment approach*.' This was seen as important due to COVID 19 site access restrictions and the EEF was subsequently developed as an energy efficiency tool with a self-assessment checklist approach.

During the final stages of writing the thesis there was a virtual meeting with Smurfit Kappa European team members to discuss energy saving within Europe, specifically within the Benelux area, including Belgium, the Netherlands and Luxembourg. The meeting presented the research outcomes and the EEF framework for consideration. It was noted by Marten Dubbelboer from the Benelux team that '*the approach was easily understood and had not previously been considered within the Corrugated Europe* *division. The stages of technology diffusion show a route to developing a local energy efficiency programme*.'

During the same meeting in November 2020 it was commented on by Frans Melisse, Benelux Country Operations Director that '*the EEF will change the focus and direction of the previous thinking across the Benelux area and will save a considerable amount of time, whilst driving considerable savings*.' It is felt that such discussions demonstrate the true value of the research programme and justify the investment in time completing the study.

It is proposed that the overall aim of the research has been met in full and delivered having presented the research to the very top level of the research organisation. In a presentation to the SK UK Executive Committee in 2020 the strength and efficiency of the proposed approach was acknowledged. It was commented on that a considerable amount of work and effort has justified what is a very clear framework to undoubtedly drive significant energy efficiency across the research organisation and the industry.

8.6.4 An approach to develop Best Practice

In Section 1.7.6 the research considered what constitutes best practice and set out to provide a framework and process that would provide good practice. During the course of the research the Energy Technology Wheel and the Energy Efficiency Framework have become adopted by the research organisation following the action research conducted extensively in Chapter 6. Here good practices were developed, adopted and evaluated to formulate the framework along with defined levels of savings.

In recognising that time and maturity plays a part in establishing Best Practice, the research company now recognises and accepts that the EEF provides a working method that is officially accepted as being the best to use in terms of delivering energy efficiency in the corrugated operations (Moynihan, 2021).

This has been demonstrated and measured in terms of a streamlined consistent approach that has delivered significant improvements in key metrics in Section 7.7. By definition and application it is proposed that the research set out to achieve good practice and has succeeded in delivering best practice within the research organisation.

8.7 Research Limitations

The research has provided quantitative and qualitative supporting information to the primary research conducted through action research. Whilst this was considerable in scope the information can only be related directly to those plants, individuals consulted and equipment researched. It is proposed that the scale of research and the similarity of manufacturing operation provides evidence to support industry wide validation of the results.

During this research the aspect of culture and human interaction with regards to energy efficiency has been noted. This research has adopted a technological approach to improving energy efficiency through the elements of the Energy Technology Wheel. Where such technologies interact with people it is proposed there will remain a challenge of culture versus technology which may need to be overcome.

The improvement in energy efficiency delivered through this research may be dependent upon the starting point for improvement. Plants that are actively pursuing energy reduction may already benefit from the existence of certain technologies. The starting point to the journey may be different but the energy efficiency benefits achievable are still relevant and justifiable.

The savings defined within this research are based on current levels of equipment and technology advancement. As new and more innovative energy efficiency measures are developed and introduced onto the market it may become necessary to revisit the framework determinants. Based on this research and industry knowledge it is expected that this will not be required for at least five years.

The research considers the current industry perspectives of original machinery manufacturers involved in the survey conducted. This research has established that there is a lack of defined energy efficiency standards for purchasing equipment. Whilst this remains improving corrugated energy efficiency performance will be a challenge and will always be considered as a retrofit as opposed to a designed in feature.

8.8 Proposed areas of further research

This research, whilst extensive and of a detailed nature, recognises and has referenced during the thesis, that there are many other areas of potential further work. These areas can influence, improve and may even be barriers to energy efficiency improvements. These are considered within the following areas of people, standards, measurement, and technology advancement.

8.8.1 Leadership, engagement and motivation

Aspects of engagement, motivation and support have been practically considered and touched upon in this research study. It is suggested, whilst not actively researched, that this area provides a significant opportunity for improvement towards energy efficiency. For energy efficiency to be sustainable it is suggested that the interaction with people is at the heart of truly delivering progress.

A question posed by the research is can energy efficiency be achieved without behavioural change and what impact does culture have on energy deployment? These are suggested to be unanswered areas for further research which would advance the opportunity for further energy efficiency improvements.

It is proposed by this research that the aspects of engagement and motivation are considered further in relation to behaviour and cultural approach. Such a study would support this thesis, which is technological in its approach, in adopting an aligned research outcome.

8.8.2 The role of 'Standards' in energy efficiency

This thesis has identified and touched upon 'Standards' as an area of opportunity in improving energy efficiency. But the question of can they, and would they and even how could this be achieved is suggested to be left unanswered. Where such standards are applied this research would question how their success will be measured and compared and contrasted to drive improvement.

8.8.2.1 International standards

During the course of this study standards such as ISO 50001, ISO 14001 and articles including the COP standards referenced in Chapter 2 were considered and reviewed. Reference is made to published studies which prescribe to adopting such standards to drive energy efficiency.

This research has been unable to determine if such standards drive improvement. Paper mill operations were reviewed during ESOS audits conducted internally during the research period. The adoption of ISO 50001 and ISO 14001 were established and in place, however energy efficiency improvements were still highlighted as an area for opportunity. It is proposed that a further research study is carried out into the impact derived from the application of such standards, specifically for the corrugated industry. This would better inform the benefits and help support the take up of such standards.

8.8.2.2 Supplier standards

An area that this research proposes remains a challenge to the industry is the creation and adoption of an energy standard that brings together suppliers, manufacturers and corrugated producers. For energy efficiency to be maximised it is suggested there is much work to do.

A wider industry body such as the Federation of European Corrugated Manufacturers could support work in this area and further academic research could provide new knowledge regarding how such standards do or do not improve energy efficiency.

8.8.3 Measuring improvement

The research found from Annual Reports reviewed in Chapter 2 that there is no standardised approach to energy efficiency reporting. As a result it is suggested that there is no industry driving force for competitive improvement and benchmarking. Whilst individual organisations provide year on year analysis, each report represents data slightly differently.

It is proposed that the development of standardised energy efficiency reporting metrics may provide an area of opportunity. Whilst this would be more practical in its application, the actual progress made whilst using comparative analysis would provide a useful research study. It may well be that such an approach would be time consuming and administrative in nature. It is proposed that research should be carried out to review the potential for reporting to drive improvement in energy efficiency.

8.8.4 Technological advancement

This research has considered levels of energy efficiency up to and including that of 'Combined Heat and Power' (CHP). It is proposed that further detailed research is carried out to look at the industry advantage gained from the application and usage of such an energy source.

The scope of the research did not encompass renewable technology, and as such this technology could be further developed in terms of its suitability and application within the corrugated industry. There is active work on this subject in the research company and further publications/reviews would add to the industry knowledge.

8.9 Beyond 2020 – Zero Carbon approach

Whilst discussed internally within the research organisation during research, the aspect of adopting a zero carbon approach specifically to the corrugated industry has not yet been considered. No research has yet been established and no published literature was currently available. It is contested by this research that such a published study and approach could significantly transform the industry and is an area of currently untapped research being considered within the research organisation.

In an internal published document by Smurfit Kappa in 2020 a new carbon target was announced by Tony Smurfit, Group Chief Executive. In the statement it reports that 'We are proud to support the EU Green Deal objectives to reach net zero emissions by 2050. We have made good progress on our existing targets and these new targets underline the organisation's continued commitment to sustainability and to do better for the planet.'

8.10 Summary

The chapter has summarised and presented the research conclusions. The research objectives have been considered and evidence presented to meet the research aim.

Whilst research was primarily within the research organisation, an industry wide understanding and recognition of the research has been achieved which has already shaped the industry with a project commencing to develop supplier energy standards for equipment.

It is proposed by the extent of the data presented and the feedback presented in stakeholder comments that the research has delivered a significant theoretical and practical contribution to energy efficiency.

It is recognised (Wilkins et al, 2019) that a PhD must always make an original contribution to knowledge, although what constitutes the notion of originality has been debated since the 19th century and the question of what constitutes knowledge has occupied the world's greatest thinkers since Plato.

For the purpose of this study, originality is defined in terms of "accepted prior knowledge and new discoveries or ideas" (Clarke & Lunt, 2014). In terms of knowledge that is known (Grant, 1996) and new knowledge as that were not known previously (McFayden & Cannella, 2004).

Research limitations have been considered and presented along with areas of further study. It is suggested from the research experience that the area of people engagement and behaviour with regards to energy and sustainability provides the largest challenge and would constitute a suitable and appropriate are of further research. If people do not change and embody energy saving behaviours it is suggested energy saving measures will not be sustainable.

In delivering a clear and substantiated contribution to new knowledge the two key questions asked in Section 1.1 related to the research aims and objectives are summarised below:

8.10.1 What do we know now that we did not know before?

- The current reality of energy efficiency practices and processes within the research organisation is clearly defined and understood.
- The corrugated industry can be considered an area for improvement in energy efficiency from the research and lack of published material in the sector.
- There is now a defined number of energy technologies depicted in the Energy Technology Wheel for the research organisation within the corrugated industry
- An applicable Action Research process has been developed and adopted within the Factory Process Model for the research organisation.

- Through the process of action research a clear structured approach to delivering energy efficiency has been established.

8.10.2 What can we do now that we couldn't do before?

- Follow a structured programme of energy efficiency activity with a prioritised approach to deliver technology diffusion.
- Understand the level of savings applicable from each energy efficiency technology when applied to manufacturing processes within the research organisation.
- Remove the uncertainty about marketing led investments into energy efficiency and save resource time and money.
- Deliver focussed investment to improve energy efficiency and reduce carbon in a cost effective manner optimising the return on investment and focussing on the 'right choices'.
- Implement a programme of energy efficiency across multiple plants that has demonstrated the delivery of significant savings which can be replicated in similar plants across an international manufacturing operation.
- Prove to stakeholders that energy efficiency in corrugated operations can deliver significant reductions in carbon, cost and engage the workforce in the morale challenge of supporting sustainable manufacturing operations.

In finally concluding this research it is argued by this research that the study has provided an opportunity for corrugated manufacturing operations to significantly improve energy efficiency, thereby reducing carbon emissions. The implementation of the Energy Efficiency Framework will provide technology choice and prioritisation. The research data has provided the organisation with the confidence to make timely decisions to pro-actively drive energy efficiency.

Epilogue

The research has developed a framework that I strongly believe and propose will lead to the establishment and adoption of a best practice approach within the corrugated industry. This has been recognised and acknowledged by key stakeholders.

In doing this research I have targeted and achieved a structure for defined technology diffusion within corrugated manufacturing operations. The adoption of the framework by others cannot be considered as simply a task to deliver. I would contest that the framework deployment should be considered as a journey towards sustainability and reducing the environmental impact of corrugated manufacturing within factory operations.

I would conclude from the research that there are many opportunities arising from the study to disseminate the knowledge to a much wider population and in doing so establish a pathway for improvement. There is an appetite for improvement that could benefit from such an approach across the industry, the question is how and who could make this a reality.

It has been suggested by Drucker in a book by Cohen (2009) that the best way to predict the future is to create it. The research provides an opportunity to create a pathway to energy efficiency for the industry, whilst establishing an approach that supports and delivers an ongoing programme of energy efficiency improvements.

In considering the outcome of this research in conjunction with the vision of Microsoft reported by Gregory (2019), its mission is to empower every person and organisation to achieve more. I believe that this study provides the approach to make such a vision a reality in relation to energy efficiency within the corrugated sector. I have often heard suggestions that we are not sure what to do, or what it might even save us. I would suggest that these barriers can be overcome by utilising the theory of the EEF and its practical deployment.

A question that I could pose is why companies and individuals wouldn't act when they know what issues the world faces on environmental management. At the COP24 (2018) People's Seat Address in Poland Sir David Attenborough stated that *'We're facing a man-made disaster of global scale, our greatest threat in thousands of years - climate change'*.

Attenborough also went onto say that '*If we don't take action, the collapse of our civilisations and the extinction of much of the natural world is on the horizon.*' I would propose that such words are motivation enough for climate action and not just discussion.

In the research I have proposed that a cultural approach needs to be developed to support the adoption of energy efficiency behaviours. In the research organisation a programme named 'Protect their Future' was created. This focussed on saving the planet for our children and our children's children. I would suggest that this is a shocking reality of what the future needs to hold and how the world needs to change. The research has shown that technology can improve energy but I would go further to suggest that people and their behaviour will drive sustainable improvement in energy reduction.

At the United Nations Climate Change Conference in Madrid COP25 its Secretary General, Antonio Guterres (2019) stated that '*the decisions we make here will ultimately define whether we choose a path of hope, or a path of surrender*.' I would suggest that the framework delivered by this thesis helps industry choose the right path, one which improves energy efficiency and reduces carbon emissions.

I would propose that the future of our world can be improved by the actions that we all take, importantly taking these decisions later will not help. The world is changing, for the worse as a result of the past, yet we have a responsibility to shape the future. I would propose it is the duty and responsibility of academic research and such studies to promote energy efficiency and support a much wider globalisation of planet protection.

Throughout this journey I believe that a lot more can be done to improve energy efficiency and reduce carbon emissions. In my role within industry over forty years this is a value I have always upheld and I believe my actions have supported this belief. If my work is able to share this belief and help others along the way then this research will have supported academic and business improvement.

I would propose that the research has definitely achieved the acquisition of new knowledge within the academic arena. I only hope that this will also apply to industry and I will strive to support this goal following the research publication.

When I set out on this research I had an active role as an industry player within the Smurfit Kappa organisation. I have been fortunate to be supported throughout by access to research opportunities and I have also experienced many keen and eager energy efficiency supporters. As a leader there is a responsibility to lead, engage and develop awareness, whilst supporting this with actionable steps and a successful outcome. I believe the research has achieved in all areas of its objectives, but as a good friend Gary Stafford said at the start of the thesis, '*If all else fails don't forget to turn the lights out when you leave.*'

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2015-2020

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