Department of Mechanical and Aerospace Engineering

Quantifying the energy used in an asphalt coating plant

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A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2012

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Signed: Iain E Gillespie Date: 6 September 2012

Abstract

Contained within this thesis are the results of an investigation into energy use at an asphalt coating plant based in Scotland. The aim of this project was to identify and quantify the influence of factors that affect the energy use in asphalt production and to develop a tool that can be used to estimate the energy use for the production of asphalt mixes. Regression analysis was undertaken on historical sales and metering data to determine which factors influenced the energy used in the production of asphalt mixtures. The key independent variables identified included material quantity and the number of plant starts. The resulting estimation formulas for both kWh and litre fuel usage were then integrated into a tool to allow energy and carbon emission estimations to be produced for a given tonnage and number of plant starts.

The key finding is that the electrical consumption, fuel use and carbon cost was calculated as 8 kWh/tonne and 9 litres/tonne with a resulting estimated carbon emission of 28.8 kgCO_2/tonne. It was also found that it is more economical to have a daily plant throughput of at least 100 tonnes at the coating plant. The effect that sand moisture has on energy use was analysed and the results showed that fuel consumption increased by an average of 0.6 litres/tonne for each 1% increase in moisture content which equates to a carbon emission increase of 1.5kgCO_2/tonne. The impact that aggregate moisture content has on energy use was estimated as an average of 0.7 litres for each 1% increase in moisture content which equates to an estimated increase of 1.8kgCO_2/tonne.

The results of this thesis show the importance of understanding energy use and identifying areas where energy and associated costs can be reduced. Reducing energy consumption also reduces related carbon emissions which is important to organisations that are part of the CRC Energy Efficiency Scheme and its associated financial drivers.

Acknowledgements

I would first of all like to thank Dr Paul Strachan for his assistance and guidance during this project.

At Barr Limited I would like to thank Sheikh Muhammad Ali for his support and information. Additionally I would like to thank Bill Weir for his in-depth knowledge of the coating plant and of the factors that affect energy use. Finally I would like to thank Geoff Hewitson for his valuable coating plant information and patience in the early stages of the project.

Importantly I would like to thank my family and friends for their advice and continued support.

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1 Introduction

The drive for energy and CO_2 emission reduction is both economic and environmental, although driven by international organisations and agreements it falls to governments to implement environmental agreements. This then filters down to companies who have to implement energy and carbon reduction measures. In modern industry the amount of CO_2 emitted is becoming as important as direct energy costs due to the move towards monetising carbon emissions.

With an increasing amount of the world’s final energy consumption being used by industry measures are being undertaken to reduce this energy usage through such measures as improving energy efficiencies. Reducing energy use will benefit industry financially, reduce associated carbon emissions and reduce fossil fuel dependence.

The scope of this analysis is to investigate and quantify the direct energy costs of an asphalt coating plant located in Scotland which is operated by Barr Limited. The energy associated with the mining, crushing, processing and transport of aggregates to the asphalt coating plant are not included in this project. This larger scope has been previously undertaken in a project which investigated the embodied carbon content of asphalt produced at Barr Limited (Gibson, 2011).

Energy reduction in asphalt coating plants is not a well researched topic and has few published papers. This may be due in part to the previously lower cost of energy; however with rising energy prices and focus on associated carbon emission this topic is now receiving the attention of the asphalt industry.

2 Literature Review

2.1 Materials

As this project thesis is concerned with the quantification of the energy used in the production of asphalt it is appropriate to consider the materials which comprise modern asphalt and then to discuss the types of asphalt before moving onto asphalt production. Asphalt plant energy reduction techniques will then be covered and then the topic of energy management and statistical analysis will be discussed.

2.1.1 Aggregate

Aggregates are widely considered to be inert materials; however, they are not as their characteristics can change over days, months and years. For instance when certain aggregates are wet they can lose up to 50% of their strength when compared to a dry sample (Hunter, 2000).

Aggregates for use in asphalt production can be broken down into three main groups. With the first group being naturally occurring aggregate which are composed of four types which are igneous, sedimentary, metamorphic, or sand and gravel. Natural aggregates include aggregates produced from quarrying, excavating from land deposits and dredging from rivers or marine deposits (Hunter, 2000). In the UK the igneous, sedimentary, metamorphic rock types are crushed to produce aggregate for use in the construction industry (MPA, 2012) (Pike, 1990). In the UK crushed gravels are excluded for use in asphalt production (Hunter, 2000).

The second group of aggregates are artificial aggregates which for example can be the waste material from steel production or other manufacturing processes. In the UK the main use of synthetic aggregate is to create hard wearing high friction surfaces with an increased prevent skid resistance (Hunter, 2000).

The last group of aggregates are those that are recycled. Historically in the UK there has been little interest in recycled aggregate however due to an increased awareness of environmental issues and technological improvements this final group is becoming a major source of aggregates. One factor that has to be considered in recycled aggregates is whether they still retain enough strength after up to 30 years of use (Hunter, 2000).

The demand for aggregates in the UK is typically around 205 million tonnes per year with construction utilizing around 90% of this amount. Fortunately aggregates are plentiful in the UK which means that local needs are met with local supplies. This is fortunate as aggregate costs double for every 30 miles that they are transported (MPA, 2012).

An important aggregate property is gradation which is the distribution of aggregate particle size expressed as a percentage of the total aggregate mass. Gradation of aggregates is achieved using sets of sieves and will be covered in more detail below. Gradation is considered one of the most important aggregate properties as it has a large impact on processes that use aggregate such as Hot Mix Asphalt (HMA) plants, and the resulting asphalt. Tightly packed aggregate consisting of various particle sizes that leave few voids between particles results in little or no air voids between the aggregate. This leaves little or no room for the bitumen binder however if the gradation is poor in the aggregate mix this will lead to large air voids. The resulting asphalt will be too weak and more bitumen will be used to bind the aggregate (Roberts et al., 1991).

Aggregates are graded dependent on their size which is done post crushing by passing the flow of aggregate material over upper and lower sets of limiting sieves. British Standard BS EN 13043 specifies aggregate properties and nomenclature which includes their geometrical properties, mechanical and physical properties.

Aggregate sizes are detailed in the first part of the aggregate description and take the form of the dimension of the lower limiting sieve (d) and following a forward slash the dimension of the upper limiting sieve (D). The ratio between the upper and lower sieves must not be less than 1.4. The next part of the aggregate description details the grading which is either coarse (G_C, D > 2mm), fine (G_F, D < 2mm) or all-in (G_A, D < 45mm & d = 0). The last part of the aggregate description details the allowable percentages of aggregate that are allowed to pass through the respective sieves. The first part of this description details the minimum percentage of aggregate that can pass through the upper limiting sieve (D), and this percentage can only be 90% or 85%. The figure following the forward slash is only for coarse aggregates and details the maximum allowable percentage of aggregate that can pass through the lower limiting sieve (d), and this percentage can be 10%, 15%, 20% or 35%. The lower limiting sieve (d) is zero for all-in aggregates (BSI_a, 2009), (MPA, 2003), (NORTHSTONE, 2012).

Shown in Figure 1 below is the description for a 20mm single size aggregate.

FIGURE 1 BS EN 13043 AGGREGATE EXAMPLE DESIGNATION

Source (NORTHSTONE, 2012)

In the UK the aggregate sizes are obtained through using the basic set of sieves with set 2 which results in the aggregate sizes shown in Figure 2 below. As shown fine and coarse aggregates are split at the 2mm size (MPA, 2003).

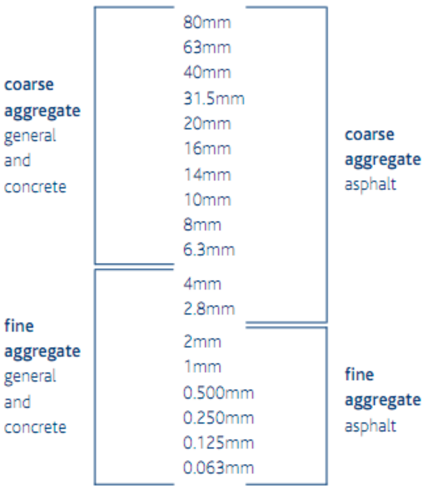
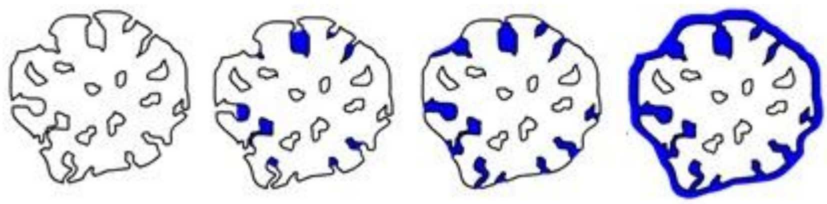


FIGURE 2 UK AGGREGATE SIZES

Source (MPA, 2003)

Another important material quality of aggregates is their moisture content which can be generalised as one of four conditions shown in Figure 3 below.



Oven-dry (OD) Air Dry (AD) Saturated Surface Dry (SSD) Wet

FIGURE 3 FOUR AGGREGATE MOISTURE STATES

Source (PI, 2007)

The first condition is when the aggregate is oven dry which means that the surface pores of the aggregate are void of moisture and the aggregate is fully absorbent. This condition is achieved by drying the aggregate at 105°C in an oven. The second condition is when the aggregate is air dry meaning that the aggregates surface has no moisture however pores connected to the surface are partially filled with moisture. In this condition the aggregate is slightly absorbent. The third moisture condition is when the aggregate is saturated surface dry which means that the surface is dry however all pores connected to the surface are filled with water. In this condition the aggregate does not contribute moisture to its surrounding mixture however it is not absorbent. The last aggregate moisture condition shown in Figure 3 above is when its condition is wet and all pores connected to the surface are filled with water, and the aggregate will contribute moisture to its surroundings as there is excess moisture on the surface (PI, 2007).

Summarized in Table 1 below are the typical moisture ranges of aggregates used in asphalt manufacturing. As shown finer aggregates (fine sand, coarse sand and 8mm aggregate) can hold considerably more moisture than coarser aggregates (Serra, 2010).

TABLE 1 TYPICAL MOISTURE RANGES OF AGGREGATES

Size	Moisture range (%)
Fine Sand	0 to 16
Coarse Sand	0 to 12
8mm	0 to 10
10mm	0 to 4
12mm	0 to 3
20mm	0 to 2

Source (Serra, 2010)

An important point to note is that aggregates with high moisture content prove more expensive to dry at latter stages of processing (Hunter, 2000).

The energy and related cost to dry aggregate are dependent on the specific and latent heats of water and also the specific heat of the aggregate type. Shown in Table 2 below are the specific and latent heats of water and also the specific heats of common aggregates used in asphalt production.

TABLE 2 SPECIFIC AND LATENT HEATS

	Specific Heat (kJ/kg.K)	Latent Heat (kJ/kg)
Water	4.18	2,257
Granite	0.79	n/a
Sandstone	0.92	n/a
Sand	0.80	n/a

Source (Çengel & Boles, 2007) (ET_a, 2012)

2.1.2 Bitumen

Bitumen has been used as a material in engineering since ancient times (rba, 2012), and is now produced to meet a variety of specifications (eurobitume_a, 2011). The physical and chemical properties of bitumen vary considerably dependant on the bituminous substances from which they are extracted (Chilingar & Yen, 1978). Bitumen is composed of a molecular structure of hydrocarbons and other atoms which gives bitumen its unique semi solid visco-elastic properties at room temperature (Hunter, 2000). Bitumen also has a complex response to stress that is dependent on temperature and loading time (eurobitume_b, 2012) (rba, 2012) (Read & Whiteoak, 2003).

Modern bitumen is produced from a variety of crude oils through a process called fractional distillation. The distillation column of an oil plant is fed with crude oil which is then heated to between 300°C and 350°C. The result is that the lighter fractions (liquid petroleum gas, petrol and diesel) of crude oil vaporize and separate from the heavier fractions of crude oil which remain liquid. These heavier fractions of crude oil form the basis of various grades of refined bitumen (eurobitume_b, 2012) (rba, 2012). Out of the estimated 1,500 plus types of crude oil less than 100 types of crude oil are suitable for the production of bitumen due to their varying content of bitumen (Hunter, 2000).

Bitumen is known as asphalt cement or asphalt in North America whereas globally the term bitumen is used, as asphalt relates to the road surface which is composed of aggregate and bitumen (eurobitume_b, 2012) (Read & Whiteoak, 2003). Although refined bitumen looks similar to coal tar in colour and constituency their properties and chemical composition are distinctly different. Petroleum pitch and bitumen are also sometimes confused as they are both derived from crude oil however pitch is a residue from the process which creates bitumen. (eurobitume_b, 2012) (Read & Whiteoak, 2003).

As shown in Figure 4 below it is estimated that in 2007 the global consumption of bitumen was 102 million tonnes, and out of this figure Europe accounted for 20 million tonnes. Around 85% of the global bitumen is used as an asphalt binder in paving applications (eurobitume_b, 2012).

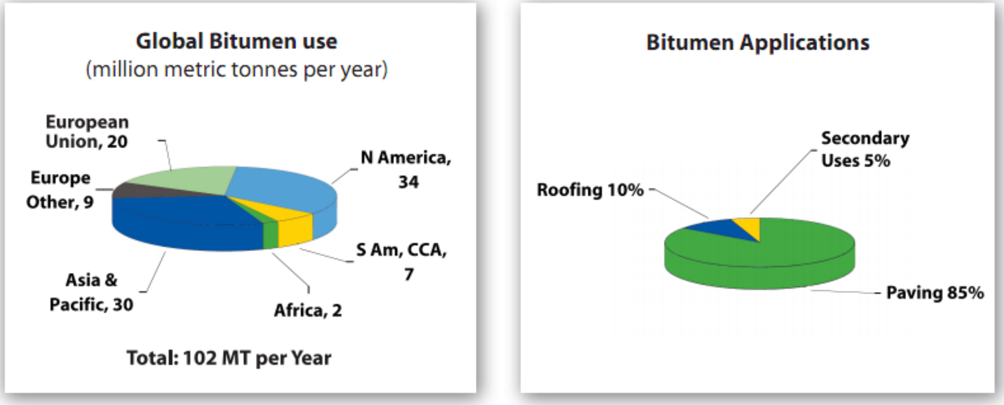


FIGURE 4 GLOBAL BITUMEN USE – 2007 FIGURES

Source (eurobitume_a, 2011)

In the UK grades of bitumen are specified by penetration tests (pen test) which records the penetration depth of a needle into a test sample which is recorded in tenths of a millimetre (mm). Hard bitumen has a low pen number whereas soft bitumen samples have high pen numbers (Hunter, 2000) (Read & Whiteoak, 2003).

Shown in Table 3 below are the two standards which specify the allowable penetration range of bitumen used in the UK for asphalt applications.

TABLE 3 BRITISH STANDARDS GOVERNING UK BITUMEN TYPES

BS EN 12591: 2009 Bitumen and bituminous binders - Specifications for paving grade bitumen									
Bitumen paving grades	20/30	30/45	35/50	40/60	50/70	70/100	100/150	160/220	250/330
Penetration at 25 °C (mm)	20 to 30	30 to 45	35 to 50	40 to 60	50 to 70	70 to 100	100 to 150	160 to 220	250 to 330
BS EN 13924 : 2006 Bitumen and bituminous binders – Specifications for hard paving grade bitumen									
Hard bitumen paving grades	10/20	15/25							
Penetration at 25 °C (mm)	10 to 20	15 to 25							

Source (BSI_b, 2009) (BSI, 2006) (rba, 2012)

2.1.3 Asphalt

Asphalt can occur naturally as lake asphalt and rock asphalt or it can be manufactured through the combination of aggregates and refined bitumen. Historically asphalt was produced with tar as a binder however tar is now classified as carcinogenic (Pike, 1990).

Modern asphalt is comprised of aggregates of varying sizes that form a skeleton for a bituminous binder to bond to (Hunter, 2000) (Pike, 1990). Even though it is true that asphalt is composed of aggregate and bitumen there are numerous asphalt mixes available with characteristics that vary significantly between each type (Read & Whiteoak, 2003). Asphalt mix properties are dependent on the aggregate gradation and related air void volume with aggregates occupying 75% to 90% of the compacted volume of asphalt (Pike, 1990). The average amount of bitumen in an asphalt mix is 5% of the mixes overall weight (EAPA, 2012).

The reason for so many asphalt mixes is due to the varying requirements that they have been designed to meet which can include heavy traffic use and extreme weather conditions. Asphalt is required to resist permanent deformation while at the same time exhibiting flexibility without cracking when loading is applied from wheels. Another factor to be considered is that asphalts need to be malleable enough to allow them to be worked when being laid whilst retaining their specified properties following compaction (EAPA, 2012).

Most asphalt mixes fall into the hot mix asphalt (HMA) category which are produced at temperatures of 150°C to 190°C. There are two other types of asphalt mixes which are warm mix asphalt (WMA) and cold mix asphalt (CMA). WMA is produced at 20°C to 40°C below HMA temperatures and CMA is produced without heating (EAPA, 2012). In 2010 the total production of HMA and WMA in the UK was 21.5 million tonnes with 45 companies involved in the asphalt industry (EAPA, 2011).

The asphalt finished product can be used to form a part a modern highway pavement which is formed through the laying of different processed materials to form the pavement. Shown in Figure 5 below are three general components that comprise a modern highway pavement. The foundation layer of a pavement sits on the native soil and comprises graded stone whose function is to provide stability for the roadbase to sit on. It also provides a means of protecting the subgrade from adverse weather conditions which may affect its stability. The next main layer is the roadbase itself which is the main structural layer whose function is to uniformly distribute the wheel loads of vehicles using the road without damaging the subgrade beneath (Rogers, 2008) (Lay, 2009). The top layer is the surfacing which provides a uniform skid resistant surface that has a reasonable life and requires little maintenance. The surfacing layer should also prevent water penetration and any subsequent surface cracking (Rogers, 2008).

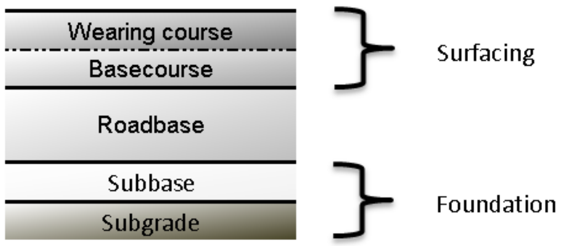


FIGURE 5 MODERN PAVEMENT LAYERS

Source (Rogers, 2008) (Lay, 2009) (Walsh, 2011)

Pavements fall into two broad types with the first being flexible pavements and the second being rigid pavements. In flexible pavements the surfacing comprises a wearing course and a basecourse which sits upon the roadbase. In a rigid pavement the surfacing layers and roadbase comprise one concrete slab (Rogers, 2008). As a rule if a pavement is comprised of asphalt layers it can be considered flexible and if the layers are comprised of cement it can be considered rigid (Walsh, 2011). The thickness of a pavement is an important design aspect as it prevents frost damage to the subgrade beneath the pavement (Rogers, 2008).

The numerous non-proprietary asphalt mixes in the UK are governed by the BS EN 13108 family of standards which detail asphalt specifications (BSI, 2010). Shown in Table 4 below are the common abbreviations for asphalts used in the UK. The most common types in the UK are variants of macadam and hot rolled asphalts (HRA) (Read & Whiteoak, 2003).

TABLE 4 COMMON ASPHALT ABBREVIATIONS

Common asphalt abbreviations	
Asphalt Concrete	AC
Dense Bituminous Macadam	DBM
High Density Macadam	HDM
High Modulous Base	HMB
Stone Mastic Asphalt	SMA
Porous Asphalt	PA
Hot Rolled Asphalt	HRA

Source (BSI, 2010) (Read & Whiteoak, 2003)

Until recently in the UK major road construction consisted of a base and binder course composed of macadam or hot rolled asphalt (HRA). However modern asphalt mixes are now replacing historical techniques due to the increased availability of materials from Europe and also to a deeper understanding of how asphalt pavements fail. Modern asphalt mixes are called stiff mixtures which if properly maintained have a long life (Read & Whiteoak, 2003).

Asphalt mixes traditionally fit into two main types the first being macadam and the second being HRA. Macadam is designated as a continuously graded mixture which means that they contain various sizes of aggregate, but not necessarily all. HRA is designated as a gap graded mixture where the aggregate sizes are in defined batches (Read & Whiteoak, 2003). This grading is achieved through the use of sieves as previously described.

Shown in Table 5 below are the gradings for traditional asphalt mixes which shows the sieve size and the percentages allowed to pass through the respective sieves.

TABLE 5 GRADINGS FOR COMMON ASPHALT

Sieve size	Percentage by weight passing each sieve			
	Coated macadams		Hot rolled asphalts	
	0/20 mm size dense binder course	0/10 mm size close graded surface course	Designation 50% 0/14 mm base, binder course and regulating course	Designation 35% 0/14 mm type F surface course
31·5 mm	100			
20 mm	95 to 100		100	100
14 mm	65 to 85	100	90 to 100	87 to 100
10 mm	52 to 72	95 to 100	65 to 100	55 to 88
6·3 mm	39 to 55	55 to 75		
2 mm	24 to 36	19 to 33[a]	30 to 55	55 to 67
1 mm		15 to 30		
0·500 mm			13 to 50	40 to 67
0·250 mm	7 to 21		6 to 31	15 to 55
0·063 mm	2 to 9	3 to 8	1 to 8	6·0 to 10·0

[a]May be increased to 38 when sand fine aggregate is used.

Source (Read & Whiteoak, 2003)

The description format for an asphalt mix is outlined in BS EN13108-1 which requires a minimum of four sections. This mix designation is shown in Figure 6 below.

AC	*D*	base/bin/surf	binder

where:

AC	is asphalt concrete;
D	is the upper sieve size of the mix, in mm;
base	is base course;
bin	is binder course;
surf	is surface course;
binder	is the designation of the binder used.

FIGURE 6 ASPHALT MIX DESIGNATION

(BSI, 2010)

To enable the adhesion of bitumen to the aggregate mixture any moisture needs to be removed from the aggregate mixture (Read & Whiteoak, 2003), meaning that the aggregate mix need to be taken to the boiling point of water (100°C) (Ang et al., 1993). The amount of bitumen content in asphalt is determined post production through exposing a sample to solvent so as to dissolve the bitumen out of the mixture. In produced asphalt if the bitumen hasn't fully bonded to the aggregate water can penetrate the asphalt product leading to failure (Hunter, 2000).

Another source of asphalt is recycled asphalt that is termed as Recycled Asphalt Product (RAP) which until recently was not widely used in the UK. In some asphalt specifications as much as 50% of the mixture can be RAP however the aggregates within the RAP could have been in use for between five to 30 years which will result in reduced durability and retained strength (Hunter, 2000). As this project is dealing with a virgin asphalt coating plant RAP is not in scope.

2.2 Asphalt Production

Asphalt production involves the blending and drying of a mixture of aggregates before being heated to an appropriate temperature for coating with a bitumen binder (Read & Whiteoak, 2003).

There are generally two component parts of an asphalt mixing plant with the first being the aggregate dryer which removes moisture from the aggregate, and the second part being the mixer where the aggregate is coated with bitumen and heated to the required mixing temperature as per the mixture specification (Read & Whiteoak, 2003).

In the UK three main types of aggregate dryer design have been developed with the first being a long rotating cylinder dryer the next type is a tower dryer where the aggregate drops through the vertical tower whist the hot heating and drying gas flows upwards. The last type of dryer is the batch heater mixer. In modern aggregate dryers oil is used as the fuel for aggregate drying (Read & Whiteoak, 2003). The aggregate dryer is a vital part of the plant in assuring the quality of the finished asphalt product due to its role in removing moisture from the aggregate mixture (Read & Whiteoak, 2003). When aggregates, sand and fines enter a dryer the heat is absorbed initially by the fine particles which when dry pass the absorbed heat onto the coarser particles. The result of this is that if the fine particles are wetter than expected and take longer to dry not enough heat is passed onto the coarse particles. Therefore the aim is to keep the fines dry so that they can more readily transfer the heat, as this heat transfer is a function of moisture content (Weir, 2012).

The storage of aggregates is common across all types of mixing plants as they are commonly stored in aggregate stockpiles prior to being loaded into eight or more cold feed storage bins, which are also known as feed hoppers (Hunter, 2000). Each storage bin is “charged” with different aggregate types and below each bin is a controlled feeder unit that feeds the required percentage of the respective aggregate mix onto a conveyor belt for transportation to the dryer and heater unit (Hunter, 2000) (Read & Whiteoak, 2003).

Asphalt plant configurations used to achieve the drying, mixing and coating of aggregates fall into one of three types which will now be covered in the following sections.

2.2.1 Batch Plant

An asphalt batch plant which is also known as a conventional asphalt batch plant deals with batches of asphalt mixes one batch at a time (Hunter, 2000). The aggregates stored in the feed bins are released in a controlled manner so as to produce the required mix. Once the aggregates leave the feed bins they are fed through a dryer and heater before being screened into hot bins. At a later time the contents of the hot bins are used to create the asphalt mx by dispatching aggregate into a mixer for combining with bitumen, dust and or filler. This type of plant is very flexible and can handle alternate batches in sequence (Read & Whiteoak, 2003). This makes this plant very common in the UK as it can handle the numerous asphalt mix types used in the UK (Curtis, 1988). The throughput of this type of plant ranges from 100 to 400 plus tonnes per hour with the weight of each batch ranging from 500kg to 5 tonnes (Grant, 1989).

The dyer component of a batch plant is usually a rotating drum inclined downwards at 3 to 4° with a gas or oil burner located at the drums lower end (Hunter, 2000) (Read & Whiteoak, 2003). This results in hot gases flowing up the drum towards the drums upper end where all cold aggregate enters the drum. This initially cold aggregate is carried down through the drum by steel angles and flights that are also known as lifters (Hunter, 2000) (Read & Whiteoak, 2003). The lifters ensure that the aggregate mixture forms a dense curtain at the feed end which ensures that the aggregate mixture is fully exposed to the heat of the burner. At the discharge end of the dryer the lifters keep the mixture to the perimeter of the drum allowing burners flame to fully combust (Hunter, 2000).The aggregate mixture is finally discharged into an elevator for further processing. In most dryers a contraflow air system forces exhaust gases in the opposite direction of the material flow which allows the waste heat to pre-heat the cold aggregate mixture (Hunter, 2000).The temperature of the aggregate mix leaving the drum is measured using a pyrometer and if required the burner is adjusted to ensure the aggregate is at the required temperature (Read & Whiteoak, 2003).

The time that the aggregate spends in the dryer is known as the retention time and this is a very energy intensive process as it takes an estimated 10 litres of fuel to heat aggregate to 160°C and remove 5% of moisture (Grant, 1989). The mixing time duration is dependent on the mixture type and batch size which means that a 2.5 tonne batch with a cycle time of one minute will result in a plant throughput of 150 tonnes per hour (Read & Whiteoak, 2003).

Drying aggregates results in the creation of dust which makes its way into the dryer exhaust. This dust can be captured using a cyclone collection system, a bag filter or a wet collector which uses water to capture the dust. This captured dust is stored onsite and can be incorporated back into the aggregate mixture at a later date (Read & Whiteoak, 2003).

Once the aggregate mix has been discharged onto the elevator it is lifted vertically to a series of screens which separate out the aggregate into various gradations for storage in hot bins. Various combinations of the aggregate contained in hot bins are measured out into a weigh hopper as per the required asphalt mixture specification. This combined aggregate mixture is then fed into a pugmill mixer where bitumen and if required dust and or a filler such as limestone are added. This blended mixture is then discharged into a truck or transported to a hot storage bin for later use (Read & Whiteoak, 2003).

2.2.2 Batch Heater Plant

This plant type differs from the batch plant as each asphalt batch is composed by the aggregate feeders and then dried and heated prior to being conveyed straight to a mixer for combining with bitumen and filler (Hunter, 2000) (Read & Whiteoak, 2003). If the moisture content of the sand is greater than 2% a sand dryer is usually used before addition to the rest of the aggregate mix (Hunter, 2000).

The drying and heating of the aggregate mix takes place in a short rotary drum with the exit temperature of the material being directly related to the period of time the aggregate mix spends being dried and heated (Hunter, 2000). As with the batch plant the asphalt mix leaving the mixer can be directly loaded into a waiting truck or it can be conveyed to a hot storage bin (Hunter, 2000).

The throughput of this type of plant can be from 50 to over 200 tonnes per hour. The batch heater plant is unique to the UK and cannot be used if the aggregate moisture content is above 2% (Read & Whiteoak, 2003).

2.2.3 Drum Mixer Plant

The drum mixer plant differs from the two previous plants as the aggregate mixes are composed by the aggregate feeders prior to being conveyed to a drum that dries, heats and then coats the mixture with bitumen binder (Hunter, 2000) (Read & Whiteoak, 2003). As this type of plant continuously dries and then heats aggregate mixes prior to coating with bitumen it achieves a higher throughput of between 100 to 700 tonnes per hour. This higher throughput is achieved as separate drying, heating and coating steps in the previous two plant designs are combined in one continuous process. This makes the drum mixer plant ideal for single material type contracts (Read & Whiteoak, 2003).

In a drum mixer plant fine asphalt mixtures are processed before coarse mixtures as the inclusion of any fine mixture remnants in a coarse mixture doesn't pose an issue (Weir, 2012). A drawback with this type of plant is that changing between mixture types can be complicated and take some time however with computer control this changeover time can be reduced (Read & Whiteoak, 2003). This type of plant is much simpler than the previous plant types which reduces maintenance costs and increases reliability (Read & Whiteoak, 2003).

The cold aggregate feed system is similar to that as described in the batch plant however it does not incorporate screens, hot aggregate bins, weigh hoppers and pugmill mixers. The result of this is that the aggregate gradation ratios in the mixture must be precise as any errors will not be uncovered until a sample is taken of the finished asphalt product (Hunter, 2000) (Read & Whiteoak, 2003). The cold aggregate leaves the cold feed bins on a conveyor belt which has a belt weigher that weighs the mixture so that the mixes moisture content can be accounted for in the mixture. This conveyor belt then feeds the plant charging conveyor which enters the drum mixer drum (Read & Whiteoak, 2003).

Shown in Figure 7 below is a diagram of a typical drum mixer plant. As shown the burner is located at the top of the drum where the cold aggregate enters meaning that the aggregate flows away from the burner (Hunter, 2000) (Read & Whiteoak, 2003). The drum mixer contains flights that are more complex than those in the batch plant drying drum. The interior of the drum is divided into two zones with the first being the aggregate drying zone nearest the burner and where the cold aggregate enters the drum. The second zone is the mixing and coating zone where the dried and heated aggregate is coated with bitumen. This zone is protected from the higher temperatures and radiant heat of the drying zone by either a plate or by a curtain of aggregate formed by flights (Hunter, 2000) (Read & Whiteoak, 2003). The bitumen is injected at the start of the second zone with the bitumen flow rate being proportional to the aggregate flow rate. The lifters in this final stage are designed to ensure the aggregate and bitumen mixture are fully combined (Hunter, 2000).

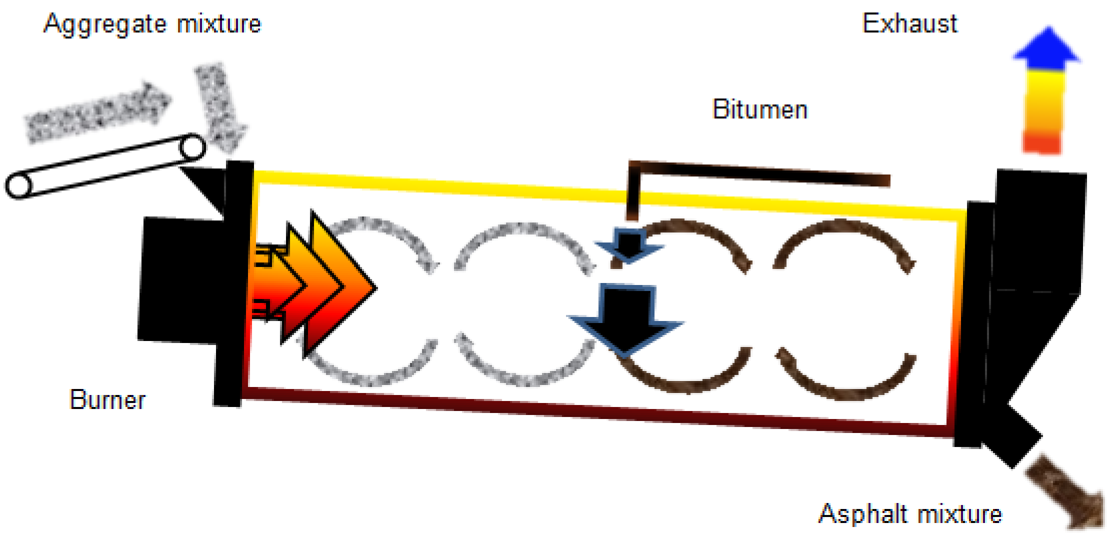


FIGURE 7 DRUM MIXER DIAGRAM

The exhaust gas of a drum plant contain less dust than a batch plant as most of the dust created by the aggregate drying and heating is incorporated into the bitumen aggregate mix (Read & Whiteoak, 2003).

In a drum mixer plant the difference between the exhaust temperature and the aggregate in the mixing zone should be within 10°C of each other. In an efficiently operating plant the difference between the exhaust temperature and the mixture exit temperature should be 4°C or less (Roberts et al., 1991).

2.3 Asphalt Plant Energy Reduction

Due to the increasing cost of energy and aggregates companies involved in asphalt production are examining their processes so as to make savings (Serra, 2010).

Plant scheduling is an initial step that can be undertaken to reduce energy consumption as operating an asphalt production plant with a high monthly tonnage throughput and with a low number of plant start and stops can result in lower specific energy consumption per tonne of asphalt (Ang et al., 1993). This means that every step should be undertaken to ensure that plant use is optimised to ensure attained operating temperatures are utilised and the plant is not left to cool back down.

Heat loss accounts for nearly 20% of the energy used in the drying of aggregates, heating of bitumen and the heating of aggregates. It is estimated that the Return On Investment (ROI) for insulating an asphalt dryer is one year (CT_c, 2010).

As discussed earlier in this section aggregates can retain moisture which is an important consideration when they are used as an input to asphalt production. Increased aggregate moisture content affects the grading of aggregates for use in an asphalt plant and importantly it increases the amount of energy used to dry the aggregate in the asphalt plant. Due to aggregates having different moisture ranges dependent on their size they can leave the asphalt plant dryer at different temperatures and moisture levels meaning some aggregates will be over dried and some will not be sufficiently dried (Serra, 2010). Studies have shown that if the moisture content of one ton of aggregate increases by 1% the additional drying requirement results in an increase of 0.6 litres in fuel. More fuel is required to dry aggregate than to heat it in an asphalt plant as it takes four litres of fuel to dry one ton of aggregate compared to three litres to heat it. If an asphalts plant throughput is 300 tonnes per hour and the aggregates moisture level is 6% the fuel required to dry the aggregate is 1,200 litres. If the moisture content dropped from 6% to 5% without the dryer being adjusted the wasted energy would equate to 180 litres of fuel (Serra, 2010).

For a single mid-sized asphalt plant reducing moisture content by 2% could save £100,000 per year (CT, 2009), and drying aggregates accounts for 30% of an asphalt plants energy consumption (CT_b, 2010).

The impact of errors in moisture measurement against wasted fuel is shown in Figure 8 below.

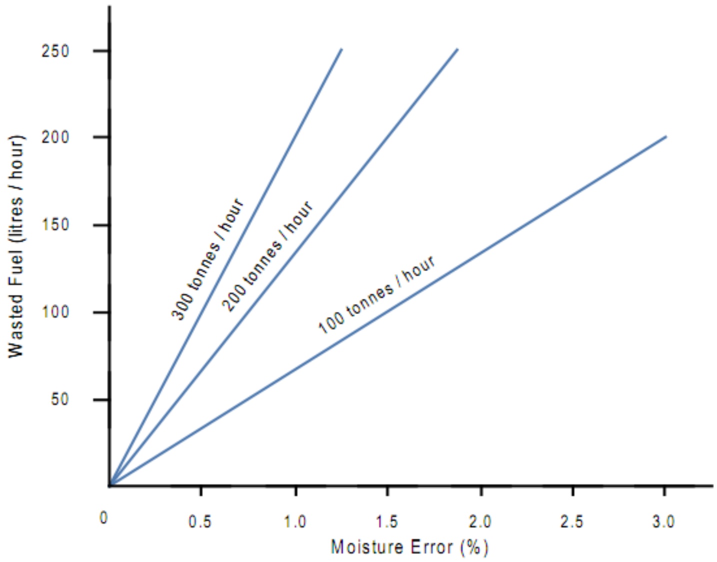


FIGURE 8 MOISTURE ERROR WITH FUEL WASTE

Source (Serra, 2010).

Measures can be taken to reduce the moisture content of aggregates and as discussed finer aggregates (sand and 8mm aggregate) can hold considerably more moisture than coarser aggregates. Therefore they should be kept in covered stockpiles even if the coarser aggregates are not.

One of the best ways in which to reduce the moisture content of sand, fines and aggregates is to locate them on inclined stockpiles as shown in Figure 9 below. The stockpile should be sloping away from the loading point at an angle of 6%.

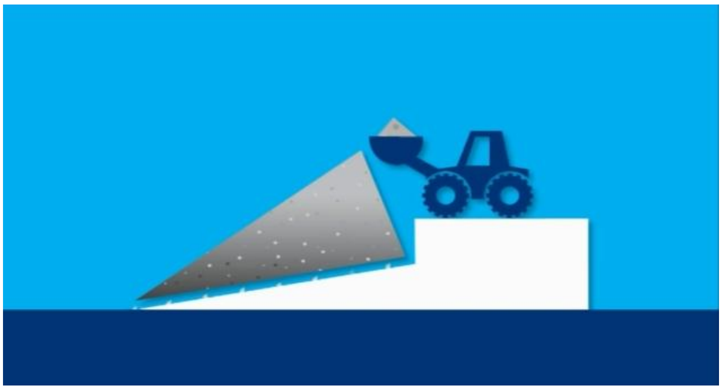


FIGURE 9 SLOPING STOCKPILE

Source (CT, 2009)

Stockpiles should also be rotated so that they have time for their moisture levels to drop. The stockpiles themselves should only have their contents removed from the top third of the stockpile as this is the driest part (CT, 2009). It is difficult to persuade people to put an incline on the concrete bases of stockpiles as they have historically always used flat concrete bases, however flat concrete bases are still better than using a virgin ground base (Weir, 2012). Another technique to reduce the moisture content of stockpiles is to use pumping as shown in Figure 10 below. Pumping of sand and fines stockpiles is difficult due to the effort required to overcome the hydrostatic head of asphalt sand/fines as they have a small particle size (Weir, 2012).

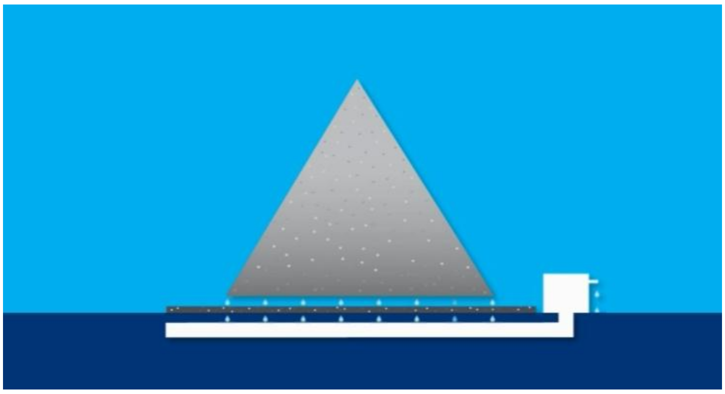


FIGURE 10 STOCKPILE WITH PUMP

Source (CT, 2009)

Studies have been undertaken which demonstrate the relationship between the specific monthly energy consumption per tonne of produced asphalt and the average daily rainfall over a month (Ang et al., 1993). If the quarry site and asphalt plant are in the same location data can be recorded so as to demonstrate the link between the recorded rainfall and the measured moisture content in the aggregate. However if the aggregates are transported from another site this link will prove to be more difficult to demonstrate.

2.4 Energy Management

Energy management is a much used term that if effectively implemented can minimize costs and or maximise profits with the benefit of increasing competiveness. It can also increase energy efficiency and reduce energy usage which has the result of reducing energy costs. Associated emissions either from on-site fuel usage or from the energy generation source can also be reduced. It also has the knock on effect of engaging employees with the energy management programme through communication methods such as newsletters. Importantly an energy monitoring and reporting plan must be developed to ensure that the relevant data is being collected and put into a suitable format for distribution (Capehart et al., 2008). The data collected will enable the tracking of energy use and the data itself can be analysed to provide an input to the energy management plan (IEA_b, 2012).

2.4.1 Energy Consumption

One third of the world's final energy consumption is used by industry and this proportion is increasing. Increased energy efficiencies and reductions in CO_2 emissions have been realised in developed countries however this has been offset by increased energy demand and CO_2 emissions from developing countries (IEA_a, 2012).

Improved energy efficiencies could cut a quarter of industrial energy use which along with improving the industry financially it will also reduce dependence on fossil fuels and reduce greenhouse gas emission (IEA_b, 2012). In the UK and other EU countries energy consumption has plateaued due in part to the previously mentioned efficiencies but also with the move away from energy intensive industries to a service based economy which consume less energy (Beggs, 2009).

Shown in Figure 11 below is the 2008 final energy consumption per industry sector in the UK. From the chart mining and quarrying can be seen to be 1 ktoe (tonne of oil equivalent) which equates to 11.8 GWh (Twidell & Weir, 2006).

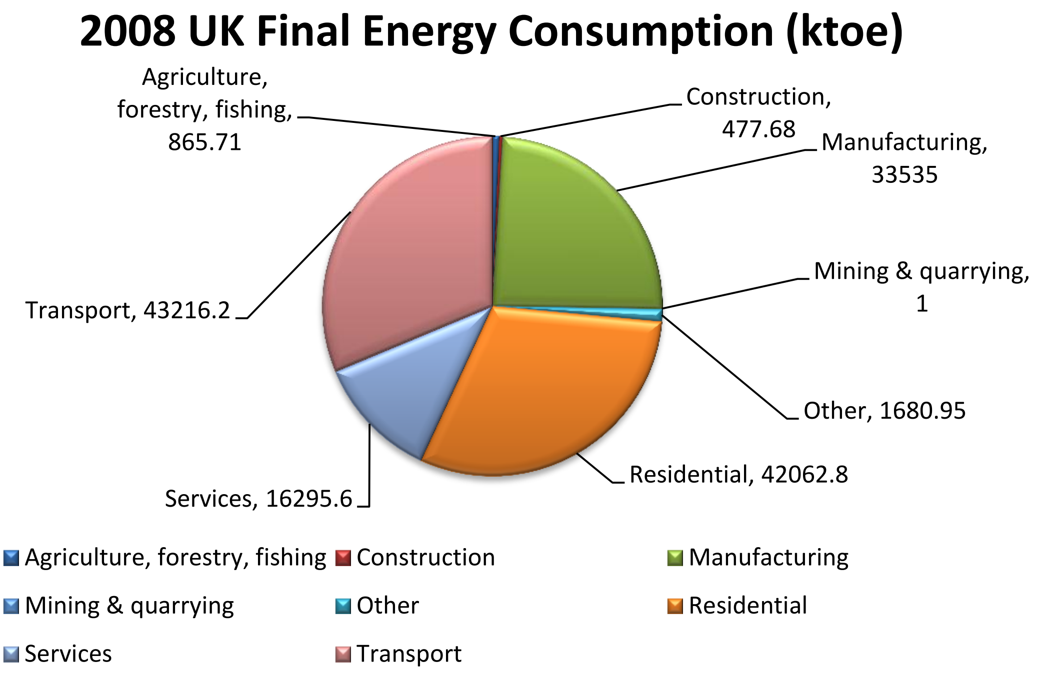


FIGURE 11 2008 UK FINAL ENERGY CONSUMPTION

Source (IEA, 2010) (IEPD, 2012).

2.4.2 Energy Auditing

An energy audit is undertaken once an energy management plan has been approved and its purpose is to examine the current use of energy, identify any areas where efficiencies can be made and to reduce consumption (Capehart et al., 2008) (Younger & Thumann, 2008).

The amount of data collected and level of analysis is directly proportional to the cost of an audit, therefore the available audit budget determines the scope and level of detail for an audit (Younger & Thumann, 2008).

There are three broad types of energy audits with the first being a walk through audit which is the least costly and complex as it involves a site visit, and analysis of energy consumption data. Analysis is undertaken on this data to identify any patterns, to compare the site to industry benchmarks and or data from similar sites. Initial energy savings and related cost saving opportunities can be identified through this type of audit. The information collected in this audit can be used in a more detailed audit if the initial energy savings warrant an increase in scope (Younger & Thumann, 2008).

The next type of audit is a standard audit which is a more detailed analysis and review of the sites equipment and systems. If required there may be some verification of the energy consumption data and efficiencies through measurement and testing onsite. This level of audit also includes an economic analysis of energy reduction measures (Younger & Thumann, 2008).

The final type of audit is a computer simulation which is the most detailed as it involves the creation of a computer simulation model of the site to evaluate patterns in energy use. This simulation will take into account weather and other variables that effect energy consumption, and it will be run for a whole year. Once the model has been created it can be used as a baseline against which changes can be measured against. As this is the most complex audit type it should only be used if the site is complex and requires such a complex form of analysis (Younger & Thumann, 2008).

All types of audits produce an energy audit report which contains the audit results and also an energy action plan to implement any measures highlighted in the report. An important aspect is that the employees of an organisation must be fully engaged as they may be charged with implementing and they have to live with the changes (Capehart et al., 2008).

2.4.3 Energy Analysis

The first step in energy analysis is the collection of data through an energy audit or through continuous monitoring. The collected data is of little use unless it is analysed correctly in order to draw out any trends in the data and to point at areas that can be improved (Beggs, 2009).

One simple way of analysing data is to create a table and chart showing the energy consumption for a site which can require the conversion of the data into a standard unit which is usually kWh (Beggs, 2009). This type of analysis does not include variable factors such as weather conditions which may alter energy performance of the buildings or facility (Beggs, 2009)

Gross calorific values and conversions to kWh for fuels (litres) typically used in asphalt production are shown in Table 6 below.

TABLE 6 GROSS CALORIFIC VALUES OF FUELS WITH CONVERSIONS TO EQUIVALENT KWH

	Gross Calorific Value	kWh MJ x 0.2778
Gas Oil (Litre)	38 MJ/L	10.5564 kWh
Kerosene (Litre)	37 MJ/L	10.2786 kWh

Source (Beggs, 2009) (Twidell & Weir, 2006)

Carbon dioxide (CO_2) is seen by many as the main contributor to global climate change and there have been international measures to limit climate change. A key measure is the Kyoto Protocol which was ratified by the EU, Russia, Canada, Japan and many developing countries; however the USA and Australia did not ratify the protocol (Capehart et al., 2008).

In the UK the Department of Energy & Climate Change (DECC) has implemented a scheme called the CRC (Carbon Reduction Commitment) Energy Efficiency Scheme which is mandatory to large public and private organisations as they account for 10% of emissions in the UK.

To promote energy management and a better understanding of energy use within organisations the CRC scheme utilises financial, behavioural and reputational drivers (DECC_a, 2012).

Conversion factors for measuring the CO_2 emissions from various energy supplies are provided through the UK governments Department for Energy and Climate Change (DECC). Some asphalt coating plant fuel types with their conversion factors are shown in Table 7 below.

TABLE 7 ASPHALT COATING PLANT FUEL TYPES WITH CO_2 CONVERSION FACTORS

Fuel Type	Measurement unit	Emissions Factor kgCO_2 / per measurement unit
Burning Oil/Kerosene/Paraffin	litres	2.532
Electricity	kWh	0.541
Gas Oil	litres	2.762

Source (DECC, 2010)

2.4.4 Degree Days

Degree days are a method to take into account the variation and effect that outside temperature has on the energy consumption of a building over a given period of time (Beggs, 2009) (Capehart et al., 2008). In the UK the temperature difference between the unheated inside of a building and the outside temperature is 3°C, with the outside temperature being lower. This means that to maintain an internal temperature of 18.5°C the building requires heating when the outside temperature falls lower than 15.5°C (McMullan, 2007). This outside temperature is called the base temperature (McMullan, 2007), (CT_a, 2010).

To count degree days each day that drops below the base temperature is counted and is then multiplied by the temperature drop from the base temperature. This is summed up over a given period with colder areas of the UK having a larger number of degree days (McMullan, 2007).

Degree days are split into two types the first being heating degree days (HDD) which in essence is described above, and cooling degree days (CDD) which is used for air-conditioned buildings that require cooling (Beggs, 2009).

Shown in Figure 12 below is a map detailing the UK monthly degree day regions that have data available for use.

FIGURE 12 UK MONTHLY DEGREE DAY REGIONS

Source (CT_a, 2010)

2.5 Statistical Analysis

Statistics involves the collection, analysis and presentation of data with the aim of providing a more detailed understanding of the data set (Anderson et al., 2011). Where a value is located in a data set or population is important. Two statistical formulas are commonly used for this purpose with the first being the sample mean or average which provides the central point of the data population. The second formula measures the variance of each sample value in relation to the mean and is called the standard deviation (Anderson et al., 2011).

2.5.1 Z-score

The relative location of a value within a data set and how far it is from the mean of the data set can be determined using the z-score. The z-score which is also known as the standardized value return the number of standard deviations a value is from the data set mean (Anderson et al., 2011).

The means of calculating the z-score for each value in a data set is shown in Equation 1 below.

$$z_i = \frac{x_i - \bar{x}}{s}$$

EQUATION 1

Where:

z_i = z-score for value x_i

x_i = sample value

$\bar{x}$ = sample mean

s = standard deviation of the sample

Each values z-score returns the number of standard deviations that it is from the sample mean and these values can be called outliers. An outlier can be due to the data being incorrectly recorded or from its improper inclusion in the data set being analysed. A z-score of +3 or -3 can be treated as an outlier and following further analysis can be excluded from the data set (Anderson et al., 2011).

2.5.2 Regression Analysis

Linear regression analysis is a widely used statistical technique that is used to quantify the relationship between a dependent variable and one or more independent variables. This technique is a useful energy management tool where the dependent variable can be energy consumption and the independent variables can be production volumes, monthly operating costs and degree days (Beggs, 2009), (Winston, 2011).

Using data analysis tools such as Excel a chart is produced using the data points and a best-fit straight line (trendline) is added which provides the equation for the line in the generic straight line equation format as shown in Equation 2 below (Beggs, 2009) (Stroud & Booth, 2007).

$$y = c + mx$$

EQUATION 2

The dependent variable is represented by y, x represents the independent variable, m represents the gradient of the line and c is the point where the line intersects the y axis (Anderson et al., 2011) (Beggs, 2009).

When used in energy management gas consumption could be the dependent variable y with degree days as the independent variable x. The y axis intersect becomes the theoretical base load for the system being analysed (Beggs, 2009), and every additional degree day will increase the gas consumption by the line gradient value times the degree day value (Winston, 2011).

Regression analysis can also take into account the relationship between multiple independent variables and is termed multivariable linear regression analysis Equation 3 below represents the relationship between the dependent and independent variables (Beggs, 2009).

$$y = c + m_1x_1 + m_2x_2 + \cdots m_nx_n$$

EQUATION 3

A key output from regression analysis is the coefficient of determination (r^2) which is a measure of how closely the trendline fits the data points. The coefficient of determination is calculated using Equation 4 below (Anderson et al., 2011).

$$r^2 = \frac{SSR}{SST} = \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2}$$

EQUATION 4

Where:

SSR = Sum of Squares due to Regression

SST = Sum of Squares Total

$\hat{y}_i$ = estimated value for the dependent variable for the ith observation

$\bar{y}$ = mean value for the dependent variable

y_i = actual value of dependent variable for the ith observation

SSR is the sum of the squared differences between the dependent variables predicted and mean values for all observations. SST is the baseline value calculated by summing the squared differences between the actual dependent variable values and their mean for all observations (Anderson et al., 2011) (Hair et al., 2010).

The higher the r^2 value the higher the trendline fit to the data points so if the r^2 value is equal to 0.69 it means that the trendline would explain 69% of the variation in the data points (Winston, 2011).

An important value that is obtained from regression analysis is the p-value of an independent variable. This p-value is a percentage of how likely it is that the variables coefficient emerged from chance and that it therefore does not describe a real relationship. The smaller the p-value is the larger the predictive power of the variable. An independent variable with a p-value of <= 0.15 is considered to be good for predicting the dependent variable (Winston, 2011).

The difference between the observed value of the dependent variable and its estimated value is called the residual (Anderson et al., 2011) (UNESCO, 2012).

The y axis intercept becomes the theoretical base load for the system being analysed (Beggs, 2009) and represents the estimated dependent variable on the y-axis if all the independent variables have zero values (UNESCO, 2012).

The quality of the data determines the usefulness of the regression analysis and as such analysis results should be treated with caution (Winston, 2011).

3 Analysis

The University of Strathclyde was approached by Barr Limited with a proposed project to investigate and quantify the impact of different factors on energy use in the production of coated materials. The project is based on a case study at their coating plant in Killoch Ayrshire, which is one of five located in South Western Scotland that are operated by Barr Limited.

Barr Limited started as an Ayrshire building and joinery company called W & J Barr & Sons in the late 1800's. In the 1960's the family owned company entered the civil engineering sector and became involved in higher value projects. Barr Limited further diversified in the 1980's and entered sectors such as house building. Since 2003 Barr Limited has divested itself of non-key activities and has refocused within the construction, environmental, manufacturing and industrial sectors.

Reduction in both energy use and CO_2 emissions from Barr's coating plants are important as they are key consumers of energy. The reduction in energy use is driven by the increase in energy prices, and the reduction in CO_2 emissions is driven by Barr Limited being part of the mandatory CRC scheme which is implemented by the UK government. Barr also has environmental and energy policies aimed at reducing energy usage and reducing their impact on the environment.

The main project deliverable for Barr is a software tool that can be used to estimate energy usage at their Killoch asphalt coating plant which will allow Barr to estimate the costs of jobs more accurately. It will also allow the identification of jobs where existing estimation techniques result in jobs that either result in a loss or a margin that is too high which may result in Barr being uncompetitive.

The tool will also be used as a benchmark against future measures undertaken to reduce energy use. Also the intention by Barr is to utilise the tool at their other four asphalt coating plants following any required tool modifications.

3.1 Aims and Objectives

The aim of this project is to determine the influence that various factors have on energy use at the Killoch asphalt coating plant and to develop an energy estimation tool that takes into account key factors that influence energy use.

The project objectives are listed below:

- Document key parts of coating plant.
- Collate energy and related data from Barr.
- Create a dataset containing key information and excluding any outlier data.
- Analyse and identify key factors affecting energy use at the coating plant.
- Undertake regression analysis to identify key independent variables that can be used to estimate the energy use.
- With input from the regression analysis an energy estimation tool will be developed to estimate energy use, fuel use and CO_2 emissions per tonne of material.
- Validate the tool against actual data.
- Document results.
- Detail meaningful conclusions.

3.2 Methodology Overview

The purpose of this section is to give an overview of the methodology used in the project with subsequent section content reflecting this methodology. The project methodology is shown below:

- Document key aspects of the plant and obtain information on metering.
- Create a process flow diagram of the coating plant.
- Obtain information on current mixtures used at the coating plant
- Undertake an energy audit to collate the data on the overall site energy consumption and coating plant consumption.
- Determine specific and latent heats of key materials used in the coating plant.
- Estimate heat loss in drum dryer/mixer.
- Collect and analyse existing data from the Barr case study using Microsoft Excel 2010.
- Use Excel to identify key factors that affect energy consumption at the coating plant.
- Create a single dataset which has had any data outliers removed.
- Undertake regression analysis on the dataset to identify key factors that influence energy consumption at the coating plant. This will be undertaken using Microsoft Excel 2010 Analysis ToolPak.
- Design and develop a tool to estimate the kWh, litres of fuel and the $kgCO_2$ emissions per tonne of produced material. This tool will be implemented in Microsoft Excel 2010 Visual Basic for Applications (VBA) due to its widespread use in the automation of spreadsheets and the fact that the metering and sales data is already stored in Excel.
- Present key results from the analysis of important factors that influence energy consumption.
- Validate the tool output against actual site data.
- Suggest improvements to the coating plant.
- List ideas for future work.
- Present overall project conclusions.

The methodology was achieved through site visits to the coating plant in Killoch and meetings with relevant employees.

3.3 Killoch Asphalt Plant

3.3.1 Plant Description

As previously mentioned the asphalt coating plant is located in Killoch Ayrshire Scotland. A Google map view of the site is shown in Figure 13 below and as can be seen it is a large site with the asphalt coating plant having a footprint of approximately 9,300m^2.

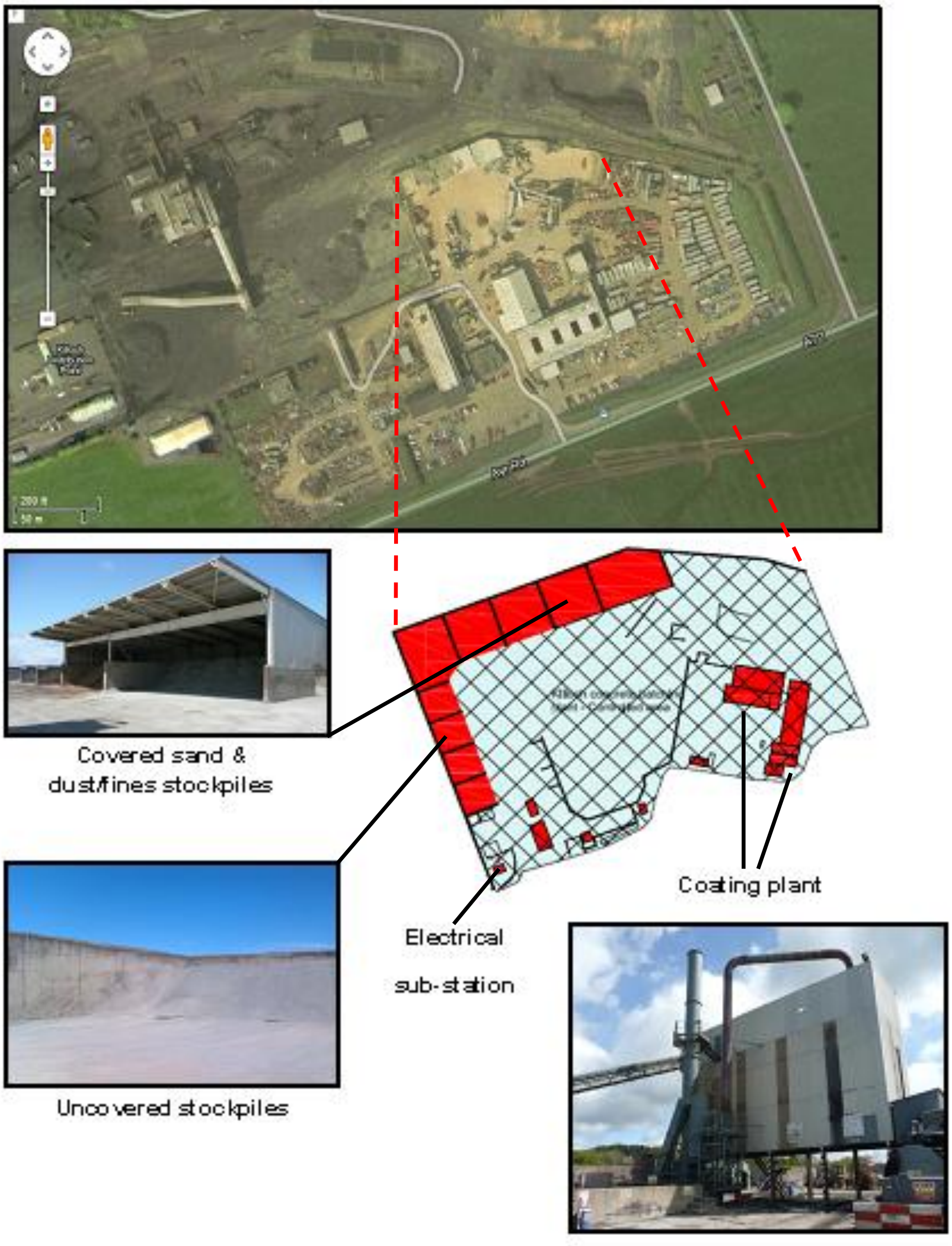


FIGURE 13 KILLOCH ASPHALT PLANT LAYOUT

Shown in Figure 13 are images of the coating plant building and of the covered and uncovered stockpiles. From the plant plan in Figure 13 the layout of the plant can be seen which includes the electrical substation.

All stockpiles have inclined concrete bases however it is only the dust and sand stockpiles that are covered as they can hold more moisture than coarser aggregates. The stockpiles are rotated ensuring that new material is left to sit allowing moisture to drain from the pile. The digger drivers are instructed to take aggregate from the top third of the pile then to vertically reform the pile to ensure proper drainage (Hewitson, 2012).

The moisture content of aggregates is noticeable as the amount of fuel required to dry them increases (Armitage , 2012). The moisture of the dust and sand stockpiles is measured by scraping away the surface of the sample area which is between two and three feet from the bottom of the stockpile (Hewitson, 2012). The moisture tester which is used is a Kett HI-520 concrete and mortar moisture sensor which detects the capacitance of the sample. This is then converted by the operator into a moisture level by referencing a table.

Each 15 tonne hopper is loaded with material from the relevant stockpile and when required the hopper will discharge a set amount controlled from the control room. This is then conveyed onto the inclined conveyor where it enters the drum dryer/mixer. Before leaving the horizontal conveyor it is weighed after the addition of any filler to ensure that the weights are correct. This also gives an indication of the moisture content as the wetter the mixture the heavier it will be (Hewitson, 2012).

The purpose of the drum burner is first of all to supply heat to dry the aggregate mixes as detailed in the literature review and then to heat the aggregate mixture to the required temperature as outlined in the mixture recipe card, and related standard. To ensure that the heat from the burner doesn’t cause combustion when the bitumen is added in the mixing stage lifters inside the drum form an aggregate curtain prior to the mixing zone. The fuel for the drum burner is a mix between kerosene and gas oil with the mix being 60/40 respectively (Hewitson, 2012).

The drum dryer/mixer is an eight metre long inclined cylinder with a diameter of 1.8 meters and is fabricated from mild steel that is between 14 and 20mm in thickness. The drum is not insulated and is exposed to the outside environment (Hewitson, 2012). An electric motor located below the drum powers a chain drive that rotates the drum, and this motor dictates the drums material throughput. The ideal throughput of the drum dryer/mixer is 100 tonnes per hour (t/hr) however the effective throughput is 80t/hr due to mixture type/operational constraints and the ability of the customer to pick up the asphalt from the plant (Hewitson, 2012). The bitumen used in the mixing stage of the drum is stored in three electrically heated tanks on site with all tanks and associated piping being insulated. The three tanks contain different bitumen mixtures which are kept at different temperatures for use in various asphalt mixtures (Hewitson, 2012).

The exhaust gases are drawn out of the drum mixer section by a fan and then sent to the exhaust stack. Before the exhaust gases reach the stack it passes through a wet scrubber which removes the fine dust particles from the drums exhaust gases. This fine dust then enters a settling pond before being added to the dust stockpile on site (Hewitson, 2012).

When the mix is complete it exits the mixer and enters the 1.5 tonne pneumatic hopper where the operator takes a temperature reading using the pyrometer. The mix is the dispatched into either the 40 tonne hopper (Bin1) or the 20 tonne hopper (Bin 2) before loading onto a truck. The 40 tonne and 20 tonne hoppers hold two and one loads respectively. With an effective material throughput of 80t/hr it will take 30 minutes to fill Bin1 and 15 minutes to fill Bin 2. For quality assurance purposes spike temperatures are taken from the mix once it has been loaded onto a truck (Armitage , 2012).

Barr Limited aim to ensure that production jobs are scheduled as effectively as possible to ensure optimal use of the coating plant, however this is not guaranteed as one off jobs can occur when the plant is not in use (Hewitson, 2012). The truck weighbridge gives the final weight of the trucks net tonnage which is then added into the Barr sales report (Hewitson, 2012) (Weir, 2012). Figure 14 below contains a flow diagram of the asphalt coating plant which details the key plant components. The total plant production over the financial year April 2011 to March 2012 was 60,657 tonnes of asphalt coated products.

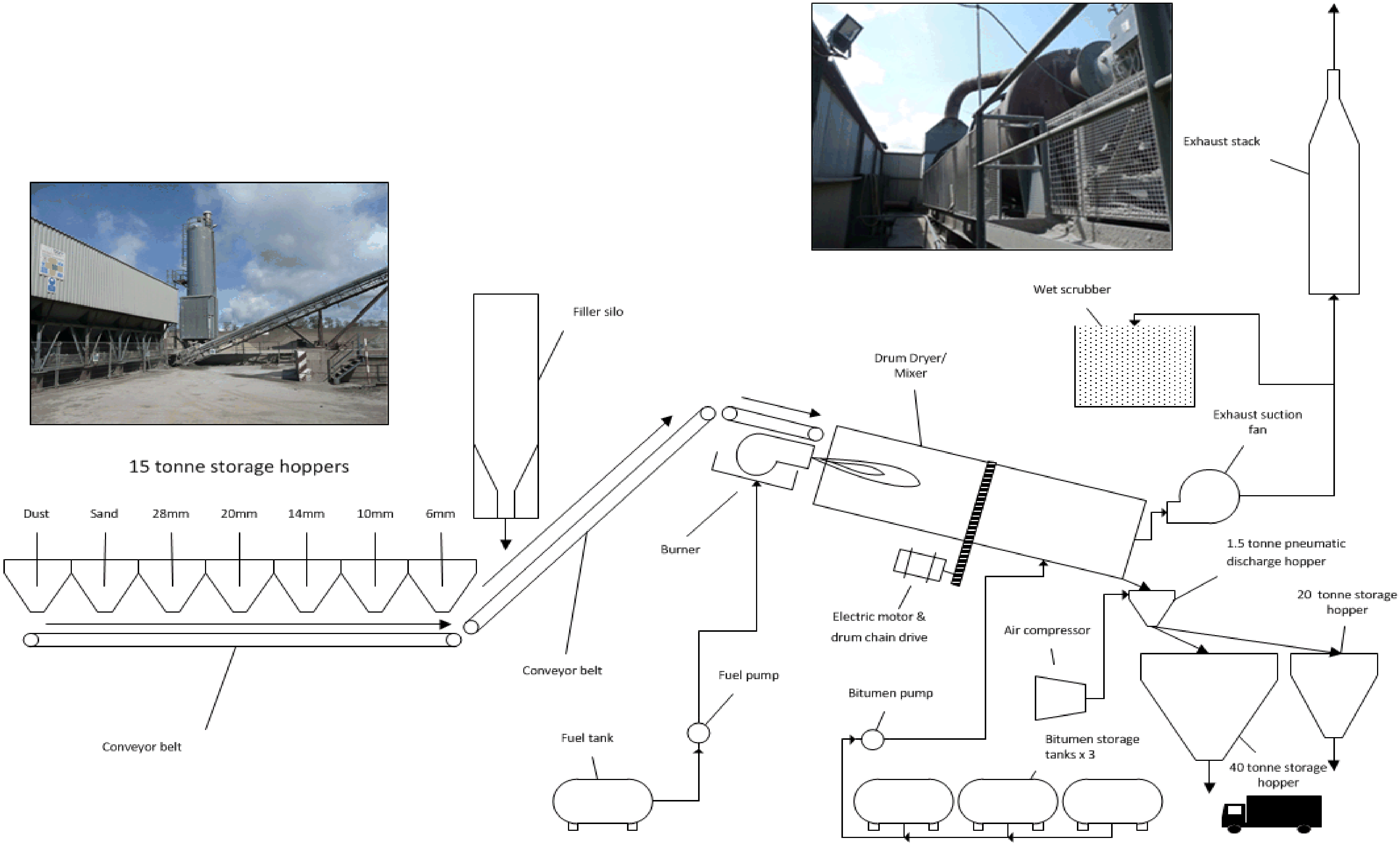


FIGURE 14 KILLOCH COATING PLANT FLOW DIAGRAM

3.3.2 Metering

The coating plant has half hourly electrical consumption and fuel usage meters whose readings are recorded electronically and which can be analysed in Excel.

The electrical consumption meter is a digital ELCOMPONENT AEM 33P which records the coating plants kWh consumption. The electrical consumption of the coating plant includes non-production specific consumption such as water pumps, lighting and bitumen heaters as well as production specific consumption which include the drum dryer/mixer motor, exhaust fan and conveyor motors. This results in an electrical base load that is not production related, unlike the fuel usage which is only used when the drum is in operation.

To record the fuel usage a CONTOIL VZO 20 pulse meter is used in the drum burner fuel line which is set so that one pulse equals one litre of fuel. This is recorded electronically over a wireless connection every half hour. Unlike the electrical consumption fuel consumption is production specific as fuel is used only when production jobs are being run.

An environmental sensor is also in use at the coating plant which records relative humidity, minimum and maximum temperatures. The sensor type is an EXTECH RHT10 humidity and temperature USB datalogger which can record data in intervals from 2 seconds to 24 hours.

There are also temperature sensors within the coating plant which detect important temperatures that are recorded by the operators. The manifold temperature which is the temperature of the bitumen before it enters the mixing stage of the drum is measured. Also the stack temperature which is the temperature of the exhaust gas is measured and the temperature of the mixture when it exits the drum is measured using a pyrometer.

3.3.3 Asphalt Mixes

The Killoch asphalt coating plant currently produces 44 mixes which are specified in recipe cards. The percentages of the various aggregate sizes, filler and bitumen for each mixture are shown in Appendix A. As a general rule bitmac mixes contain dust and asphalt mixes contain sand. The asphalt mixtures produced also have to meet required temperatures as shown in Appendix B.

3.4 Energy Audit

An audit on the energy used at the Killoch site was undertaken which consisted of collecting data on the energy used, determining latent and specific heats of materials used in asphalt production and also the estimation of the drum dryer/mixer convective and irradiative losses at an internal temperature of 100°C. The data was then analysed to show the percentage of energy used at the coating plant and how much is involved in heating the drum. Regression analysis was then undertaken on the dataset to determine which factors influence energy use at the coating plant.

The Killoch site incorporates offices, workshops and support buildings which also consume electricity in addition to the asphalt coating plant.

Before analysing the energy use at the Killoch site some energy conversions need to be calculated as shown below.

As previously stated the fuel used in the drum dryer/mixer is 60% Kerosene and 40% Gas Oil which is a mixture chosen due to economic reasons (Hewitson, 2012). This results in a litre of fuel equating to 37.4MJ, 388.6kWh and 2.624kgCO_2 as shown below.

Litre to Joule

1 Litre = 37MJ x 60% + 38MJ x 40%

1 Litre = 37.4MJ

Litre to kWh

1 Litre = 37MJ x 60% x 10.2786 + 38MJ x 40% x 10.5564

1 Litre = 388.6MWh

Litre to CO_2

1 Litre = 60% x 2.532 + 40% x 2.762

1 Litre = 2.624kgCO_2

3.4.1 Latent and Specific Heat Analysis

Bitumen is excluded from this analysis as it is brought to site at temperature and its heat is maintained with electrical heating elements.

Average ambient temperature: 13.3°C = 286K

Average mixing temperature: 162.7°C = 436K

Boiling point of water: 100°C = 373K

Latent heat of vaporisation of water: 2,257kJ/kg

Specific heat of water: 4.18kJ/kg.K

Specific heat of sandstone aggregate: 0.92kJ/kg.K

Specific heat of sand: 0.8kJ/kg.K

Energy required to heat 1kg of **water** to vaporisation

q $= m.hfg + m.c_p.\Delta T$

q $= [1kg.2257kJ/kg] + [1kg.4.18kJ/kg.K.(373 - 286)]$

q $= [2257kJ] + [1kg.4.18kJ/kg.K.(373 - 286)]$

q $= \mathbf{2.6}\boldsymbol{MJ}$ = 70ml fuel = 0.18kgCO_2

Energy required to heat 1kg of **sandstone** aggregate to average mixing temperature

q $= m.c_p.\Delta T$

q $= 1kg.0.92kJ/kg.K.(436 - 286)$

q $= \mathbf{138}\boldsymbol{kJ}$ = 4ml fuel = 0.01kgCO_2

Energy required to heat 1kg of **sand** to average mixing temperature

$q = m.c_p.\Delta T$

$q = 1kg.0.8kJ/kg.K.(436 - 286)$

$\mathbf{q = 120kJ}$ **= 3ml fuel = 0.01kgCO_2**

3.4.2 Drum Dryer/Mixer Heat Loss

Shown below are calculations to estimate the drum dryer/mixer heat loss due to convective and irradiative losses with an internal temperature of 100°C.

Drum dimensions

Outer radius: r1 = 1.8m

Drum length: L = 8m

Drum Material

Mild Steel

ε = 0.26 (ET_b, 2012)

Temperatures

Inner drum temperature: T_1 = 100°C = 373K

External ambient temperature (average): T_2/ T_4 = 14°C = 287K

$$Q = Q_{RAD} + Q_{CONV}$$

$$Q = \sigma\varepsilon A\left({T_1}^4 - {T_2}^4\right) + hA(\Delta T)$$

$$Q_{RAD} = \sigma\varepsilon A\left({T_1}^4 - {T_2}^4\right)$$

$$Q_{RAD} = 5.67 \cdot 10^{-8} \cdot 0.26 \cdot (\pi \cdot 1.8 \cdot 8) \cdot (373^4 - 287^4)$$

$$Q_{RAD} = 8{,}385W$$

For forced convection air flow across a cylinder

$$T_{film} = \frac{T_{fluid} + T_{surface}}{2}$$

$$T_{film} = 330\text{K}$$

$$R_e = \frac{\rho v l}{\mu}$$

$$R_e = \frac{1.0689 \ \cdot 4 \ \cdot 1.8}{1.99 \ \cdot \ 10^{-5}}$$

$$R_e = 38{,}674$$

For 4,000 < Re < 40,000 $\quad N_u = 0.193 R_e^{0.618} \ \cdot \ P_r^{0.33}$ (Çengel, 2008)

$$N_u = 0.193 \cdot 38674^{0.618} \cdot 0.721^{0.33}$$

$$N_u = 118.5$$

$$N_u = \frac{hl}{k_{air}}$$

$$h = \frac{118.5 \ \cdot 0.027861}{1.8}$$

$$h = 1.8 \text{ W/m^2} \cdot \text{K}$$

$$Q_{CON} = hA(\Delta T)$$

$$Q_{CON} = 1.8 \ \cdot (\pi \cdot 1.8 \cdot 8) \cdot \ (86)$$

$$Q_{CON} = 7{,}003W$$

$$Q = 8{,}385 + 7{,}003$$

$$Q = 15kW$$

So the estimated heat loss from the surface of the drum mixer is 15kW which over a half hourly period equates to a fuel loss of

15kW x 30 x 60 = 27MJ

27MJ/37.4MJ = **0.73 fuel = 1.92kgCO_2 for every half hour of operation**

3.4.3 Site Energy Consumption

Shown in Table 8 below is the energy consumption for the whole Killoch site which includes the offices and maintenance workshops. This data covers the financial year from April 2011 to March 2012.

TABLE 8 SITE ENERGY CONSUMPTION 2011 - 2012

	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
Killoch electrical (kWh)	96,706	94,677	89,007	88,233	86,006	85,576	102,048	112,820	124,808	128,289	128,037	116,851
Coating plant electrical (kWh)	28,570	29,129	31,886	27,029	25,999	32,914	32,776	34,015	36,137	36,522	39,224	38,430
Coating plant fuel (litres)							66,542	25,734	17,127	19,394	34,636	34,197
Coating plant fuel (kWh)							691,353	267,369	177,945	201,498	359,858	355,297

The coating plant electrical kWh consumption figures were manually recorded meter readings up to September 2011, and from then submeter readings were used. From October onwards there is also data provided on the fuel consumption of the drum burner as prior to this data metering was not in place. The reason for implementing metering for both the coating plants kWh and fuel consumption is to provide the ability to monitor production energy use and make changes to improve efficiencies, reduce emissions and to reduce costs.

For purposes of analysis readings from October 2011 through to March 2012 were totalled and used in the Sankey diagram shown in Figure 15 below. This shows that the coating plant fuel consumption is the largest percentage of the Killoch site energy consumption, followed by the non-coating plant electrical consumption and then the coating plant electrical consumption.

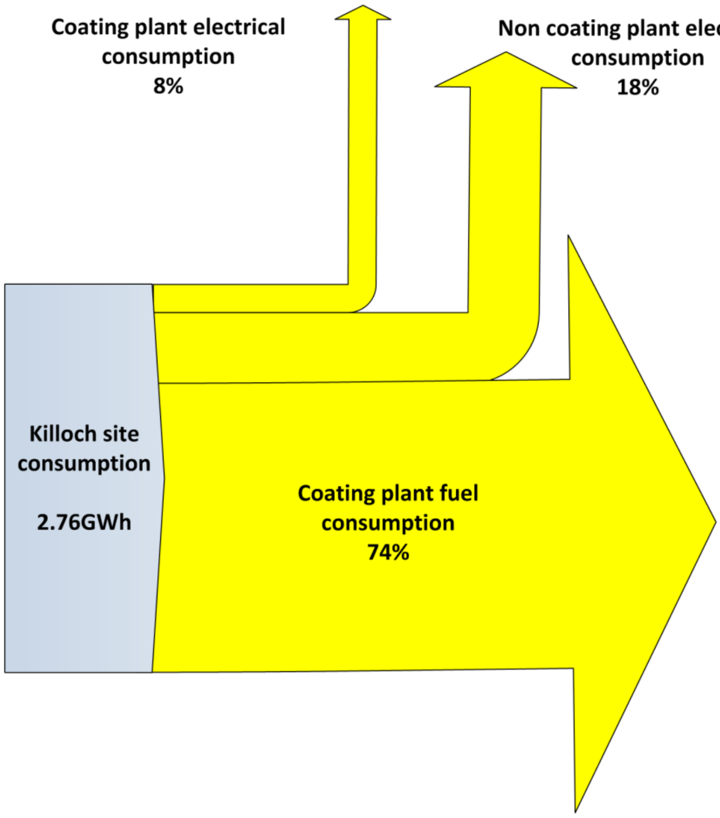


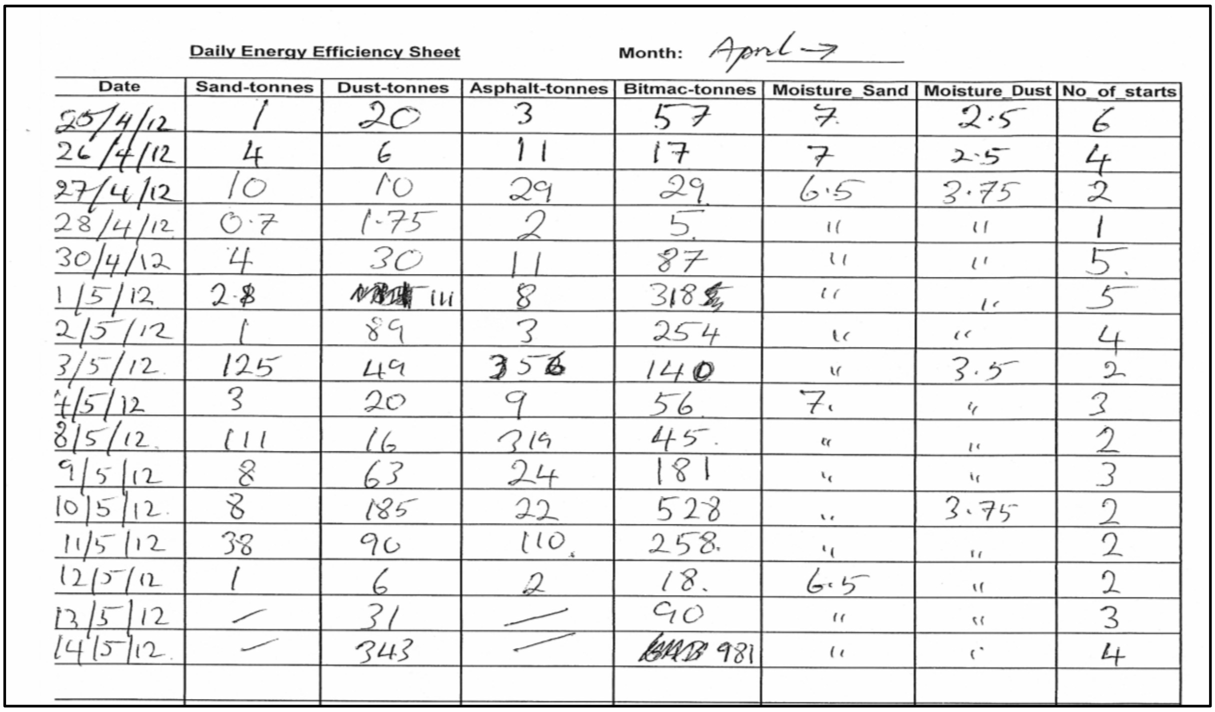
FIGURE 15 KILLOCH SITE TOTAL ENERGY CONSUMPTION 10/11 TO 03/12

3.5 Asphalt Coating Plant Data Analysis

Several sources of data were included in the analysis with the aim of creating a single dataset that would contain mixture information and key factors that influence energy use at the coating plant. As will be shown the commencement date of data used in the analysis is the 13 February 2012 as this is when the energy efficiency data started to be collected. The data across all sources will cover data from this date to the end of June as the data for July is to be used to validate the estimation tools output. The different sources of data will now be covered with any data validation discussed. This will then be followed by the regression analysis of the dataset.

3.5.1 Energy Efficiency Sheet

The first source of data analysed was the energy efficiency sheet which the coating plant operators complete at the end of a daily shift. An example of this is shown Figure 16 below.



Daily Energy Efficiency Sheet

Month: April →

Date	Sand-tonnes	Dust-tonnes	Asphalt-tonnes	Bitmac-tonnes	Moisture_Sand	Moisture_Dust	No_of_starts
25/4/12	1	20	3	57	7	2.5	6
26/4/12	4	6	11	17	7	2.5	4
27/4/12	10	10	29	29	6.5	3.75	2
28/4/12	0.7	1.75	2	5	''	''	1
30/4/12	4	30	11	87	''	''	5
1/5/12	2.8	[illegible] 111	8	318	''	''	5
2/5/12	1	89	3	254	''	''	4
3/5/12	125	49	356	140	''	3.5	2
7/5/12	3	20	9	56	7	''	3
8/5/12	111	16	319	45	''	''	2
9/5/12	8	63	24	181	''	''	3
10/5/12	8	185	22	528	''	3.75	2
11/5/12	38	90	110	258	''	''	2
12/5/12	1	6	2	18	6.5	''	2
13/5/12	–	31	–	90	''	''	3
14/5/12	–	343	–	[illegible] 981	''	''	4

FIGURE 16 DAILY ENERGY EFFICIENCY SHEET

As previously explained the date period for this data is from the 13 February 2012 to the 30 June and contains 139 values. The fields completed by the operator are first of all the date followed by production data which is the amount of sand used in the production of asphalt and the amount of dust used in the production of bitmac. The next data entered is the moisture of the sand and dust which is collected daily using the procedure outlined in the Plant Description section. The last column on the sheet is for the number of times that the plant was started for production and then stopped if no further jobs were scheduled. As can be seen from Figure 16 it is completed manually and as such the data recorded sometimes has to be corrected. Overall the validity and usefulness of the production related data is in question as it cannot easily be validated.

3.5.2 Energy Efficiency Spreadsheet

The data from the energy efficiency sheet is used to populate a spreadsheet which is shown in Figure 17 below. The energy efficiency spreadsheet also includes additional information recorded from the coating plant fuel, electricity metering and data from the humidity and temperature datalogger.

Date	ton_total	sand_tonnes	dust_tonnes	asphalt_tonnes	bitmac_tonnes	temp_min	temp_max	Avg.RH%	moisture_sand	moisture_dust	no_starts	plant_kwh	fuel_litres
5-Apr-12	591	112	101	321	289	1.7	23.3	38%	7.0%	2.50%	3	1841	4918
6-Apr-12	0	0	0	0	0	7.3	9.7	89%				852	0
7-Apr-12	0	0	0	0	0	6.2	13.2	73%				809	0
8-Apr-12	0	0	0	0	0	8.7	10.8	87%				852	0
9-Apr-12	0	0	0	0	0	5.8	10.4	82%				842	0
10-Apr-12	589	118	85	337	242	7.5	15.2	72%	7.5%	2.50%	5	1780	5340
11-Apr-12	327	107	7	306	21	7.9	19.9	51%	7.5%	2.50%	3	1391	3015
12-Apr-12	292	84	16	240	47	5.8	17.1	56%	7.5%	3.00%	3	1622	2904
13-Apr-12	288	92	6	264	17	10.3	19.9	40%	7.5%	3.00%	2	1372	2435
14-Apr-12	231	80	1	228	3	8	13.8	45%	7.5%	3.00%	3	1247	2096
15-Apr-12	38	14	0	38	0	5	23.2	33%	7.0%	3.00%	6	996	352
16-Apr-12	77	2	24	6	68	5	22.6	40%	7.0%	2.50%	2	1313	822
17-Apr-12	103	5	30	14	87	5.6	14.1	67%	6.5%	2.50%	5	1353	1044
18-Apr-12	189	9	57	25	163	6	19.3	46%	6.5%	3.00%	5	1551	1828
19-Apr-12	98	8	26	23	74	5.3	15.2	67%	6.5%	3.00%	3	1255	1029
20-Apr-12	88	5	25	15	72	6.6	20.7	53%	6.5%	2.50%	4	1142	855
21-Apr-12	11	2	1.8	6	5	9	21.3	56%	7.0%	2.50%	2	742	162
22-Apr-12	7	1.4	1	4	3	11.6	18.3	52%	7.0%	3.00%	2	758	131
23-Apr-12	97	2	31	6	89	5.9	15.7	55%	7.0%	3.00%	4	1240	949
24-Apr-12	31	7.5	4	21	11	6.5	23.1	45%	7.0%	3.00%	3	1032	375
25-Apr-12	60	1	20	3	57	5.8	12	67%	7.0%	2.50%	6	1204	636
26-Apr-12	29	4	6	11	17	7.1	10.5	76%	7.0%	2.50%	4	1051	424
27-Apr-12	58	10	10	29	29	11.2	21.7	34%	6.5%	3.75%	2	1100	630
28-Apr-12	7	0.7	1.75	2	5	7.4	14.9	48%	6.5%	3.75%	1	897	84
29-Apr-12		0	0	0	0	4.2	8.9	64%			0	850	0
30-Apr-12	100	4	30	11	87	6.6	15.8	75%	6.5%	3.75%	5	1445	1020
1-May-12	327	2.8	111	8	318	8.7	16.5	70%	6.5%	3.75%	5	1664	2737
2-May-12	255	1	89	3	254	7.3	18.9	63%	6.5%	3.75%	4	1338	2072
3-May-12	498	125	49	356	140	7	21.8	71%	6.5%	3.50%	2	1645	4228
4-May-12	66	3	20	9	56	7.7	15.5	61%	7.0%	3.50%	3	1102	671

FIGURE 17 ENERGY EFFICIENCY SPREADSHEET

As shown in Figure 17 above there are periods of missing data in the spreadsheet which have to be cleaned prior to analysis.

Due to the lack of mixture specific information in the energy efficiency spreadsheet it was decided that the environmental and stop/start data from the spreadsheet should be used in conjunction with the more detailed mixture specific information contained in the sales data.

3.5.3 Sales Data

Sales data was provided by Barr which covered the months from February 2012 to the end of June 2012, an example of which is shown in Figure 18 below and as can be seen it is already in an Excel spreadsheet.

Daily Quarry Material Output Report

KILLOCH 01/02/12 To 29/02/12

barr quarries

Ticket ID	Delivery Date	Time In	Time Out	Vehicle	Haulier	Haulage Type	Cust Ref	Site Address	Material Ref	Material Description	Material Quantity
387188	01/02/12	07:31	08:27							AC 6 DENSE SURF 160/220	5.84
387216	01/02/12	08:31	08:34							0/6MM BARR PAVE	3.64
387240	01/02/12	09:17	09:31							AC 10 CLOSE SURF 160/220	8.76
387243	01/02/12	09:23	09:39							HRA 15/10 F SURF 40/60 REC	6.02
387250	01/02/12	09:31	10:02							AC 20 DENSE DBM BIN 40/60 DES	20.46
387251	01/02/12	09:32	10:35							AC 20 DENSE DBM BIN 40/60 DES	20.34
387315	01/02/12	12:08	12:08							AC 6 DENSE SURF 160/220	6.1
387417	02/02/12	07:52	08:22							AC 6 DENSE SURF 160/220	5.96
387434	02/02/12	08:41	08:52							0/6MM BARR PAVE	6.02
387436	02/02/12	08:42	08:49							0/6MM BARR PAVE	5.1
387495	02/02/12	11:29	11:52							AC 6 DENSE SURF 160/220	4.96
387527	02/02/12	13:03	13:03							AC 14 CLOSE SURF 160/220	16.1
387601	03/02/12	07:44	07:50							AC 20 DENSE DBM BIN 160/220 REC	2
387644	03/02/12	09:17	09:18							0/6MM BARR PAVE	3.88
387645	03/02/12	09:18	09:43							0/6MM BARR PAVE	3.96
387659	03/02/12	09:41	09:41							HRA 15/10 F SURF 40/60 REC	8.58
387688	03/02/12	11:06	11:26							AC 14 CLOSE SURF 160/220	8.42
387730	03/02/12	13:34	13:35							AC 6 DENSE SURF 160/220	2.58
387781	04/02/12	08:03	08:33							AC 32 DENSE DBM BASE 160/220 REC	18
387785	04/02/12	08:51	12:08							0/10MM BARR PAVE	20.5
387789	04/02/12	09:17	11:17							0/10MM BARR PAVE	19.4
387791	04/02/12	09:19	11:19							0/10MM BARR PAVE	20.1

FIGURE 18 BARR FEBRUARY SALES DATA

The sales report includes the material description, material quantity and the time out field which will all be used in the analysis. The timeout field is the time that the truck with the asphalt mixture on board drives over the weighbridge and it is this weight that is billed to the customer. The data included in the sales reports for February through to the end of June were date sorted and then filtered to remove blank entries and material references that didn’t start with a C reference as these are non-coating products.

This cleaned data was then merged into one spreadsheet as shown in Figure 19 below.

Sales Data				
Time Out	Vehicle	Material Ref	Material Description	Material Quantity
1/02/2012 8:27			AC 6 DENSE SURF 160/220	5.84
1/02/2012 8:34			0/6MM BARR PAVE	3.64
1/02/2012 9:31			AC 10 CLOSE SURF 160/220	8.76
1/02/2012 9:39			HRA 15/10 F SURF 40/60 REC	6.02
1/02/2012 10:02			AC 20 DENSE DBM BIN 40/60 DES	20.46
1/02/2012 10:35			AC 20 DENSE DBM BIN 40/60 DES	20.34
1/02/2012 12:08			AC 6 DENSE SURF 160/220	6.1
2/02/2012 8:22			AC 6 DENSE SURF 160/220	5.96
2/02/2012 8:49			0/6MM BARR PAVE	5.1
2/02/2012 8:52			0/6MM BARR PAVE	6.02
2/02/2012 11:52			AC 6 DENSE SURF 160/220	4.96
2/02/2012 13:03			AC 14 CLOSE SURF 160/220	16.1
3/02/2012 7:50			AC 20 DENSE DBM BIN 160/220 REC	2
3/02/2012 9:18			0/6MM BARR PAVE	3.88
3/02/2012 9:41			HRA 15/10 F SURF 40/60 REC	8.58
3/02/2012 9:43			0/6MM BARR PAVE	3.96
3/02/2012 11:26			AC 14 CLOSE SURF 160/220	8.42
3/02/2012 13:35			AC 6 DENSE SURF 160/220	2.58
4/02/2012 8:33			AC 32 DENSE DBM BASE 160/220 REC	18
4/02/2012 10:54			HRA 35/14 F SURF 40/60 DES	12
6/02/2012 8:32			AC 6 DENSE SURF 160/220	6.1
6/02/2012 9:03			HRA 30/14 F SURF 40/60 DES	1.88
6/02/2012 10:30			0/6MM BARR PAVE	4.62
6/02/2012 10:32			0/6MM BARR PAVE	3.7
6/02/2012 14:18			AC 20 DENSE DBM BIN 40/60 DES	20.56
6/02/2012 14:20			AC 20 DENSE DBM BIN 40/60 DES	21.9
6/02/2012 14:21			10MM BARTEX HT THIN SURF STYRELF 13/80 65 PSV	19.44
6/02/2012 14:22			10MM BARTEX HT THIN SURF STYRELF 13/80 65 PSV	20.8
6/02/2012 14:22			10MM BARTEX HT THIN SURF STYRELF 13/80 65 PSV	19.64
6/02/2012 14:22			10MM BARTEX HT THIN SURF STYRELF 13/80 65 PSV	19.2

FIGURE 19 MERGED SALES DATA

3.5.4 Metering Data

To include the electrical and fuel consumption for each asphalt mixture in the sales report the metering data for the matching date period was obtained from Barr. This data was already in an Excel spreadsheet and as shown in Figure 20 below this metering data is in 30 minute increments.

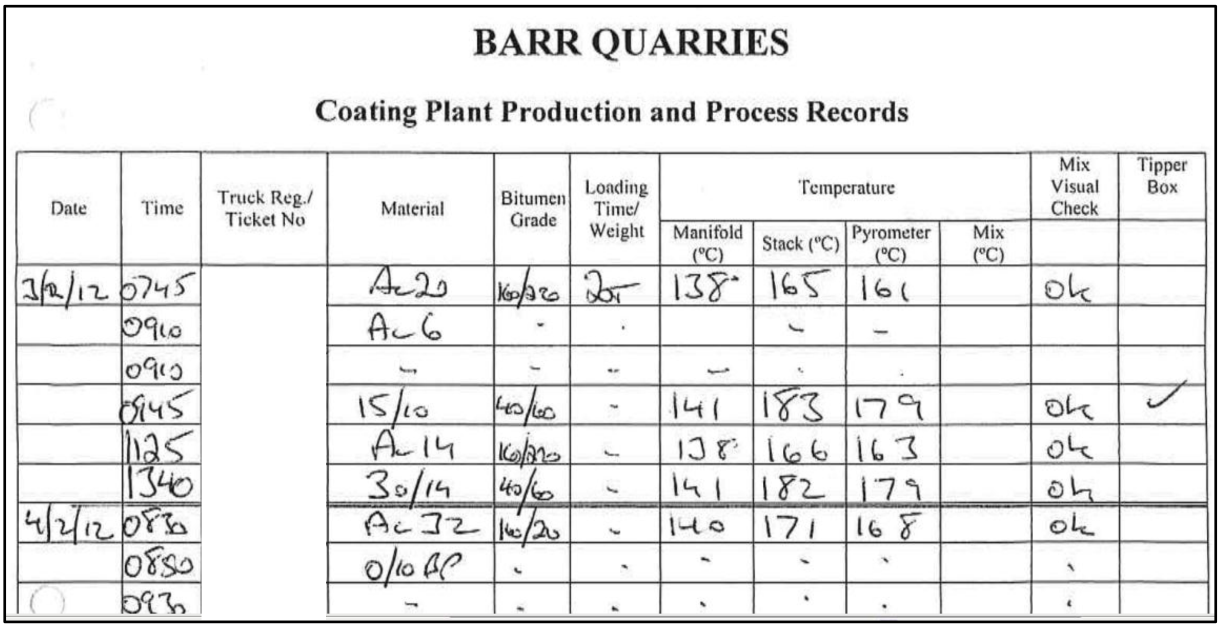
Week 1		
HH Period	kWh	Litre
6/02/2012 5:00	24	0
6/02/2012 5:30	13	0
6/02/2012 6:00	30	0
6/02/2012 6:30	18	0
6/02/2012 7:00	20	0
6/02/2012 7:30	39	0
6/02/2012 8:00	24	0
6/02/2012 8:30	60	91
6/02/2012 9:00	56	148
6/02/2012 9:30	48	45
6/02/2012 10:00	30	0
6/02/2012 10:30	59	108
6/02/2012 11:00	32	0
6/02/2012 11:30	33	0
6/02/2012 12:00	23	0
6/02/2012 12:30	40	0

FIGURE 20 METERING DATA

Metering data was added to the efficiency and sales data using the Excel VLOOKUP function which matched the date and time from each mixture to the closest match in the metering data. Closest match in the function means either an exact time match for the date and time or for a time that is lower, to the nearest half hour increment.

3.5.5 Coating Plant Production and Process Records

The operators in the control room of the coating plant complete a record of the asphalt batches produced and key temperatures, an example of this sheet is shown in Figure 21 below.



BARR QUARRIES

Coating Plant Production and Process Records

Date	Time	Truck Reg./ Ticket No	Material	Bitumen Grade	Loading Time/ Weight	Temperature				Mix Visual Check	Tipper Box
						Manifold (°C)	Stack (°C)	Pyrometer (°C)	Mix (°C)		
3/2/12	0745		Ac20	160/220	20t	138°	165	161		ok	
	0910		Ac6	-	-		-	-			
	0910		-	-	-	-	-	-			
	0945		15/10	40/60	-	141	183	179		ok	✓
	1125		Ac14	160/220	-	138	166	163		ok	
	1340		30/14	40/60	-	141	182	179		ok	
4/2/12	0830		Ac32	160/220	-	140	171	168		ok	
	0850		0/10 BC	-	-	-	-	-		-	
	0930		-	-	-	-	-	-		-	

FIGURE 21 COATING PLANT PRODUCTION AND PROCESS RECORDS

The data in the coating plant production and process records were manually added into a spreadsheet so that the process temperatures could be added into the dataset. To include them in the dataset the unique ticket number present in both the sales report and in the coating plant production and process data was referenced.

It was decided to use the mixture production date and time from the coating plant production and process record as this was deemed to be more reliable as this is the time that the mixture is loaded onto a truck prior to being weighed at the weighbridge. This means that the time will more closely correlate to the period of energy use. This decision was also reinforced by discrepancies in the sales report data as detailed in Figure 22 below, which shows errors in the timeout of material in the sales data which was being used to match the metering data.

Ticket ID	Time In	Time Out	Vehicle	Material Ref	Material Description	Material Quantity
405308	26/05/2012 5:05	31/05/2012 15:22		C010A	AC 20 DENSE DBM BIN 40/60 REC	20.3
405312	26/05/2012 6:28	31/05/2012 15:22		C010A	AC 20 DENSE DBM BIN 40/60 REC	20.22
405313	26/05/2012 6:36	31/05/2012 15:22		C010A	AC 20 DENSE DBM BIN 40/60 REC	18.92
405315	26/05/2012 6:58	31/05/2012 15:22		C010A	AC 20 DENSE DBM BIN 40/60 REC	19.74
405319	26/05/2012 7:09	31/05/2012 15:22		C010A	AC 20 DENSE DBM BIN 40/60 REC	19.96
405321	26/05/2012 7:12	31/05/2012 15:23		C010A	AC 20 DENSE DBM BIN 40/60 REC	19.78
405325	26/05/2012 7:51	31/05/2012 15:23		C010A	AC 20 DENSE DBM BIN 40/60 REC	19.7

Sales data – 26 May 2012

					Temperatures °C			
Ticket ID	Operator Time	Material Description	Material Quantity	Loading Time/Weight	Manifold	Stack	Pyrometer	Mix
405308	26/05/2012 5:05	AC 20 DENSE DBM BIN 40/60 REC	20.3	20	148	179	176	
405312	26/05/2012 6:30	AC 20 DENSE DBM BIN 40/60 REC	20.22	20	148	179	176	
405313	26/05/2012 6:36	AC 20 DENSE DBM BIN 40/60 REC	18.92	20	148	179	176	175
405315	26/05/2012 7:00	AC 20 DENSE DBM BIN 40/60 REC	19.74	20	148	179	176	
405319	26/05/2012 7:09	AC 20 DENSE DBM BIN 40/60 REC	19.96	20	148	179	176	
405321	26/05/2012 7:12	AC 20 DENSE DBM BIN 40/60 REC	19.78	20	148	179	176	
405325	26/05/2012 8:00	AC 20 DENSE DBM BIN 40/60 REC	19.7	20	148	179	176	

Coating plant production and process record data – 26 May 2012

FIGURE 22 SALES DATA ERROR

3.5.6 Heating Degree Days

To determine the usefulness of HDD as a means of taking into account the influence of ambient temperature on energy use an HDD base temperature of 100°C was used as this is closer to the temperature within the drum dyer/mixer. An example of the data is shown Figure 23 below.

Description:	Celsius-based heating degree days for a base temperature of 100.0C	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)	
Station:	Prestwick Airport (4.59W,55.51N)	
Station ID:	EGPK	
Date	HDD	% Estimated
13/02/2012	93	0
14/02/2012	92.4	0
15/02/2012	91.8	0
16/02/2012	92	0
17/02/2012	91.9	0
18/02/2012	95.1	0
19/02/2012	96.7	0
20/02/2012	92.8	0
21/02/2012	89.7	0
22/02/2012	89.3	0

FIGURE 23 HDD DATA

3.5.7 Data Quality Assurance

On closer analysis of the dataset created from the sales and metering data it was discovered that some mixtures had the same matched kWh and litre energy values. This is due to the VLOOKUP function matching the closest metering data which means that numerous times in the same half hour increment can be matched to the same meter reading.

One approach would be to decrease the metering time increment however this requires changes to both metering and data recording software settings. It also requires an increase to the amount of space on servers to take the increased amount in data. Another issue is that the change isn't retrospective meaning that within the scope of this project it cannot be applied to the data already collected.

As the time recorded on the coating plant production and process record is the time that the mixture is loaded onto a truck prior to leaving the site confirmation was obtained from Barr to determine the usual time lag between the asphalt mixture being produced and the time it is loaded onto the truck. This time lag was deemed usually to be no more than ten minutes as the asphalt mixes cannot spend excessive time in the storage hoppers as the mixture will begin to set.

To correct the operator time so that the metering period for 10 minutes prior is matched a formula in Excel was used with the logic described in Table 9 below.

TABLE 9 OPERATOR TIME ADJUSTMENT LOGIC

Operator Time	If Rule	Adjusted Time
8:15	>0 & <30	8:00
8:50	>30 & <59	8:30
8:30	=30	8:00
9:00	=0	8:30

An example of the data with duplicate values highlighted in orange and underlined in red is shown in Figure 24 below .

			Meterng Matches		Metering Data		
Adjusted time	Material Description	Material Quantity	kWh	Litre	HH Period	kWh	Litre
1/02/2012 8:00	0/6MM BARR PAVE	3.64	41	24	1/02/2012 0:00	20	0
1/02/2012 8:00	AC 6 DENSE SURF 160/220	5.84	41	24	1/02/2012 0:30	21	0
1/02/2012 9:00	AC 10 CLOSE SURF 160/220	8.76	65	26	1/02/2012 1:00	11	0
1/02/2012 9:30	AC 20 DENSE DBM BIN 40/60 DES	20.46	68	152	1/02/2012 1:30	22	0
1/02/2012 9:30	HRA 15/10 F SURF 40/60 REC	6.02	68	152	1/02/2012 2:00	21	0
1/02/2012 10:00	AC 20 DENSE DBM BIN 40/60 DES	20.34	71	285	1/02/2012 2:30	11	0
1/02/2012 12:00	AC 6 DENSE SURF 160/220	6.1	61	82	1/02/2012 3:00	24	0
2/02/2012 8:00	AC 6 DENSE SURF 160/220	5.96	43	50	1/02/2012 3:30	24	0
2/02/2012 8:30	0/6MM BARR PAVE	6.02	65	156	1/02/2012 4:00	12	0
2/02/2012 8:30	0/6MM BARR PAVE	5.1	65	156	1/02/2012 4:30	26	0
2/02/2012 11:30	AC 6 DENSE SURF 160/220	4.96	29	0	1/02/2012 5:00	22	0
2/02/2012 12:30	AC 14 CLOSE SURF 160/220	16.1	29	0	1/02/2012 5:30	13	0
3/02/2012 7:30	AC 20 DENSE DBM BIN 160/220 REC	2	37	27	1/02/2012 6:00	31	0
3/02/2012 9:00	0/6MM BARR PAVE	3.88	65	143	1/02/2012 6:30	19	0
3/02/2012 9:00	0/6MM BARR PAVE	3.96	65	143	1/02/2012 7:00	18	0
3/02/2012 9:30	HRA 15/10 F SURF 40/60 REC	8.58	64	89	1/02/2012 7:30	40	0
3/02/2012 11:00	AC 14 CLOSE SURF 160/220	8.42	26	0	1/02/2012 8:00	41	24
3/02/2012 13:30	AC 6 DENSE SURF 160/220	2.58	53	63	1/02/2012 8:30	67	156
4/02/2012 8:00	AC 32 DENSE DBM BASE 160/220 REC	18	32	4	1/02/2012 9:00	65	26
4/02/2012 8:00	0/10MM BARR PAVE	20.5	32	4	1/02/2012 9:30	68	152
4/02/2012 9:00	0/10MM BARR PAVE	19.4	72	293	1/02/2012 10:00	71	285
4/02/2012 9:30	0/10MM BARR PAVE	20.1	69	217	1/02/2012 10:30	64	152
4/02/2012 10:30	HRA 35/14 F SURF 40/60 DES	12	47	69	1/02/2012 11:00	45	0
5/02/2012 7:00	0/10MM BARR PAVE	19.4	65	102	1/02/2012 11:30	48	0
5/02/2012 7:00	0/10MM BARR PAVE	19.4	65	102	1/02/2012 12:00	61	82
5/02/2012 7:30	AC 20 DENSE DBM BIN 40/60 DES	20.56	72	318	1/02/2012 12:30	38	0
5/02/2012 8:00	AC 20 DENSE DBM BIN 40/60 DES	20.58	73	285	1/02/2012 13:00	36	0
5/02/2012 8:00	AC 20 DENSE DBM BIN 40/60 DES	20.42	73	285	1/02/2012 13:30	9	0

FIGURE 24 DUPLICATE ENERGY MATCHES

The total number of values, duplicate and the percentage of duplicate in the data are shown in Table 10 below.

TABLE 10 DUPLICATE VALUES

	kWh	Litre
duplicates	1188	1180
total values	1742	1742
% duplicates	68%	68%

Some of the mixtures also have zero values for their energy values as shown in Figure 25 below.

			Meterng Matches		Metering Data		
Adjusted time	Material Description	Material Quantity	kWh	Litre	HH Period	kWh	Litre
1/02/2012 8:00	0/6MM BARR PAVE	3.64	41	24	1/02/2012 0:00	20	0
1/02/2012 8:00	AC 6 DENSE SURF 160/220	5.84	41	24	1/02/2012 0:30	21	0
1/02/2012 9:00	AC 10 CLOSE SURF 160/220	8.76	65	26	1/02/2012 1:00	11	0
1/02/2012 9:30	AC 20 DENSE DBM BIN 40/60 DES	20.46	68	152	1/02/2012 1:30	22	0
1/02/2012 9:30	HRA 15/10 F SURF 40/60 REC	6.02	68	152	1/02/2012 2:00	21	0
1/02/2012 10:00	AC 20 DENSE DBM BIN 40/60 DES	20.34	71	285	1/02/2012 2:30	11	0
1/02/2012 12:00	AC 6 DENSE SURF 160/220	6.1	61	82	1/02/2012 3:00	24	0
2/02/2012 8:00	AC 6 DENSE SURF 160/220	5.96	43	50	1/02/2012 3:30	24	0
2/02/2012 8:30	0/6MM BARR PAVE	6.02	65	156	1/02/2012 4:00	12	0
2/02/2012 8:30	0/6MM BARR PAVE	5.1	65	156	1/02/2012 4:30	26	0
2/02/2012 11:30	AC 6 DENSE SURF 160/220	4.96	29	0	1/02/2012 5:00	22	0
2/02/2012 12:30	AC 14 CLOSE SURF 160/220	16.1	29	0	1/02/2012 5:30	13	0
3/02/2012 7:30	AC 20 DENSE DBM BIN 160/220 REC	2	37	27	1/02/2012 6:00	31	0
3/02/2012 9:00	0/6MM BARR PAVE	3.88	65	143	1/02/2012 6:30	19	0
3/02/2012 9:00	0/6MM BARR PAVE	3.96	65	143	1/02/2012 7:00	18	0
3/02/2012 9:30	HRA 15/10 F SURF 40/60 REC	8.58	64	89	1/02/2012 7:30	40	0
3/02/2012 11:00	AC 14 CLOSE SURF 160/220	8.42	26	0	1/02/2012 8:00	41	24
3/02/2012 13:30	AC 6 DENSE SURF 160/220	2.58	53	63	1/02/2012 8:30	67	156
4/02/2012 8:00	AC 32 DENSE DBM BASE 160/220 REC	18	32	4	1/02/2012 9:00	65	26
9/02/2012 10:00	AC 20 DENSE DBM BIN 160/220 REC	20.2	72	251	2/02/2012 7:30	18	0
9/02/2012 10:30	AC 20 DENSE DBM BIN 160/220 REC	20.26	62	135	2/02/2012 8:00	43	50
9/02/2012 11:00	AC 10 CLOSE SURF 160/220	8.56	38	0	2/02/2012 8:30	65	156
9/02/2012 11:30	HRA 30/14 F SURF 40/60 DES	3	62	90	2/02/2012 9:00	44	0
9/02/2012 11:30	AC 20 DENSE DBM BIN 160/220 REC	4.98	62	90	2/02/2012 9:30	37	0
9/02/2012 12:00	AC 20 DENSE DBM BIN 160/220 REC	20.44	68	176	2/02/2012 10:00	21	0
9/02/2012 12:30	AC 10 CLOSE SURF 160/220	15.8	67	150	2/02/2012 10:30	14	0
9/02/2012 13:00	AC 20 DENSE DBM BIN 160/220 REC	20.36	72	267	2/02/2012 11:00	24	0
10/02/2012 7:30	AC 20 DENSE DBM BIN 160/220 REC	20.5	43	81	2/02/2012 11:30	29	0
10/02/2012 8:00	HRA 30/14 F SURF 40/60 DES	3	68	163	2/02/2012 12:00	42	70
10/02/2012 8:00	AC 20 DENSE DBM BIN 160/220 REC	7	68	163	2/02/2012 12:30	29	0
10/02/2012 8:00	HRA 15/10 F SURF 40/60 REC	1	68	163	2/02/2012 13:00	65	176
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FIGURE 25 ZERO ENERGY VALUES

Using conditional formatting mixture energy matches that contained zero values were highlighted in yellow. The total number of zero values for kWh and litres are shown in Table 11 below.

TABLE 11 ZERO ENERGY VALUES

	kWh	Litre
zero values	0	243
total values	1742	1742
% zero values	0%	14%

The first step to resolve the duplicate energy values was to identify them using the VBA macro detailed in Appendix C, and then adjusting them using the VBA macro detailed in Appendix D. The duplicate energy values were adjusted using the logic detailed in Equation 5 and Equation 6 below.

EQUATION 5

$$Adjusted\ kWh = \frac{kWh\ Duplicate\ Reading}{\sum Material\ Quantity}\ x\ Material\ Quantity$$

EQUATION 6

$$Adjusted\ Litre = \frac{Litre\ Duplicate\ Reading}{\sum Material\ Quantity}\ x\ Material\ Quantity$$

All days that contained zero values for kWh and litres were removed as there was no quick way to resolve where the energy used for each mixture was used in that day, and as the data set was large this technique was deemed the most appropriate. The result of this zero value removal was that the number of values was reduced from 1,742 to 351 which is an 80% reduction.

The next step in the data quality assurance was to remove outliers from the data using Equation 7 and Equation 8 below to calculate the z-value for each energy value. If the z-value was more than 3, or less than – 3 it was removed.

EQUATION 7

$$\text{z value} = \frac{kWh/t/day\ -\ Mean}{\text{SD}}$$

EQUATION 8

$$\text{z value} = \frac{Litre/t/day\ -\ Mean}{\text{SD}}$$

The data table for the z-value calculations is shown in Table 12 below.

TABLE 12 OUTLIER CALCULATIONS

	kWh/t/0.5hr	Litre/t/0.5hr
Mean	4.8	0.8
SD	6.1	0.6
Values	208	208
z > 3	3	0
%	1.4%	0.0%

The result of the outlier removal is that the number of values was reduced from 351 to 348 values.

3.5.8 Large Dataset Regression

The efficiency, process temperatures, moisture levels and HDD values were added to the cleaned data and zero efficiency values were removed resulting in 316 values. Multivariate regression analysis was then undertaken to predict both litre and kWh dependent values. The results of the regression analysis are shown in Figure 26 below.

KWH SUMMARY OUTPUT				LITRE SUMMARY OUTPUT		
Regression Statistics				*Regression Statistics*		
R Square	0.233264636			R Square	0.348849595	
Observations	316			Observations	316	
	Coefficients	*P-value*			*Coefficients*	*P-value*
Intercept	-401.9491396	0.006261667		Intercept	-883.5861189	0.104877081
Material Quantity	1.387702283	7.69211E-17		Material Quantity	5.730249479	6.21286E-20
Manifold °C	-0.026117795	0.841710427		Manifold °C	0.820696942	0.092421182
Stack °C	-0.204130508	0.829714291		Stack °C	-0.940242833	0.790049618
Pyrometer °C	-0.05343349	0.955892796		Pyrometer °C	1.273812324	0.723082256
Stop/Starts	0.17403707	0.861533013		Stop/Starts	0.650843513	0.860830945
temp_min	0.972468689	0.113799642		temp_min	2.678892231	0.241233984
temp_max	2.552357998	0.000214608		temp_max	1.803584066	0.477302008
Avg.RH%	62.28736058	0.003293987		Avg.RH%	71.50366851	0.361438998
moisture_sand	476.5143473	0.063538022		moisture_sand	1622.807872	0.089304117
moisture_dust	252.7485556	0.297780874		moisture_dust	134.0353428	0.881920059
HDD	3.661384713	0.003816647		HDD	5.785227957	0.216635425

FIGURE 26 LARGE DATASET REGRESSION RESULTS

The R^2 results for both the kWh and litre regression in Figure 26 are very low which indicates that the trendline explains a low percentage of the dependent values. However the results do indicate the significance of the cells highlighted.

Additional regression analyses were also undertaken on data where rows containing zero values were removed which returned similar results to those presented. Also regression analysis was undertaken using mixture types and mixture families which also returned similar results.

As the mixture specific dataset returned weak regression results it was decided to create a dataset with the daily energy efficiency data, corresponding daily energy values and daily tonnage values.

3.5.9 Reduced Dataset Regression

Following the creation of a dataset containing values for the daily tonnage, efficiency, energy, moisture levels and HDD the outliers were removed using the method previously described which resulted in a total number of 112 values, which are shown in Appendix E. The process temperatures were removed from the analysis as these are mixture specific values.

Shown in Figure 27 below are the results from the reduced dataset regression analysis with the p-values of the key independent variables highlighted.

KWH SUMMARY OUTPUT		
Regression Statistics		
R Square	0.839831012	
Observations	112	
	Coefficients	*P-value*
Intercept	152.3450398	0.832280826
Stop/Starts	41.11790128	9.71211E-08
temp_min	-3.198347778	0.562993399
temp_max	-3.373356006	0.443329083
Avg.RH%	-19.54486349	0.888095922
moisture_sand	4496.91247	0.047179396
moisture_dust	2912.843025	0.192793252
HDD	5.077834939	0.463570133
Material Quantity	1.43442386	3.27075E-35

LITRE SUMMARY OUTPUT		
Regression Statistics		
R Square	0.986278094	
Observations	112	
	Coefficients	*P-value*
Intercept	-2271.539013	0.019454901
Stop/Starts	27.99176971	0.004187401
temp_min	1.559481657	0.832395103
temp_max	5.182232474	0.377413004
Avg.RH%	252.8469081	0.174152056
moisture_sand	7066.221229	0.019803871
moisture_dust	-2286.795714	0.44202439
HDD	18.17249653	0.051011113
Material Quantity	8.169533252	7.08388E-95

FIGURE 27 REDUCED DATASET REGRESSION RESULTS

The R^2 results for both the kWh and litre regression are high which indicates that the trendline explains a high percentage of the dependent values. Also the highlighted p-values show that the independent variables have a high predictive power when used to estimate the dependent variable and that they are not random.

A further regression analysis was undertaken using the key independent variables that can be used as inputs to the estimation tool which produced the results shown in Figure 28 below.

KWH SUMMARY OUTPUT		
Regression Statistics		
R Square	0.783121975	
Observations	112	
	Coefficients	*P-value*
Intercept	902.8958522	5.58777E-53
Stop/Starts	39.56461311	2.72673E-06
Material Quantity	1.466797028	2.40007E-33

LITRE SUMMARY OUTPUT		
Regression Statistics		
R Square	0.985052702	
Observations	112	
	Coefficients	*P-value*
Intercept	-1463.234252	0.000298015
HDD	16.87074949	0.000165058
Stop/Starts	26.62110011	0.006757921
Material Quantity	8.139869189	7.78264E-98

FIGURE 28 KEY INDEPENDENT VARIABLES

The large negative intercept in the litre regression indicates a very large theoretical base load which cannot be true due to fuel litre consumption being used only when the drum dryer/mixer is in use. This differs to the kWh intercept where there is a large positive value, as the daily kWh consumption does have a base load of non-production consumption.

As the HDD independent variable was an introduced independent variable and not part of the existing data being recorded it was excluded from the regression analysis to determine if it was the cause for the negative intercept. The regression analysis results for the litre dependent variable without the HDD independent variable is shown in Figure 29 below.

LITRE SUMMARY OUTPUT		
Regression Statistics		
R Square	0.982943313	
Observations	112	
	Coefficients	*P-value*
Intercept	57.76501373	0.150170221
Stop/Starts	23.46030839	0.023527345
Material Quantity	8.196698285	1.85634E-96

FIGURE 29 KEY INDEPENDENT VARIABLES WITHOUT HDD

The results indicate that the HDD variable was the cause of the negative intercept coefficient and as such this regression result and the previously shown kWh result were used to create energy prediction formulas for the tool.

3.6 Energy Consumption Tool

As previously explained the main project deliverable is a software tool that can be used to estimate energy usage at Barr Limited's Killoch asphalt coating plant. Shown in Figure 30 below is a high level flow diagram of the tool detailing the inputs and outputs of the tool.

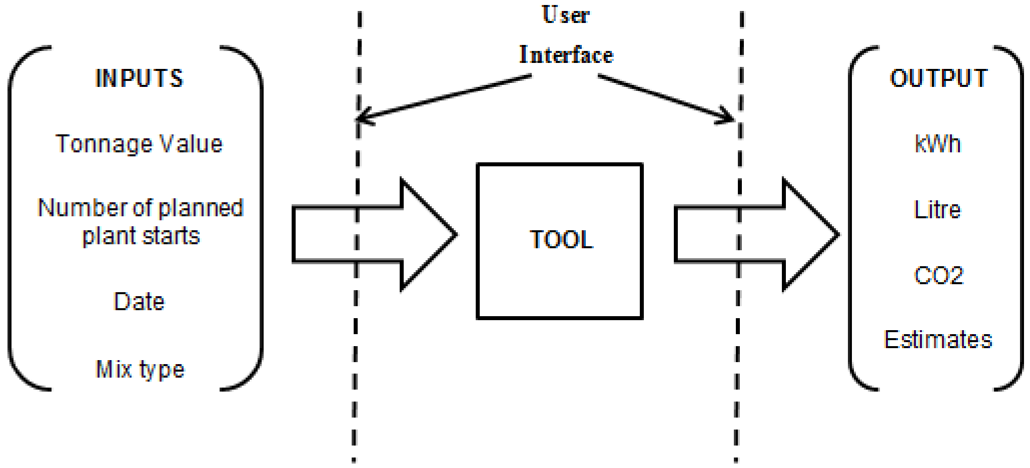


FIGURE 30 ENERGY ESTIMATION TOOL - FLOW DIAGRAM

3.6.1 Requirements

Barr require a tool that can be used to estimate the energy consumption used in the production of asphalt mixtures. The key functionality and outputs from the tool are listed below:

- Provide energy estimates in kWh and litres for a selected batch of asphalt mixes, and for a planned number of plant starts.
- Estimate the amount of CO_2 produced for the estimated energy used.

3.6.2 Design

Using the litre and kWh regression results the formulas below were created which were then implemented in the VBA user form macro detailed in Appendix F.

EQUATION 9

$$\text{ykWh} = 39.56461311 * \text{number of stop/starts} + 1.466797028 * \text{material quantity} + 902.8958522$$

EQUATION 10

$$\text{yLitre} = 23.46030839 * \text{number of stop/starts} + 8.196698285 * \text{material quantity} + 57.76501373$$

To calculate the estimated CO_2 emission the formulas detailed in Appendix G were used in conjunction with the user form code.

Shown in Figure 31 below is a screenshot of the energy estimation user form with a sample of asphalt mixes, estimated energy use and CO_2 emissions.

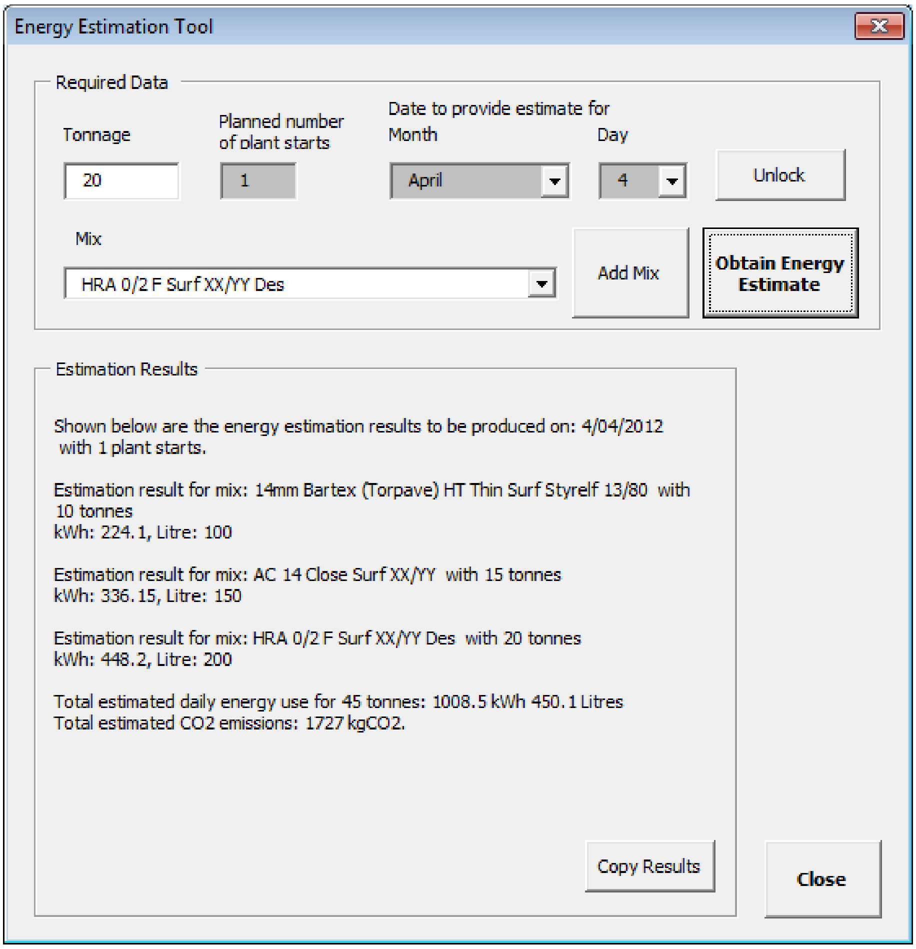


FIGURE 31 EXAMPLE OF USER FORM

4 Results and Discussion

In this section results that impact the energy used within the coating plant are presented and discussed. The tool validation is also presented in this section which details the accuracy of the developed tool.

4.1 Coating Plant Totals

Using the dataset shown in Appendix E the values shown in Table 13 below were calculated. Using fuel prices covering the months analysed the estimated cost (DECC_b, 2012) (DECC_c, 2012) has been included for both kWh and litre consumption per tonne.

TABLE 13 COATING PLANT TOTALS

Material Quantity (t)	22,838
kWh	189,946
Litres	211,531
kWh/t	8
Litres/t	9
kWh/t cost	£0.56
Litres/t cost	£6.00
kWh/t kgCO2	4.5
Litres/t kgCO2	24.3

The estimated fuel cost per tonne of material to heat and dry aggregate is nearly ten times that to electrically power the coating plant and the carbon emission from fuel usage is more than five times that of the electrical consumption. This shows that in addition to the expected high fuel usage to dry and mix the aggregate there is also a considerable associated carbon footprint meaning that steps should be undertaken to minimise the fuel consumption. Using the data contained in Table 13 the estimated totals for both cost and carbon emissions per tonne can be calculated as shown in Table 14 below. This data can be used by Barr to give them a better idea of the amount of energy involved in the production of asphalt and provide them with an estimate of the true energy cost which can be used to price jobs.

TABLE 14 ESTIMATED COST AND KGCO$_2$ PER TONNE

Cost/t	£6.56
kgCO2/t	28.8

4.2 Total Coating Plant Energy Use

The metering data from 1 February 2012 to 30 June 2012 was used to create the pie chart shown in Figure 32 below which shows that the drum dryer/mixer consumes 92% of the equivalent kWh energy consumption. This data differs from that used in the Sankey diagram shown in Figure 15 in the Site Energy Consumption section as this covers data from February through to the end of June. It does show the large amount of energy required to dry and heat aggregate in an asphalt coating plant, as it accounts for 92% of the total equivalent energy consumption.

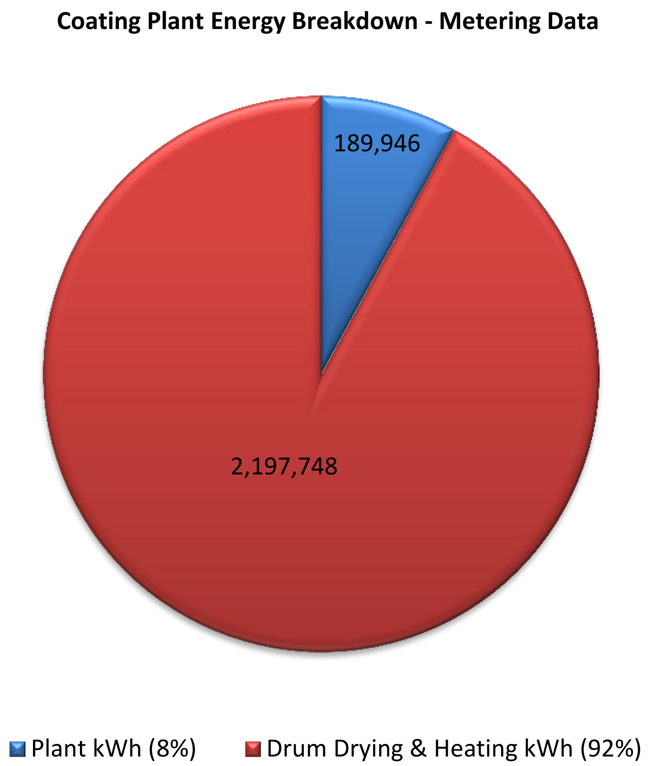


FIGURE 32 COATING PLANT ENERGY BREAKDOWN

4.3 Effect of Estimated Convective and Irradiative Losses on Fuel Consumption

Using the estimated drum dryer/mixer convective and irradiative losses per half hour metering period the estimated losses were calculated in terms of litres of fuel, cost and in CO_2 emissions as shown in Table 15 below.

TABLE 15 ESTIMATED IMPACT OF CONVECTIVE AND IRRADIATIVE LOSSES

	Total fuel usage (litres)	Number of metering periods	Estimated Impact of Convective and Irradiative Losses			
			Litres	£	kgCO2	Litres %
Feb-12	34,215	238	173.7	£112.5	455.9	0.5%
Mar-12	34,197	280	204.4	£132.3	536.3	0.6%
Apr-12	41,626	249	181.8	£117.7	477.0	0.4%
May-12	65,809	342	249.7	£161.6	655.1	0.4%
Jun-12	35,684	276	201.5	£130.4	528.7	0.6%
Total	211,531	1,385	1,011.1	£654.6	2,653	2.5%

The Sankey diagram in Figure 33 below depicts the data contained in Table 15 and graphically shows the estimated losses from the drum's surface which account for a small percentage of the overall fuel consumption. Whether or not it is financially viable for Barr to insulate the drum is dependent on the cost of insulating the drum and on the duration of time that the plant will be out of commission due to the retrofitting of the insulation.

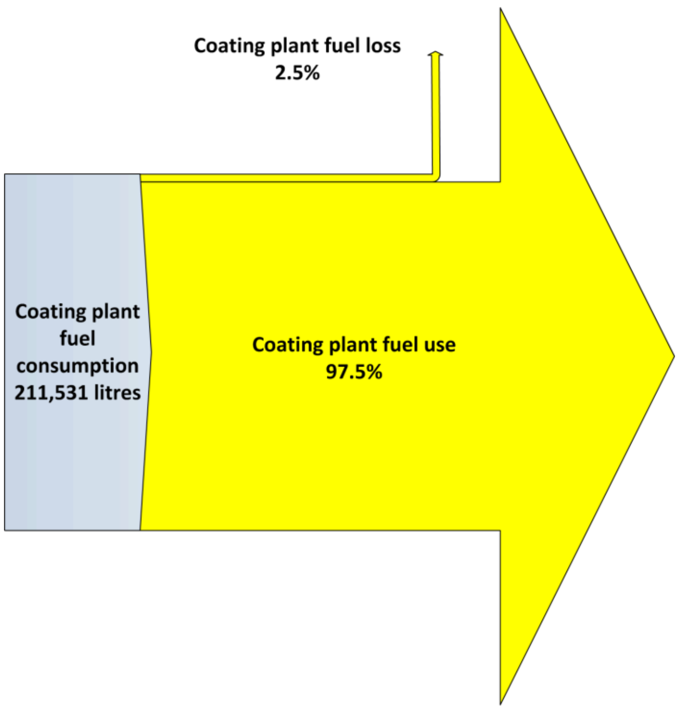


FIGURE 33 ESTIMATED FUEL LOSS

4.4 Coating Plant Electrical Consumption

To examining the half hourly metering data for the coating plant the pie chart in Figure 34 below was produced which shows the production specific kWh consumption and the non-production kWh consumption. Production related kWh is taken to be a half hourly kWh period that has a corresponding litre period that has a value greater than zero. As fuel consumption only occurs when the drum dryer/mixer is in use this will correspond to a litre value greater than zero.

From Figure 34 it can be observed that non production electrical consumption accounts for 58% of the total electrical usage. This larger demand is due to the water pumps, lighting, bitumen heaters and other non-production electrical consumption.

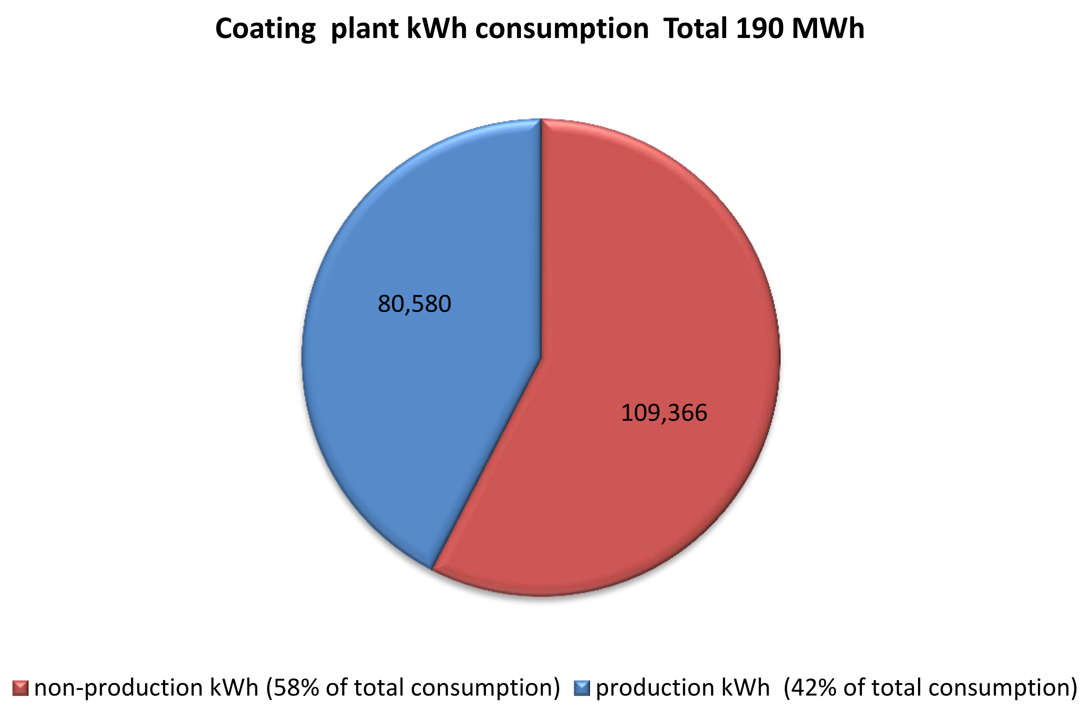


FIGURE 34 ELECTRICAL PRODUCTION SPECIFIC KWH CONSUMPTION

This is a large value for non-production kWh consumption which equates to an estimated cost of £7,404 as shown below in Table 16. As such a detailed energy audit should be undertaken to determine which plant equipment can be turned off or have their efficiency increased. Another aspect of the non-production kWh consumption is that it accounts for 59,163 $kgCO_2$ over a five month period which is a large value that Barr could reduce through energy reduction measures.

TABLE 16 SPLIT KWH CONSUMPTION TOTALS

	non-production kWh	production kWh
Total kWh	109,366	80,580
Percentage	58%	42%
CO2kg	59,167	43,594
Cost	£7,404	£5,455

4.5 Material Quantity

Shown in Figure 35 below is a chart detailing the daily material quantity, kWh and litre consumption for the data shown in Appendix E. As one would expect there is a close correlation between the increase in material quantity and the increases in litre and kWh consumption. However the kWh values are not clustered as tightly as the litre values which may indicate the influence of non-production electrical consumption, whereas the litre consumption is directly related to production.

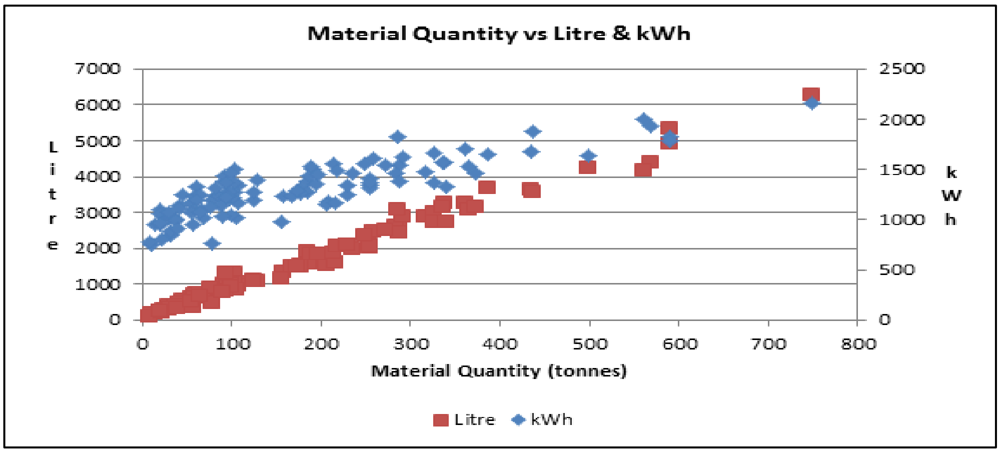


FIGURE 35 MATERIAL QUANTITY AND ENERGY CHART

Shown in Figure 36 below is the specific energy consumption against material quantity which indicates that it is more economical to have a daily plant throughput of at least 100 tonnes as both kWh and litre consumption level out at lower values after this threshold. It also gives an indication that the litre consumption is dependent on more variables than material quantity whereas electrical kWh consumption is more closely related to material quantity.

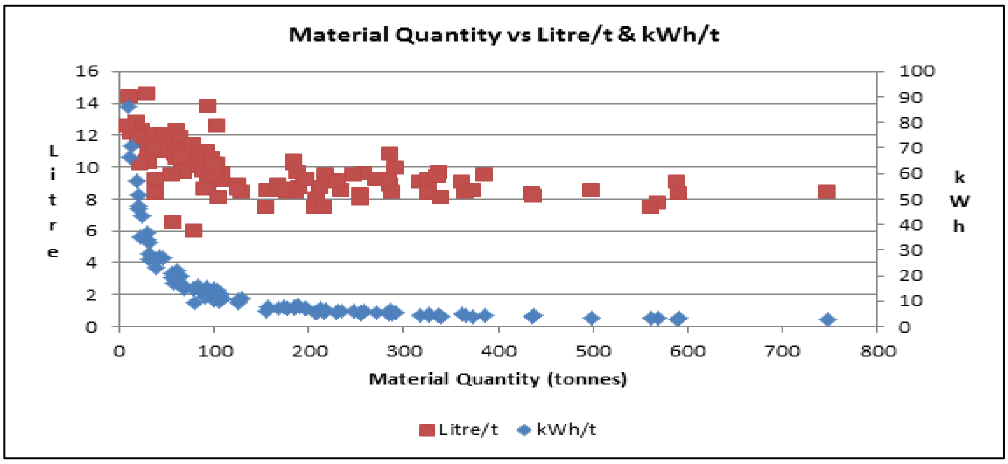


FIGURE 36 SPECIFIC ENERGY CONSUMPTION

4.6 Plant Stop/Starts

The data contained in Appendix E was sorted by ascending plant stop/starts to provide data for the following analysis. Shown in Figure 37 below is the increase in litre consumption as the number of stop/starts increases. This is expected as the drum dryer/mixer will be in operation for longer periods with resulting higher fuel consumption.

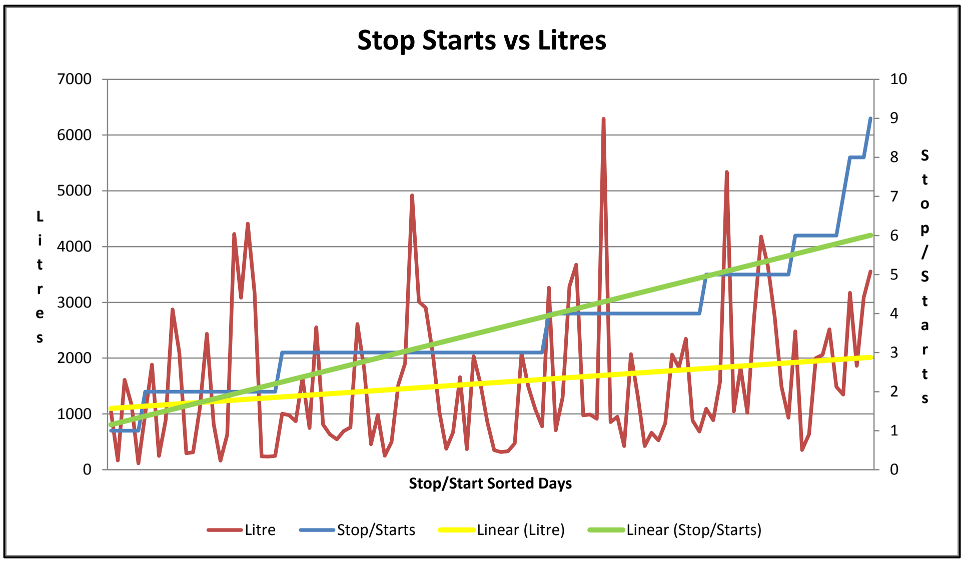


FIGURE 37 STOP STARTS AND LITRE FUEL CONSUMPTION

Figure 38 below shows that with an increase in plant stop/starts there is an increase in the material throughput as the specific fuel consumption drops as the number of plant stop/starts increases.

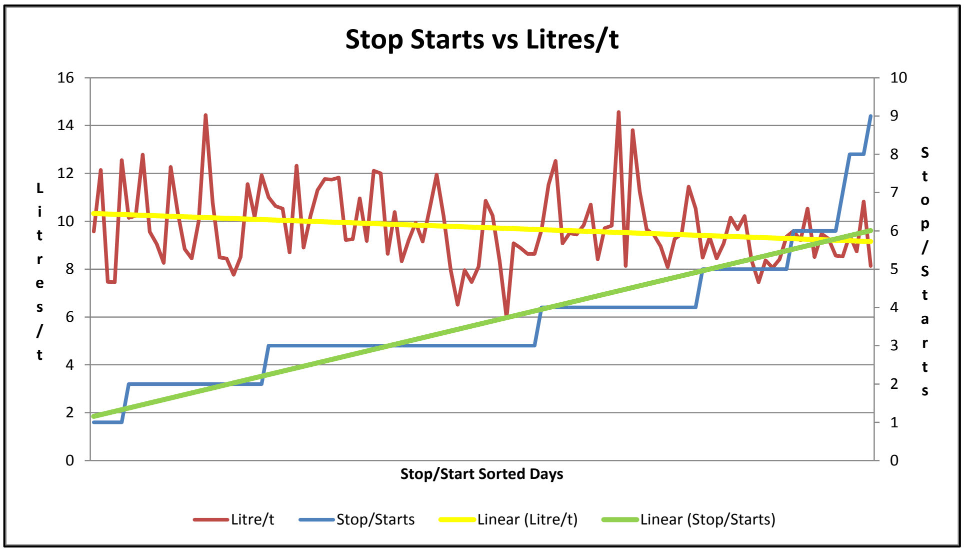


FIGURE 38 STOP STARTS AND LITRE/T FUEL CONSUMPTION

Figure 39 below shows the increase in kWh consumption as the number of plant stop/starts increases which is as expected because of the longer plant operation time.

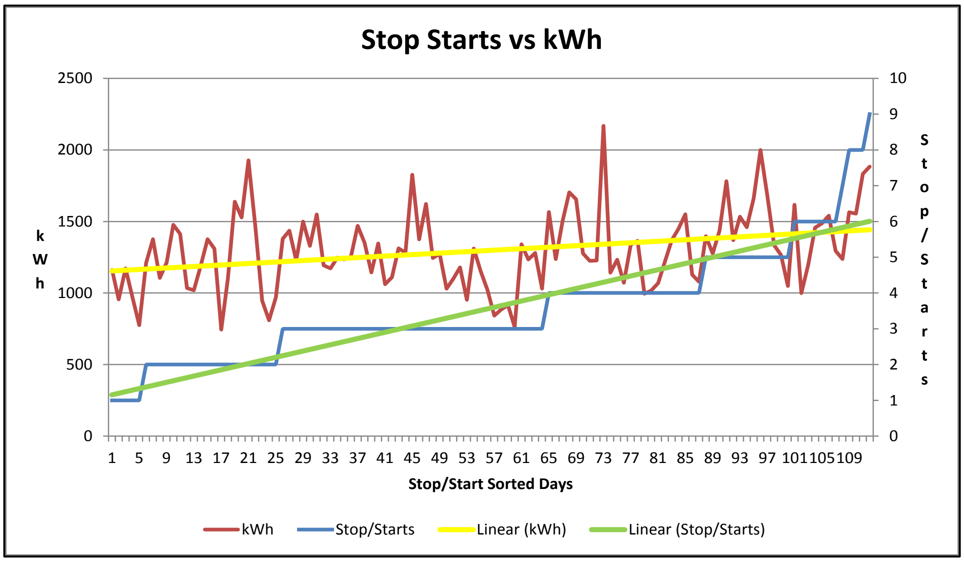


FIGURE 39 STOP STARTS AND KWH CONSUMPTION

Figure 40 below shows that as well as the specific fuel consumption dropping as the number of plant stop/starts increases the kWh/t also drop showing again the impact of material throughput.

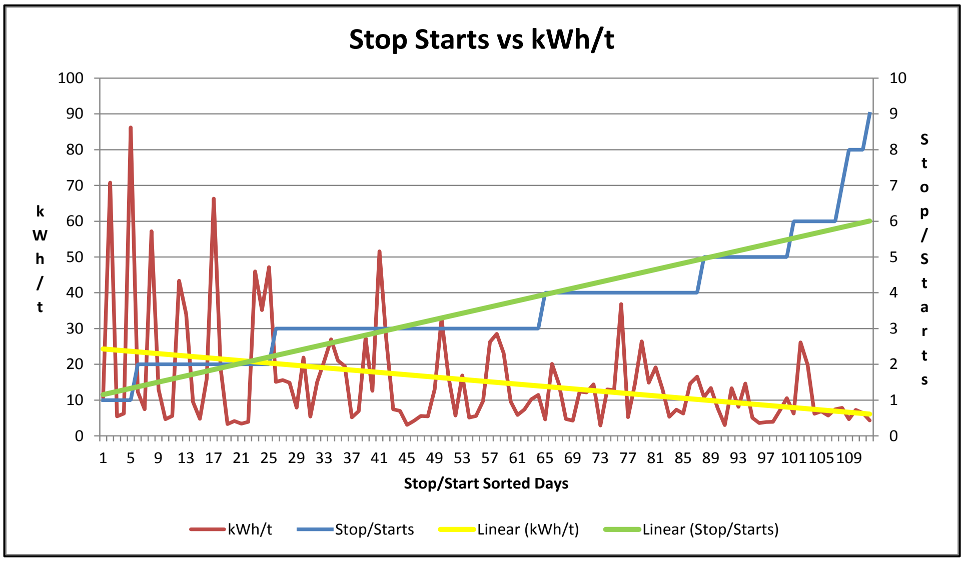


FIGURE 40 STOP STARTS AND KWH/T CONSUMPTION

These results indicate the importance of operating the plant with a high throughput as the specific energy consumption drops with increased material throughput.

4.7 Mean Ambient Temperature

Using the data in Appendix E Figure 41 shown below was produced which shows that as the mean ambient temperature increases the consumption of fuel decreases. The effect on fuel consumption is not considerable as the difference between the minimum and maximum temperatures is 16.2°C whereas the difference between the minimum and maximum fuel usage per tonne is 8.62 litres/t. From this a figure of half a litre of fuel usage per degree drop in temperature can be assumed however as previously shown there are numerous variables that affect fuel usage and not just the outside ambient temperature.

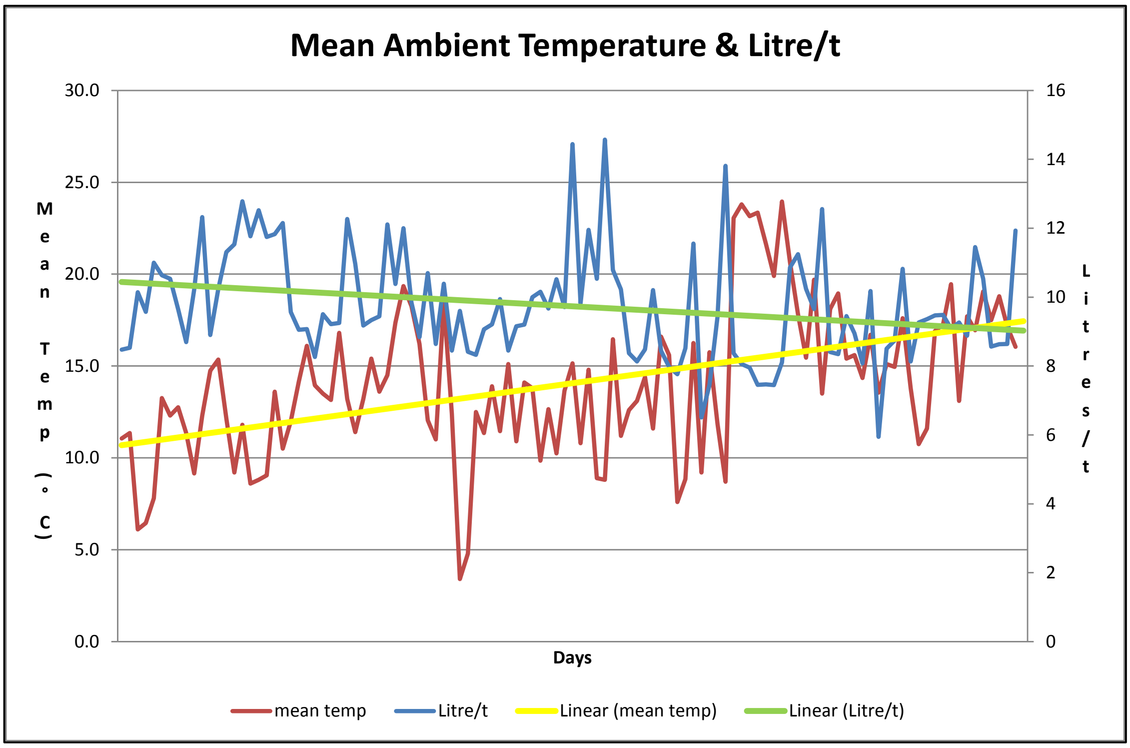


FIGURE 41 MEAN AMBIENT TEMPERATURE AND FUEL CONSUMPTION

4.8 Effect of Moisture on Energy Use

Moisture levels in sand, fines and aggregates have a known impact on the energy used in asphalt production, and as the moisture levels are collected for the sand and fines in the coating plant stockpiles their impact on energy have been analysed. Shown in Figure 42 below is the average daily fuel consumption in litres for the four moisture content levels of sand that were recorded in Appendix E. The fuel consumption increases as the moisture levels increase however the number of days at each recorded level varies quite considerably with the 8.5% sand moisture level only having 4 recorded days.

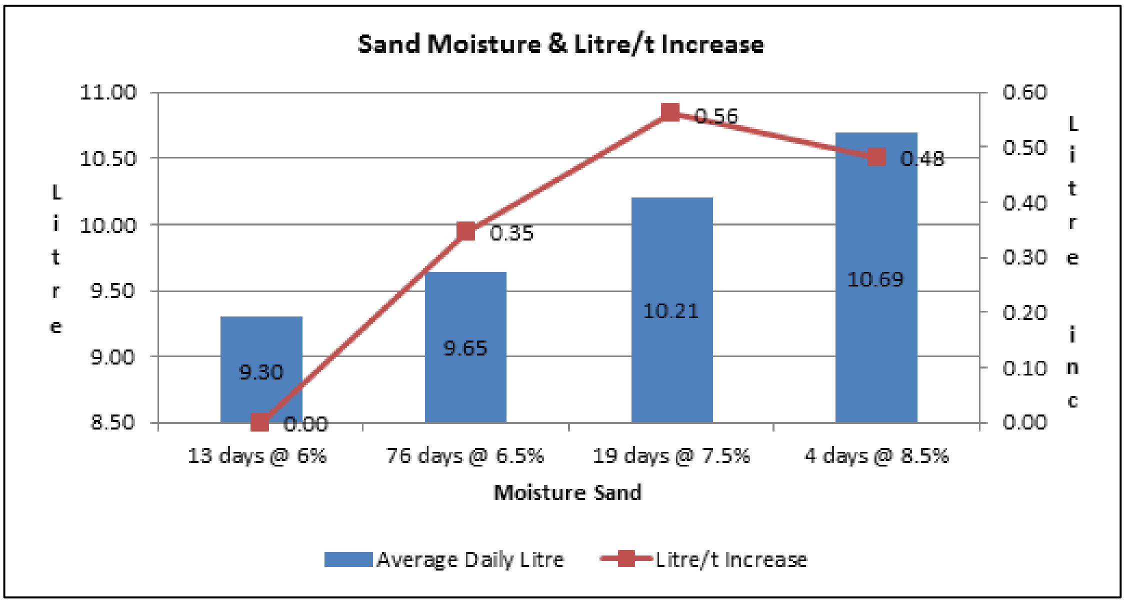


FIGURE 42 SAND MOISTURE AND LITRE CONSUMPTION

Figure 42 above indicates that the litres/t fuel usage increases as the moisture content of sand increases and as shown in Table 17 below the fuel usage from 6% sand moisture content to 6.5% is 0.35 litres/t and the increase from 6.5% to 7.5% and from 7.5% to 8.5% is 0.56 litres/t, and 0.48 litres/t respectively. Also shown for completeness are the associated fuel costs and carbon emissions.

TABLE 17 LITRE/T INCREASE SUMMARY

moisture_sand	Average Daily Litre/t	Litre/t Increase	Litre/t Increase Cost	Litre/t Increase kgCO2
13 days @ 6%	9.3	0	£0.00	0.0
76 days @ 6.5%	9.6	0.35	£0.22	0.9
19 days @ 7.5%	10.2	0.56	£0.36	1.5
4 days @ 8.5%	10.7	0.48	£0.31	1.3

The data contained in Table 17 above shows that the fuel consumption increases by an average of 0.6 litres for each 1% increase in moisture content which correlates to the data presented in the Asphalt Plant Energy Reduction section. Therefore reducing the moisture content by 1% will result in an estimated saving of 0.6 litres/t, £0.64/t and 1.5kgCO_2/t.

To further investigate the effect that moisture has on fuel usage the impact of plant throughput was analysed as shown in Figure 43 below, which contains the average daily throughput values and the litre per tonne increase in fuel consumption. This indicates the effect of higher moisture levels on plant throughput as the throughput drops after the 7.5% moisture level which points to the throttling back of plant production at higher moisture levels. This is due to the increase in moisture in the drum which reduces the suction of the pump which takes away the exhaust gases and dust.

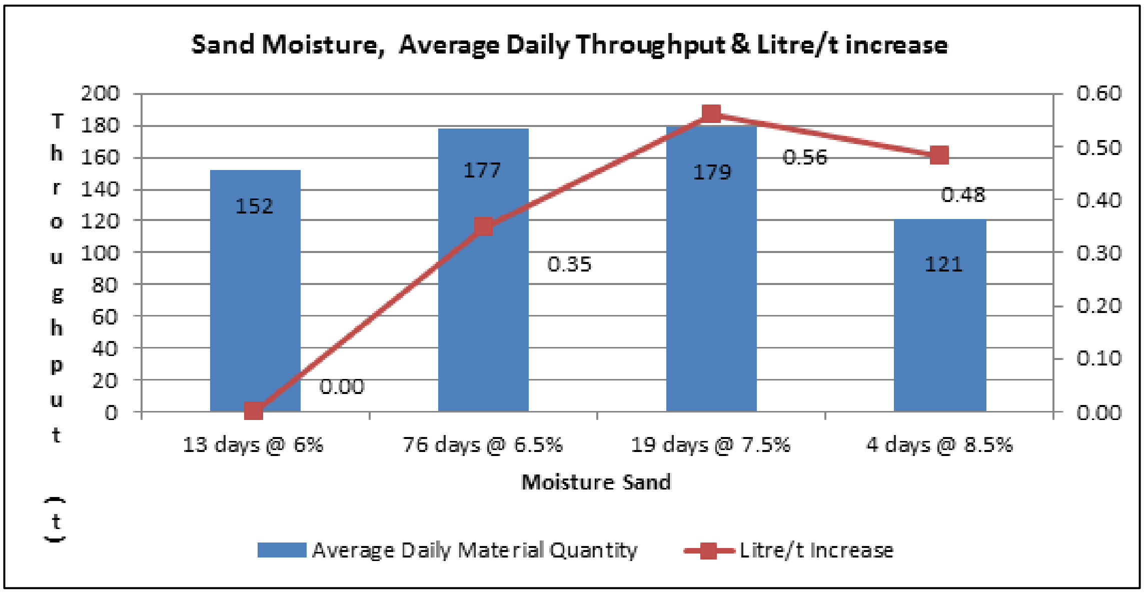


FIGURE 43 SAND MOISTURE, THROUGHPUT AND LITRE CONSUMPTION

The increase in kWh/t electrical consumption per recorded sand moisture level is shown in Figure 44 below. When compared against the noticeable increase in fuel consumption shown previously there is no discernible link between the increase in sand moisture and the increase in kWh consumption. As previously discussed this indicates the influence that other non-production demand has on the plant's electrical consumption, which includes lighting and certain elements of the plant that are left in operation.

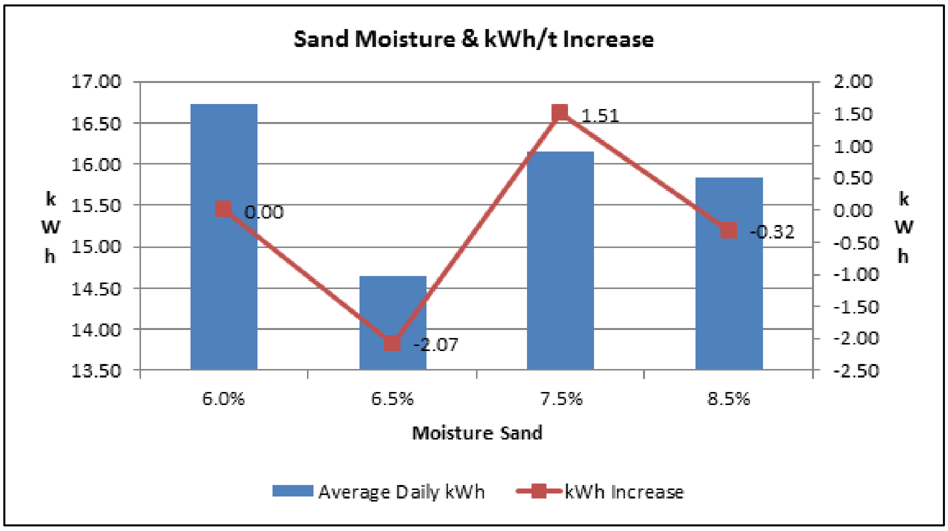


FIGURE 44 SAND MOISTURE AND KWH CONSUMPTION

The impact of material throughput on kWh consumption was investigated and unlike fuel consumption there is no apparent link between material throughput and kWh consumption as shown in Figure 45 below.

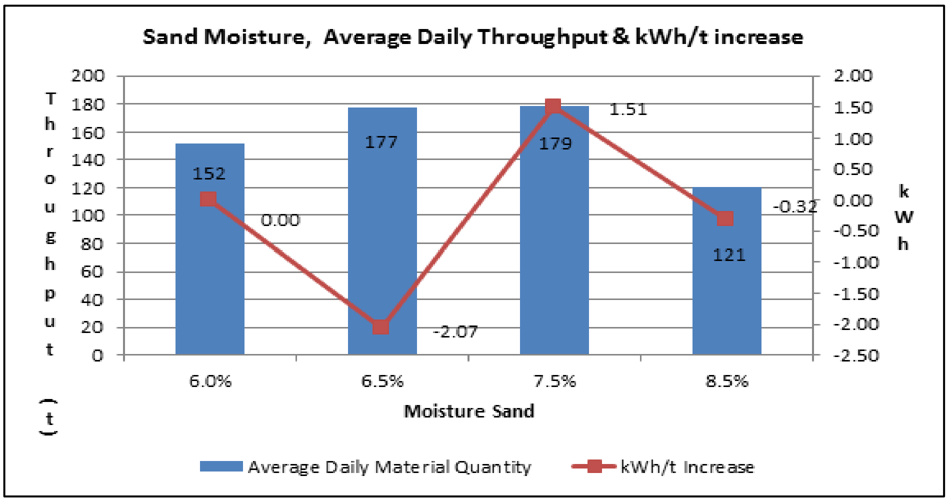


FIGURE 45 SAND MOISTURE, THROUGHPUT AND KWH CONSUMPTION

4.9 Estimated Aggregate Mixture Moisture Content

Using the latent and specific heats calculated in the analysis section Table 18 shown below was produced to show the estimated fuel usage to dry and heat aggregate mixtures at increasing moisture levels. This calculation does not take into account the sand, fines, filler and aggregate proportions in asphalt mixtures as it treats the entire tonnage value as being aggregate. It takes an estimated four litres of fuel to heat one tonne of aggregate after the moisture has been driven off, which is dependent on the amount of water present.

Also not part of the calculation is the amount of energy required to bring the already heated bitumen and aggregate up to an increased mix temperature in the mixing section of the drum.

TABLE 18 ESTIMATED FUEL USE TO DRY AND HEAT AGGREGATE MIXTURE

Moisture Level	Amount of water per tonne (kg)	Fuel required to dry one tonne of mixture (litre)	Fuel required to heat mixture (litre)	Estimated total fuel usage per tonne (litre)	Estimated total fuel usage per tonne (cost)	Estimated total fuel usage per tonne (kgCO2)
6.0%	60	4.2	4	8.2	£5.31	21.5
6.5%	65	4.55	4	8.55	£5.54	22.4
7.5%	75	5.25	4	9.25	£5.99	24.3
8.5%	85	5.95	4	9.95	£6.44	26.1

The data contained in Table 18 above indicates that the fuel consumption increases by an average of 0.7 litres for each 1% increase in moisture content which equates to an estimated increase of 1.8kgCO_2/t. Therefore reducing the moisture content by 1% will result in an estimated saving of 0.7 litres/t, £0.78/t and 1.8kgCO_2/t. Using this data an estimate can be made of the daily fuel costs for each moisture level as shown in Table 19 below.

TABLE 19 ESTIMATED FUEL COSTS PER MOISTURE LEVEL

Moisture Level	Estimated total fuel usage per tonne (litre)	Estimated total fuel usage per tonne (£)	Average Daily Tonnage	Estimated Daily Fuel Cost	Estimated Daily Fuel kgCO2
8.5%	9.95	£6.44	172.71	£1,113	4,509.3
7.5%	9.25	£5.99	172.71	£1,034	4,192.0
6.5%	8.55	£5.54	172.71	£956	3,874.8
6.0%	8.2	£5.31	172.71	£917	3,716.2

From analysing the data in Table 19 above reducing the aggregate moisture level from 8.5% to 6% would result in an estimated saving of £196 and a carbon saving of 793 kgCO_2.

The cost to cover the aggregate stockpiles has been estimated at £50,000 (Ali, 2012) which with the above data has been used to estimate the payback periods for different moisture level reductions as shown in Table 20 below.

TABLE 20 PAYBACK PERIODS PER MOISTURE LEVEL REDUCTION

Moisture Level Drop	Payback Period (days)
8.5% to 6%	256
7.5% to 6%	426
6.5% to 6%	1,278

The results from Table 20 above show that the greater the reduction in moisture level achieved the shorter the payback period as is expected due to the increase in fuel usage required to drive out moisture from aggregates.

4.10 Tool Validation

Sales and metering data for July was withheld from the analysis to allow validation of the tool against real data. To provide a good measure of data days with small, typical and large tonnage values were chosen. This data is shown in Table 21 below with rows for total material quantity, total kWh, total litres and the number of plant stop/starts. The columns show the data for the Barr site and the per tonne energy values. This structure is repeated for the tool generated data with the final two columns containing the difference (Δ) between the Barr and the tool per tonne energy values, which is then shown as a percentage.

TABLE 21 TOOL VALIDATION DATA AND RESULTS

SMALL - 2/07/2012	Barr Data	per ton	Tool	per ton	Δ	Estimation
Total Material Quantity	18.7		18.7			n/a
Total kWh	951	51	1049	56	5	10.3%
Total Litre	269	14	282	15	1	4.7%
Stop/Starts	3		3			n/a
TYPICAL - 4/07/2012	Barr Data	per ton	Tool	per ton	Δ	Estimation
Total Material Quantity	150.3		150.3			n/a
Total kWh	1195	8	1361	9	1	13.9%
Total Litre	1476	10	1431	10	0	-3.1%
Stop/Starts	6		6			n/a
LARGE - 12/07/2012	Barr Data	per ton	Tool	per ton	Δ	Estimation
Total Material Quantity	363.2		363.2			n/a
Total kWh	1528	4	1633	4	0	6.9%
Total Litre	3046	8	3152	9	0	3.5%
Stop/Starts	5		5			n/a
TYPICAL - 17/07/2012	Barr Data	per ton	Tool	per ton	Δ	Estimation
Total Material Quantity	129.5		129.5			n/a
Total kWh	1176	9	1251	10	1	6.4%
Total Litre	1126	9	1213	9	1	7.8%
Stop/Starts	5		5			n/a

The total and average estimation errors are shown in Table 22 below which shows that the tool's litre estimation is more accurate than the estimation for the kWh. The increased accuracy of the litre estimation indicates that the kWh prediction accuracy is lower due to the non-production electrical consumption as previously detailed.

TABLE 22 TOOL VALIDATION RESULTS SUMMARY

	Total Error	Average Error
kWh	37%	9%
Litre	13%	3%

5 Plant improvements

This section covers the suggested plant improvements that have arisen through the analysis undertaken in this project. As such these improvements are based on the information contained in this thesis and aren't privy to internal Barr strategies, market or financial constraints.

As shown in the results section if the moisture content of aggregates can be reduced from a high moisture content of 8.5% to 6% the payback period for covering the stockpiles is 256 days. If it can be reduced from 7.5% to 6% the payback period becomes 426 days, and if it was reduced from 6.5% to 6% the estimated payback becomes 1,278 days. Ultimately whether to cover the aggregate stockpiles is a business decision for Barr however the analysis undertaken does indicate that there is a cost saving which results in a relatively short payback period.

Decreasing the metering increment to at least 15 minute intervals has been presented in the analysis section as the belief is that reducing the metering time periods will provide better matching between mixture and metering times leading to the regression analysis being able to estimate energy use per mixture type. This suggestion has been authorised and once it has been implemented and a sufficient amount of data has been collected further analysis can be undertaken by Barr as outlined in the analysis section.

The moisture sensor type and collection technique at Barr should be changed as the moisture sensor currently used is for concrete and mortar moisture detection and not aggregates. There are specific moisture sensors for use in the aggregate sector which takes the form of a spear up to 2 meters in length. With this sensor type the moisture level within the stockpile can be taken which is more representative of the stockpiles true moisture content. If this improvement is implemented moisture detection can be expanded to the aggregate stockpiles. With this data the energy estimation tool can be modified to use the moisture levels from all materials allowing it to predict energy use on a daily basis. In addition once the moisture levels of the aggregate stockpiles are known the energy required to dry the aggregate can be obtained which can then be used to re-estimate the payback period to cover the stockpiles.

6 Further Work

A thorough investigation into the heat losses at the coating plant could be undertaken with the aim of pointing out any high loss areas. This could be accomplished through the use of a thermal imaging camera in addition to analysis. The investigation could provide costing for additional insulation to the bitumen tanks and pipers, and it could also confirm the viability of insulating the drum. Waste heat reclamation could also be added into this investigation as it is a common means of reducing energy use however it may prove too costly for the Barr coating plant.

Once the 15 minute metering data is available and further regression analysis has been undertaken the regression results can be used to update the tool to allow for a per mixture energy estimation. The estimation tool could be modified to allow operators to input any key environmental variables identified in the new regression analysis directly into the tool to provide daily energy estimates prior to plant operation.

Dependent on the outcome of further regression analysis a closer investigation into whether HDD can be used to factor in the influence of ambient temperature on the drum heating requirements could be undertaken.

A practical experimental based investigation could be undertaken at Barr to take on-site tests of moisture content and compare the tools estimated energy results against actual usage.

7 Conclusions

The aim of this project was to identify and quantify the influence of factors that affect the energy use at an asphalt coating plant and to develop a tool that can be used to estimate the energy used to produce asphalt mixtures. Both site and data analysis has been undertaken and a tool has been developed which can estimate energy use within a reasonable level of accuracy. Also delivered has been an insight into the energy consumption, costs and carbon emission per tonne of material which is further expanded on below.

The primary key finding is that the monetary and carbon cost of fuel use is £6 per litre/tonne and 24.3 $kgCO_2$ per tonne which shows the higher carbon footprint of the fuel consumption when compared to the electrical consumption which was £0.56 per kWh/tonne and 4.5 $kgCO_2$ per tonne. When these values are totalled the estimated energy cost per tonne is £6.56 with a carbon emission of 28.8 $kgCO_2$. These values can be used by Barr to provide them with an estimate of the true energy costs per tonne to dry, heat and mix asphalt.

When the coating plants litre fuel consumption was converted into the equivalent kWh value and compared to the electrical kWh consumption of the plant it was found to account for 92% of the total kWh consumption over the five month metering period. This demonstrated the considerable amount of energy involved in drying and heating aggregates.

Using the estimated drum dryer/mixer convective and irradiative losses from the analysis section in conjunction with the litre metering the percentage of convective and irradiative loss, and resulting monetary and carbon cost were calculated. On analysis it was found that the losses over the five month period equated to £654.6 and 2,653 $kgCO_2$. Overall it was estimated to be a loss of 2.5% which may not be high enough to warrant insulating the drum as there is also the associated loss of production cost that has to be taken into account. However if Barr could obtain competitive insulation quotes and plan the insulation retrofit into any plant downtime it would make the retrofit more viable.

When the electrical consumption of the coating plant was analysed to determine the proportion that was attributable to times when the drum dryer/mixer was in operation it was found that 58% of consumption was outwith times when the drum dryer/mixer was in operation. The estimated monetary and carbon cost is large for this non-production electrical usage as it has an estimated total cost of £7,404 and 59,167 $kgCO_2$. It must be pointed out however that this figure does not take into account the initial plant ramp up and ramp down which will not require fuel use even through electrically powered plant equipment is in operation, which includes the drum motor and the conveyors. The suggested change to a 15 minute metering period will provide clarification on this issue and this non-production value may be reduced.

Charts were plotted to show the relationship between energy consumption and material throughput and as expected there is a relationship between total material throughput and energy use as the more material throughput the greater the plant operating time. The charts do indicate the effect of the non-production electrical consumption as the kWh values are not clustered as tightly as the litre values. The specific energy consumption against material quantity were plotted which indicated the optimal daily plant throughput should be at least 100 tonnes as the energy values level out at lower values after this throughput value. Also indicated in the specific energy consumption charts is the influence that other factors have on litre usage as the data points are not clustered as tightly as the kWh data points. The influence of material throughput on energy use was also shown when the number of plant stop/starts were investigated as the higher the number of plant stop/starts the lower the specific energy costs per tonne. This reduced the impact of starting and stopping the plant many times during a day as it corresponded to a higher material throughput therefore reducing the specific energy usage.

As identified a key factor that influences energy use in asphalt production is the moisture content of sands, fines and aggregates. Through analysis of the moisture content of sand it was found that fuel consumption increases by an average of 0.6 litres for each 1% increase in moisture content which equates to an average increase of 1.5kgCO_2/t. Therefore reducing the sand moisture content by 1% would result in an estimated saving of 0.6 litres/t, £0.64/t and 1.5kgCO_2/t.

The sand and fines stockpiles are already covered therefore the moisture levels where they are sourced need to be controlled, and the inclination of the Barr stockpiles should be examined to ensure that it is at 6%. Through the implementation of the suggested changes to the moisture collection procedure the moisture levels are predicted to change. The moisture content of fines was not analysed and aggregate moisture content is not currently measured at the coating plant.

Even though the moisture levels of the aggregates are not currently recorded through the use of the calculated latent and specific heats the estimated fuel consumption was determined. This indicated that the fuel consumption increases by an average of 0.7 litres for each 1% increase in moisture content which equates to an estimated increase of 1.8kgCO_2/t. Reducing the moisture content by 1% would result in an estimated saving of 0.7 litres/t, £0.78/t and 1.8kgCO_2/t.

Once the tool was developed its output was validated against actual plant data for the month of July that been withheld from analysis for this purpose. The validation results were good for the estimation of the amount of fuel used as the average error was 3%. However the average error for the estimation of kWh use was 9%. This larger estimation error is believed to be due to the non-production electrical usage uncovered in the analysis which can result in a changing electrical base load. The accuracy of both estimations may improve following the regression analysis of the 15 minute metering data once a suitable amount of data has been collected. Once there is a better understanding of the non-production electrical consumption, and ideally a reduction in the consumption the kWh estimation should improve.

It is estimated that if RAP were introduced into the coating plant the energy use and associated carbon emissions would be lower than for virgin aggregate as the moisture content of the RAP will be lower. This is because the sand, fines and aggregate in the RAP has already been dried and then coated with the bitumen which acts as a water repellent.

This analysis has quantified that asphalt production is a very energy intensive process with large carbon emissions. The results of this analysis also provide Barr with a deeper understanding of the true energy costs per tonne. The analysis also points out the associated carbon footprint of the energy used at the plant and it is a business decision at Barr as to whether they bring in measures to reduce it.

Through the use of the developed tool Barr will be able to undertake better plant scheduling, and the tool will provide Barr with a means to estimate jobs more accurately. It can also be used as a benchmark to measure future changes against. Both the analysis and tool can be expanded on due to the analysis process being documented along with code comments in the tool, additionally all related project files will be handed to Barr to enable the above.

Analysing the energy used in such a complex industrial system is time consuming and if the data has originally been collected for other non-energy management purposes it can increase the difficulty of the task. A key factor in achieving the successful outcome of this project has been the full engagement and assistance from the employees at Barr.

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9 Appendix

9.1 Appendix A

KILLOCH COATED PROPORTIONS	Bitumen	20/32	PSV 10/14	14/20	10/14	6/10	PSV 6/10	4/6	0/4mm	0/1 Asphalt Sand	Filler
AC 32 Dense DBM Base 40/60 Des											
AC 32 Dense DBM Base XX/YY Rec											
AC 32 Dense HDM Base 40/60 Des											
AC 20 Open Bin XX/YY											
AC 32 Sin Surf XX/YY											
AC 32 Dense DBM Bin XX/YY Rec											
AC 32 Dense HDM Bin 40/60 Des											
AC 20 Dense DBM Bin XX/YY Rec											
SMA 20 40/60											
SMA 14 40/60											
SMA 10 40/60											
SMA 6 40/60											
AC 14 Close Surf XX/YY											
AC 10 Close Surf XX/YY											
AC 6 Dense Surf XX/YY											
AC 6 Med Surf XX/YY											
AC 6 Tennis Court Surf XX/YY											
14mm Bartex (Torpave) HT Thin Surf Styrelf 13/80											
14mm Bartex (Torpave) MT Thin Surf Styrelf 13/80											
10mm Bartex (Torpave) HT Thin Surf Styrelf 13/80											
10mm Bartex (Torpave) MT Thin Surf Styrelf 13/80											
AC 14 Close Barpave Surf XX/YY											
AC 10 Close Barpave Surf XX/YY											
AC 6 Dense Barpave Surf XX/YY											
AC 14 EME2 Base/Bin 10/20											
HRA 50/10 Base/Bin/Reg 40/60											
HRA 50/14 Base/Bin/Reg 40/60											
HRA 50/20 Base/Bin/Reg 40/60											
HRA 60/20 Base/Bin 40/60											
HRA 60/32 Base/Bin 40/60											
HRA 0/2 F Surf XX/YY Rec											
HRA 15/10 F Surf XX/YY Rec											
HRA 30/10 F Surf XX/YY Rec											
HRA 30/14 F Surf 40/60 Rec											
HRA 35/14 F Surf 40/60 Rec											
HRA 30/14 F Surf 40/60 Des											
HRA 35/14 F Surf 40/60 Des											
HRA 55/10 F Surf 40/60 Des											
HRA 55/14 F Surf 40/60 Des											
HRA 0/2 F Surf XX/YY Des											
HRA 15/10 F Surf XX/YY Prop Des											
HRA 30/10 F Surf 40/60 Prop Des											
HRA 45/10 F Surf 40/60 Prop Des											
HRA 45/14 F Surf 40/60 Prop Des	[illegible]				[illegible]				[illegible]	[illegible]	[illegible]

9.2 Appendix B

TEMPERATURES OF MIXED MATERIALS

Includes temperature data for manufacturing from BS EN 13043-1, 4 and 5 and BS 594987 for laying.

Asphalt Concrete (AC) Rec(ipe)

Type of Mixture	Pen Grade	Mixing Temperature Min (°C)	Mixing Temperature Max (°C)	Min Temp on Arrival (°C)	Rolling Temp Min prior to starting (°C)
Open Surf(acing) and Bin(der) Courses	160/220	130	170	95	75
	250/330	120	160	85	65
Close, Fine, Medium or Dense Surf	70/100	140	180	130	100
	100/150	130	170	120	95
	160/220	130	170	110	85
	250/330	120	160	100	80
Dense Bin, Base Recipe Mixtures	40/60	150	190	130	100
	70/100	140	180	125	95
	100/150	130	170	120	90
	160/220	130	170	110	80
Hot Rolled Asphalt Rec & Des					
Surf Course	30/45	160	200	140	110
	40/60	150	190	140	110
	70/100	140	180	125	90
	100/150	130	170	125	85
Reg, Bin, Base	30/45	160	200	130	105
	40/60	150	190	130	105
	70/100	140	180	125	90
	100/150	130	170	120	85
Stone Mastic Asphalt (SMA)					
SMA Surf	40/60	160	220	130	100
	100/150	150	190	120	85
Note: Proprietary SMA Surf may be subject to additional guidance. Refer to installation procedure.					
Note: The above Minimum Temperatures for rolling arrival onsite are Recommended. Temperature on site is within 30 minutes of arrival. Mixing Temperatures are specified.					
Asphalt Concrete Design (AC Des)					Min at completion (°C)
Base & Bin(der) Courses (including EME2)	10/20, 15/25	160	220	!	110
	30/45	155	195	!	110
	35/50, 40/60	150	190	!	105
	70/100	140	180	!	90
	100/150	130	170	!	75
	160/220	130	170	!	60
! None Recommended – Temperature should be high enough to complete rolling above min stated					
Thin Surfacing					
Bartex (Torpave)	Styrelf 13/80	170 (180)	190	160 (170)*	100**
Bartex (Torpave)	Styrelf 13/60	170 (180)	190	160 (170)*	100**
* 170 °C minimum for air temps below 10°C or breezy conditions. ** Guidance values see installation procedure.					

Note: The above Minimum Temperatures are Recommended. Delivery temperature is within 30 minutes of arrival on site. Mixing Temperatures are **specified**.

9.3 Appendix C

```
Function ColorFunction(rColor As Range, rRange As Range, Optional SUM As Boolean)

Dim rCell As Range

Dim lCol As Long

Dim vResult

lCol = rColor.Interior.ColorIndex

If SUM = True Then

For Each rCell In rRange

If rCell.Interior.ColorIndex = lCol Then

vResult = WorksheetFunction.SUM(rCell, vResult)

End If

Next rCell

Else

For Each rCell In rRange

If rCell.Interior.ColorIndex = lCol Then

vResult = 1 + vResult

End If

Next rCell

End If

ColorFunction = vResult

End Function


Sub DuplicatesHighlight()

'

' Duplicates Macro


'   SETS UP THE ARRAYS AND VARIABLES
```

```
        Dim kWhArray(), LitreArray(), dateArray()

        Dim j As Long


'   PASSES RANGES INTO ARRAYS TO SPEED UP DUPLICATE CHECKING


        kWhArray() = Range("kWh").Value

        LitreArray() = Range("Litre").Value

        dateArray() = Range("date").Value


'   CHECKS KWH ARRAY FOR DUPLICATES


            j = 1


'           DO WHILE J IS LESS THAN THE NUMBER OF ENTRIES IN THE ARRAY


            Do While j < UBound(kWhArray)


'                IF THE DATE VALUES ARE THE SAME THEN


                If dateArray(j, 1) = dateArray(j + 1, 1) Then


'                             IF THE KWH VALUES ARE THE SAME THEN CHANGE THE COLOURS OF THEIR
CELLS


                            If kWhArray(j, 1) = kWhArray(j + 1, 1) Then


                                Range("kWh").Cells(j, 1).Interior.Color = 49407

                                Range("kWh").Cells(j + 1, 1).Interior.Color = 49407
```

```
                End If

            End If

        j = j + 1

        Loop


'   CHECKS LITRE ARRAY FOR DUPLICATES - SAME STEPS AS ABOVE


        j = 1


        Do While j < UBound(LitreArray)

            If dateArray(j, 1) = dateArray(j + 1, 1) Then

                If LitreArray(j, 1) = LitreArray(j + 1, 1) Then

                    Range("Litre").Cells(j, 1).Interior.Color = 49407

                    Range("Litre").Cells(j + 1, 1).Interior.Color = 49407

                End If

            End If

        j = j + 1

        Loop


End Sub
```

9.4 Appendix D

```
Sub Duplicates()

'

' Duplicates Macro



'   SETS UP THE ARRAYS AND VARIABLES



        Dim kWhArray(), LitreArray(), dateArray(), kWhArrayAdj(), LitreArrayAdj(), matQArray()

        Dim j As Long

        Dim matQVal As Single



'   PASSES RANGES INTO ARRAYS TO SPEED UP DUPLICATE CHECKING



        kWhArray() = Range("kWh").Value

        kWhArrayAdj() = Range("kWhAdj").Value

        LitreArray() = Range("Litre").Value

        LitreArrayAdj() = Range("LitreAdj").Value

        dateArray() = Range("Date").Value

        matQArray() = Range("MatQ").Value



'   CHECKS KWH ARRAY FOR DUPLICATES



            j = 1



'           DO WHILE J IS LESS THAN THE NUMBER OF ENTRIES IN THE ARRAY



            Do While j <= UBound(kWhArray)
```

```
'               CATCHES LAST VALUE IN THE ARRAY

                If j = UBound(kWhArray) Then

                        kWhArrayAdj(j, 1) = kWhArray(j, 1)
                        Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                        MsgBox "Check the last two values in the range! "

                Else

'                IF THE DATE VALUES ARE THE SAME THEN

                If dateArray(j, 1) = dateArray(j + 1, 1) Then

                    '   IF THE THE ARRAY VALUES ARE NOT DUPLICATES THEN COPY VALUES ACROSS TO
THE ADJUSTED ARRAY

                    If kWhArray(j, 1) <> kWhArray(j + 1, 1) Then

                        kWhArrayAdj(j, 1) = kWhArray(j, 1)
                        Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                    '   SUBSEQUENT ARRAY VALUES ARE EQUAL

'                   CODE FOR TWO DUPLICATED KWH VALUES
```

```
                    ElseIf j + 2 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j, 1) <> kWhArray(j + 2, 1) Then

'                               If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j, 1) <> kWhArray(j + 2, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1)

                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 1

'                            End If

'                   CODE FOR THREE DUPLICATED KWH VALUES

                    ElseIf j + 3 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j, 1) <> kWhArray(j + 3, 1) Then

'                              If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j, 1) <> kWhArray(j + 3, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1)
```

```
                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j,
1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)


                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)


                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)


                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS


                                j = j + 2


'                            End If


'                    CODE FOR FOUR DUPLICATED KWH VALUES


                    ElseIf j + 4 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1)
And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And
kWhArray(j, 1) <> kWhArray(j + 4, 1) Then


'                              If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) =
kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j, 1) <>
kWhArray(j + 4, 1) Then


                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j
+ 2, 1) + matQArray(j + 3, 1)


                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j,
1)
```

```
                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                j = j + 3

'               End If

'          CODE FOR FIVE DUPLICATED KWH VALUES

          ElseIf j + 5 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j, 1) <> kWhArray(j + 5, 1) Then

'               If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j, 1) <> kWhArray(j + 6, 1) Then

                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1)
```

```
                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)


                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)


                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)


                                kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)


                                kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)


                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS


                                j = j + 4


'                             End If


'                    CODE FOR SIX DUPLICATED KWH VALUES


                    ElseIf j + 6 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j, 1) <> kWhArray(j + 6, 1) Then
```

```
'                             If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j, 1) <> kWhArray(j + 8, 1) Then

                              matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1)

                              kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                              Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                              kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                              Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                              kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                              Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                              kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                              Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                              kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                              Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

                              kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                              Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

                              '   INCREMENT J TO SKIP OVER ADJUSTED CELLS
```

```
                        j = j + 5

'                       End If

'               CODE FOR SEVEN DUPLICATED KWH VALUES

                ElseIf j + 7 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j, 1) <> kWhArray(j + 7, 1) Then

'                       If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j, 1) <> kWhArray(j + 8, 1) Then

                        matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1)

                        kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                        Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                        kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                        Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                        kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                        Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                        kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                        Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)
```

```
                              kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                              Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

                              kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                              Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

                              kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 6, 1)

                              Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

                              '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                              j = j + 6

'                           End If

'                  CODE FOR EIGHT DUPLICATED KWH VALUES

                   ElseIf j + 8 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j, 1) <> kWhArray(j + 8, 1) Then

'                            If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j, 1) <> kWhArray(j + 8, 1) Then

                              matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1)
```

```
kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j,
1)

Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 1, 1)

Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 2, 1)

Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 3, 1)

Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 4, 1)

Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 5, 1)

Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

kWhArrayAdj(j + 7, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 7, 1)

Range("kWhAdj").Cells(j + 7, 1).Value = kWhArrayAdj(j + 7, 1)
```

```
                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 7

'                            End If

'                   CODE FOR NINE DUPLICATED KWH VALUES

                    ElseIf j + 9 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j, 1) <> kWhArray(j + 9, 1) Then

'                             If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j, 1) <> kWhArray(j + 10, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1)

                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)
```

```
                              kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 3, 1)

                              Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                              kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 4, 1)

                              Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

                              kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 5, 1)

                              Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

                              kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

                              Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

                              kWhArrayAdj(j + 7, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 7, 1)

                              Range("kWhAdj").Cells(j + 7, 1).Value = kWhArrayAdj(j + 7, 1)

                              kWhArrayAdj(j + 8, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 8, 1)

                              Range("kWhAdj").Cells(j + 8, 1).Value = kWhArrayAdj(j + 8, 1)

                              '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                              j = j + 8

'                            End If

'                  CODE FOR TEN DUPLICATED KWH VALUES
```

```
                    ElseIf j + 10 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j, 1) <> kWhArray(j + 10, 1) Then

'                              If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j, 1) <> kWhArray(j + 10, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1)

                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                                kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                                kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)
```

```
                              kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                              Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

                              kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 6, 1)

                              Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

                              kWhArrayAdj(j + 7, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 7, 1)

                              Range("kWhAdj").Cells(j + 7, 1).Value = kWhArrayAdj(j + 7, 1)

                              kWhArrayAdj(j + 8, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 8, 1)

                              Range("kWhAdj").Cells(j + 8, 1).Value = kWhArrayAdj(j + 8, 1)

                              kWhArrayAdj(j + 9, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 9, 1)

                              Range("kWhAdj").Cells(j + 9, 1).Value = kWhArrayAdj(j + 9, 1)

                              '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                              j = j + 9

'                           End If

'                  CODE FOR 11 DUPLICATED KWH VALUES

                  ElseIf j + 11 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And
```

```
kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j + 9, 1) = kWhArray(j + 10, 1) And kWhArray(j, 1) <> kWhArray(j + 11, 1) Then

'                               If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j + 9, 1) = kWhArray(j + 10, 1) And kWhArray(j + 10, 1) = kWhArray(j + 11, 1) And kWhArray(j, 1) <> kWhArray(j + 12, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1) + matQArray(j + 10, 1)

                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                                kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                                kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

                                kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                                Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)
```

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                                kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 6, 1)

                                Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

                                kWhArrayAdj(j + 7, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 7, 1)

                                Range("kWhAdj").Cells(j + 7, 1).Value = kWhArrayAdj(j + 7, 1)

                                kWhArrayAdj(j + 8, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 8, 1)

                                Range("kWhAdj").Cells(j + 8, 1).Value = kWhArrayAdj(j + 8, 1)

                                kWhArrayAdj(j + 9, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 9, 1)

                                Range("kWhAdj").Cells(j + 9, 1).Value = kWhArrayAdj(j + 9, 1)

                                kWhArrayAdj(j + 10, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j + 10, 1)

                                Range("kWhAdj").Cells(j + 10, 1).Value = kWhArrayAdj(j + 10, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 10

'                            End If

'                   CODE FOR 12 DUPLICATED KWH VALUES

                    ElseIf j + 12 < UBound(kWhArray) And kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) = kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) = kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) = kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And
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kWhArray(j + 7, 1) = kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And
kWhArray(j + 9, 1) = kWhArray(j + 10, 1) And kWhArray(j + 10, 1) = kWhArray(j + 11, 1) And
kWhArray(j, 1) <> kWhArray(j + 12, 1) Then

'                              If kWhArray(j, 1) = kWhArray(j + 1, 1) And kWhArray(j + 1, 1) =
kWhArray(j + 2, 1) And kWhArray(j + 2, 1) = kWhArray(j + 3, 1) And kWhArray(j + 3, 1) =
kWhArray(j + 4, 1) And kWhArray(j + 4, 1) = kWhArray(j + 5, 1) And kWhArray(j + 5, 1) =
kWhArray(j + 6, 1) And kWhArray(j + 6, 1) = kWhArray(j + 7, 1) And kWhArray(j + 7, 1) =
kWhArray(j + 8, 1) And kWhArray(j + 8, 1) = kWhArray(j + 9, 1) And kWhArray(j + 9, 1) =
kWhArray(j + 10, 1) And kWhArray(j + 10, 1) = kWhArray(j + 11, 1) And kWhArray(j, 1) <>
kWhArray(j + 12, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j
+ 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6,
1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1) + matQArray(j + 10, 1) +
matQArray(j + 11, 1)

                                kWhArrayAdj(j, 1) = (kWhArray(j, 1) / matQVal) * matQArray(j,
1)

                                Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

                                kWhArrayAdj(j + 1, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 1, 1)

                                Range("kWhAdj").Cells(j + 1, 1).Value = kWhArrayAdj(j + 1, 1)

                                kWhArrayAdj(j + 2, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 2, 1)

                                Range("kWhAdj").Cells(j + 2, 1).Value = kWhArrayAdj(j + 2, 1)

                                kWhArrayAdj(j + 3, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 3, 1)

                                Range("kWhAdj").Cells(j + 3, 1).Value = kWhArrayAdj(j + 3, 1)

                                kWhArrayAdj(j + 4, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 4, 1)

                                Range("kWhAdj").Cells(j + 4, 1).Value = kWhArrayAdj(j + 4, 1)

                                kWhArrayAdj(j + 5, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 5, 1)
```

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                        Range("kWhAdj").Cells(j + 5, 1).Value = kWhArrayAdj(j + 5, 1)

                        kWhArrayAdj(j + 6, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 6, 1)
                        Range("kWhAdj").Cells(j + 6, 1).Value = kWhArrayAdj(j + 6, 1)

                        kWhArrayAdj(j + 7, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 7, 1)
                        Range("kWhAdj").Cells(j + 7, 1).Value = kWhArrayAdj(j + 7, 1)

                        kWhArrayAdj(j + 8, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 8, 1)
                        Range("kWhAdj").Cells(j + 8, 1).Value = kWhArrayAdj(j + 8, 1)

                        kWhArrayAdj(j + 9, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 9, 1)
                        Range("kWhAdj").Cells(j + 9, 1).Value = kWhArrayAdj(j + 9, 1)

                        kWhArrayAdj(j + 10, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 10, 1)
                        Range("kWhAdj").Cells(j + 10, 1).Value = kWhArrayAdj(j + 10,
1)

                        kWhArrayAdj(j + 11, 1) = (kWhArray(j, 1) / matQVal) *
matQArray(j + 11, 1)
                        Range("kWhAdj").Cells(j + 11, 1).Value = kWhArrayAdj(j + 11,
1)

                        '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                        j = j + 11

'                     End If
```

```
                Else

                End If

            Else

'                    If kWhArray(j, 1) = kWhArray(j + 1, 1) Then

                    '   FOR THE VALUES THAT ARE NOT ON THE SAME DAY AND ARE NOT EQUAL

                    kWhArrayAdj(j, 1) = kWhArray(j, 1)
                    Range("kWhAdj").Cells(j, 1).Value = kWhArrayAdj(j, 1)

'                    End If

            End If

            End If

        j = j + 1
        Loop

'   CHECKS LITRE ARRAY FOR DUPLICATES - ESSENTIALLY THE SAME AS ABOVE

        j = 1

'       DO WHILE J IS LESS THAN THE NUMBER OF ENTRIES IN THE ARRAY
```

```
            Do While j <= UBound(LitreArray)

'               CATCHES LAST VALUE IN THE ARRAY

                If j = UBound(LitreArray) Then

                        LitreArrayAdj(j, 1) = LitreArray(j, 1)
                        Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                        MsgBox "Check the last two values in the range! "

                Else

'                IF THE DATE VALUES ARE THE SAME THEN

                If dateArray(j, 1) = dateArray(j + 1, 1) Then

                    '   IF THE THE ARRAY VALUES ARE NOT DUPLICATES THEN COPY VALUES ACROSS TO
THE ADJUSTED ARRAY

                    If LitreArray(j, 1) <> LitreArray(j + 1, 1) Then

                        LitreArrayAdj(j, 1) = LitreArray(j, 1)
                        Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                    '   SUBSEQUENT ARRAY VALUES ARE EQUAL
```

```
'                   CODE FOR TWO DUPLICATED KWH VALUES

                    ElseIf j + 2 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j, 1) <> LitreArray(j + 2, 1) Then

'                             If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j, 1) <> LitreArray(j + 2, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)
                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)
                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 1

'                            End If

'                   CODE FOR THREE DUPLICATED KWH VALUES

                    ElseIf j + 3 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j, 1) <> LitreArray(j + 3, 1) Then
```

```
'                              If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j, 1) <> LitreArray(j + 3, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 2

'                             End If

'                    CODE FOR FOUR DUPLICATED KWH VALUES

                    ElseIf j + 4 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j, 1) <> LitreArray(j + 4, 1) Then

'                              If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j, 1) <> LitreArray(j + 4, 1) Then
```

```
                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                                LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 3

'                             End If

'                   CODE FOR FIVE DUPLICATED KWH VALUES

                    ElseIf j + 5 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j, 1) <> LitreArray(j + 5, 1) Then
```

```
'                              If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j, 1) <> LitreArray(j + 6, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                                LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

                                LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 4
```

```
'                            End If

'                   CODE FOR SIX DUPLICATED KWH VALUES

                    ElseIf j + 6 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j, 1) <> LitreArray(j + 6, 1) Then

'                             If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j, 1) <> LitreArray(j + 8, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                                LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)
```

```
                                LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4, 1)



                                LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                                Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5, 1)



                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS



                                j = j + 5



'                            End If



'                   CODE FOR SEVEN DUPLICATED KWH VALUES



                    ElseIf j + 7 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j, 1) <> LitreArray(j + 7, 1) Then



'                            If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j, 1) <> LitreArray(j + 8, 1) Then



                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1)



                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)
```

```
                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1,
1)


                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2,
1)


                                LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 3, 1)

                                Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3,
1)


                                LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 4, 1)

                                Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4,
1)


                                LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 5, 1)

                                Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5,
1)


                                LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

                                Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6,
1)


                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS


                                j = j + 6


'                             End If
```

```
'                  CODE FOR EIGHT DUPLICATED KWH VALUES

                  ElseIf j + 8 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j, 1) <> LitreArray(j + 8, 1) Then

'                            If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j, 1) <> LitreArray(j + 8, 1) Then

                              matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1)

                              LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                              Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                              LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                              Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                              LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                              Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                              LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                              Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

                              LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)
```

```
                                Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4,
1)

                                LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 5, 1)

                                Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5,
1)

                                LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

                                Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6,
1)

                                LitreArrayAdj(j + 7, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 7, 1)

                                Range("LitreAdj").Cells(j + 7, 1).Value = LitreArrayAdj(j + 7,
1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 7

'                            End If

'                   CODE FOR NINE DUPLICATED KWH VALUES

                    ElseIf j + 9 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1,
1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j +
3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j
+ 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) =
LitreArray(j + 7, 1) And LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j, 1) <>
LitreArray(j + 9, 1) Then

'                            If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1,
1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j +
3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j
+ 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And
```

```
LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8, 1) = LitreArray(j + 9, 1) And LitreArray(j, 1) <> LitreArray(j + 10, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1)

                                LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                                Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                                LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                                Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                                LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                                Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                                LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                                Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

                                LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                                Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4, 1)

                                LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                                Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5, 1)

                                LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 6, 1)
```

```
                                Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6,
1)



                                LitreArrayAdj(j  +  7,  1)  =  (LitreArray(j,  1)  /  matQVal)  *
matQArray(j + 7, 1)

                                Range("LitreAdj").Cells(j + 7, 1).Value = LitreArrayAdj(j + 7,
1)



                                LitreArrayAdj(j  +  8,  1)  =  (LitreArray(j,  1)  /  matQVal)  *
matQArray(j + 8, 1)

                                Range("LitreAdj").Cells(j + 8, 1).Value = LitreArrayAdj(j + 8,
1)



                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS



                                j = j + 8



'                            End If



'                   CODE FOR TEN DUPLICATED KWH VALUES



                    ElseIf j + 10 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j +
1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j
+  3,  1)  And  LitreArray(j  +  3,  1)  =  LitreArray(j  +  4,  1)  And  LitreArray(j  +  4,  1)  =
LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1)
= LitreArray(j + 7, 1) And LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8,
1) = LitreArray(j + 9, 1) And LitreArray(j, 1) <> LitreArray(j + 10, 1) Then



'                             If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1,
1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j +
3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j
+  5,  1)  =  LitreArray(j  +  6,  1)  And  LitreArray(j  +  6,  1)  =  LitreArray(j  +  7,  1)  And
LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8, 1) = LitreArray(j + 9, 1)
And LitreArray(j, 1) <> LitreArray(j + 10, 1) Then



                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j
+ 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6,
1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1)
```

```
LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)

Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4, 1)

LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 5, 1)

Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5, 1)

LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 6, 1)

Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6, 1)

LitreArrayAdj(j + 7, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 7, 1)
```

```
                                Range("LitreAdj").Cells(j + 7, 1).Value = LitreArrayAdj(j + 7, 1)

                                LitreArrayAdj(j + 8, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 8, 1)

                                Range("LitreAdj").Cells(j + 8, 1).Value = LitreArrayAdj(j + 8, 1)

                                LitreArrayAdj(j + 9, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 9, 1)

                                Range("LitreAdj").Cells(j + 9, 1).Value = LitreArrayAdj(j + 9, 1)

                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS

                                j = j + 9

'                            End If

'                   CODE FOR 11 DUPLICATED KWH VALUES

                    ElseIf j + 11 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8, 1) = LitreArray(j + 9, 1) And LitreArray(j + 9, 1) = LitreArray(j + 10, 1) And LitreArray(j, 1) <> LitreArray(j + 11, 1) Then

'                            If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8, 1) = LitreArray(j + 9, 1) And LitreArray(j + 9, 1) = LitreArray(j + 10, 1) And LitreArray(j + 10, 1) = LitreArray(j + 11, 1) And LitreArray(j, 1) <> LitreArray(j + 12, 1) Then

                                matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1) + matQArray(j + 10, 1)
```

```
                    LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j, 1)

                    Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)


                    LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 1, 1)

                    Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1,
1)


                    LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 2, 1)

                    Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2,
1)


                    LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 3, 1)

                    Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3,
1)


                    LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 4, 1)

                    Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4,
1)


                    LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 5, 1)

                    Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5,
1)


                    LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

                    Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6,
1)


                    LitreArrayAdj(j + 7, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 7, 1)
```

```
                                Range("LitreAdj").Cells(j + 7, 1).Value = LitreArrayAdj(j + 7,
1)



                                LitreArrayAdj(j + 8, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 8, 1)

                                Range("LitreAdj").Cells(j + 8, 1).Value = LitreArrayAdj(j + 8,
1)



                                LitreArrayAdj(j + 9, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 9, 1)

                                Range("LitreAdj").Cells(j + 9, 1).Value = LitreArrayAdj(j + 9,
1)



                                LitreArrayAdj(j + 10, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 10, 1)

                                Range("LitreAdj").Cells(j + 10, 1).Value = LitreArrayAdj(j +
10, 1)



                                '   INCREMENT J TO SKIP OVER ADJUSTED CELLS



                                j = j + 10



'                            End If



'                   CODE FOR 12 DUPLICATED KWH VALUES



                    ElseIf j + 12 < UBound(LitreArray) And LitreArray(j, 1) = LitreArray(j +
1, 1) And LitreArray(j + 1, 1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j
+ 3, 1) And LitreArray(j + 3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) =
LitreArray(j + 5, 1) And LitreArray(j + 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1)
= LitreArray(j + 7, 1) And LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8,
1) = LitreArray(j + 9, 1) And LitreArray(j + 9, 1) = LitreArray(j + 10, 1) And LitreArray(j +
10, 1) = LitreArray(j + 11, 1) And LitreArray(j, 1) <> LitreArray(j + 12, 1) Then



'                             If LitreArray(j, 1) = LitreArray(j + 1, 1) And LitreArray(j + 1,
1) = LitreArray(j + 2, 1) And LitreArray(j + 2, 1) = LitreArray(j + 3, 1) And LitreArray(j +
3, 1) = LitreArray(j + 4, 1) And LitreArray(j + 4, 1) = LitreArray(j + 5, 1) And LitreArray(j
+ 5, 1) = LitreArray(j + 6, 1) And LitreArray(j + 6, 1) = LitreArray(j + 7, 1) And
LitreArray(j + 7, 1) = LitreArray(j + 8, 1) And LitreArray(j + 8, 1) = LitreArray(j + 9, 1)
```

```
And LitreArray(j + 9, 1) = LitreArray(j + 10, 1) And LitreArray(j + 10, 1) = LitreArray(j + 11, 1) And LitreArray(j, 1) <> LitreArray(j + 12, 1) Then

                        matQVal = matQArray(j, 1) + matQArray(j + 1, 1) + matQArray(j + 2, 1) + matQArray(j + 3, 1) + matQArray(j + 4, 1) + matQArray(j + 5, 1) + matQArray(j + 6, 1) + matQArray(j + 7, 1) + matQArray(j + 8, 1) + matQArray(j + 9, 1) + matQArray(j + 10, 1) + matQArray(j + 11, 1)

                        LitreArrayAdj(j, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j, 1)

                        Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

                        LitreArrayAdj(j + 1, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 1, 1)

                        Range("LitreAdj").Cells(j + 1, 1).Value = LitreArrayAdj(j + 1, 1)

                        LitreArrayAdj(j + 2, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 2, 1)

                        Range("LitreAdj").Cells(j + 2, 1).Value = LitreArrayAdj(j + 2, 1)

                        LitreArrayAdj(j + 3, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 3, 1)

                        Range("LitreAdj").Cells(j + 3, 1).Value = LitreArrayAdj(j + 3, 1)

                        LitreArrayAdj(j + 4, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 4, 1)

                        Range("LitreAdj").Cells(j + 4, 1).Value = LitreArrayAdj(j + 4, 1)

                        LitreArrayAdj(j + 5, 1) = (LitreArray(j, 1) / matQVal) * matQArray(j + 5, 1)

                        Range("LitreAdj").Cells(j + 5, 1).Value = LitreArrayAdj(j + 5, 1)
```

```
                        LitreArrayAdj(j + 6, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 6, 1)

                        Range("LitreAdj").Cells(j + 6, 1).Value = LitreArrayAdj(j + 6,
1)


                        LitreArrayAdj(j + 7, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 7, 1)

                        Range("LitreAdj").Cells(j + 7, 1).Value = LitreArrayAdj(j + 7,
1)


                        LitreArrayAdj(j + 8, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 8, 1)

                        Range("LitreAdj").Cells(j + 8, 1).Value = LitreArrayAdj(j + 8,
1)


                        LitreArrayAdj(j + 9, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 9, 1)

                        Range("LitreAdj").Cells(j + 9, 1).Value = LitreArrayAdj(j + 9,
1)


                        LitreArrayAdj(j + 10, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 10, 1)

                        Range("LitreAdj").Cells(j + 10, 1).Value = LitreArrayAdj(j +
10, 1)


                        LitreArrayAdj(j + 11, 1) = (LitreArray(j, 1) / matQVal) *
matQArray(j + 11, 1)

                        Range("LitreAdj").Cells(j + 11, 1).Value = LitreArrayAdj(j +
11, 1)


                        '   INCREMENT J TO SKIP OVER ADJUSTED CELLS


                        j = j + 11


'                     End If
```

```
                Else

                End If

            Else

'                    If LitreArray(j, 1) = LitreArray(j + 1, 1) Then

                        '   FOR THE VALUES THAT ARE NOT ON THE SAME DAY AND ARE NOT EQUAL

                        LitreArrayAdj(j, 1) = LitreArray(j, 1)
                        Range("LitreAdj").Cells(j, 1).Value = LitreArrayAdj(j, 1)

'                    End If

            End If

            End If

        j = j + 1
        Loop

End Sub
```

9.5 Appendix E

Date	temp_min	temp_max	Avg.RH%	moisture_sand	moisture_dust	Stop/Starts	Material Quantity	HDD	kWh	Litre
16-Feb-12	9.8	12.3	0.77	0.07	0.04	5	129	92	1398	1093
17-Feb-12	9.2	13.5	0.66	0.07	0.04	7	158	91.9	1237	1346
18-Feb-12	3.1	9.1	0.73	0.07	0.04	2	98	95.1	1211	995
19-Feb-12	0.4	12.5	0.57	0.07	0.04	1	108	96.7	1162	1036
20-Feb-12	5.3	10.3	0.85	0.07	0.04	3	91	92.8	1379	1006
21-Feb-12	11.3	15.2	0.76	0.07	0.04	3	92	89.7	1435	979
22-Feb-12	9.5	15.1	0.87	0.07	0.04	3	83	89.3	1228	869
23-Feb-12	11.1	14.4	0.81	0.08	0.04	4	338	89.4	1566	3263
24-Feb-12	7.6	15.1	0.66	0.08	0.04	3	190	91.7	1499	1650
25-Feb-12	7.5	10.8	0.75	0.08	0.04	2	184	92.3	1376	1885
27-Feb-12	11.2	13.4	0.83	0.09	0.04	3	61	89.5	1329	748
28-Feb-12	12.9	16.6	0.78	0.09	0.04	3	287	89.3	1549	2554
1-Mar-12	10.1	20.6	0.64	0.09	0.03	3	79	89.8	1193	808
2-Mar-12	8.4	15.9	0.66	0.09	0.03	3	56	92	1172	633
3-Mar-12	5.6	12.8	0.74	0.08	0.04	4	61	92.1	1237	708
5-Mar-12	4.0	19.6	0.55	0.08	0.04	2	19	95	1105	247
6-Mar-12	4.0	13.2	0.69	0.08	0.04	3	46	94.3	1247	544
7-Mar-12	3.8	13.8	0.71	0.08	0.04	4	104	93.6	1503	1298
8-Mar-12	5.6	12.5	0.74	0.08	0.03	3	59	92	1235	690
9-Mar-12	10.6	16.6	0.74	0.07	0.03	3	64	89.6	1252	758
10-Mar-12	8.8	12.2	0.81	0.08	0.03	1	14	91	956	164
11-Mar-12	9.8	14.2	0.68	0.08	0.03	2	93	91.3	1213	893
12-Mar-12	11.9	16.4	0.63	0.07	0.03	2	317	91.4	1477	2872
13-Mar-12	12.6	19.6	0.51	0.07	0.03	4	362	91.3	1703	3285
14-Mar-12	10.7	17.2	0.53	0.07	0.03	2	254	92.2	1414	2102
15-Mar-12	9.4	17.6	0.54	0.07	0.03	4	387	92.4	1655	3675
16-Mar-12	10.6	15.7	0.80	0.07	0.03	3	283	91	1469	2613
17-Mar-12	10.8	22.8	0.46	0.07	0.03	3	195	93.7	1352	1802
18-Mar-12	3.5	22.9	0.47	0.07	0.03	2	24	95.3	1035	293
19-Mar-12	9.0	13.8	0.58	0.07	0.03	3	42	91.2	1144	458
20-Mar-12	11.4	15.0	0.73	0.08	0.03	3	107	88.5	1347	982
21-Mar-12	13.3	17.5	0.50	0.08	0.03	5	95	89.9	1276	888
22-Mar-12	7.2	20.0	0.48	0.06	0.02	4	103	90.1	1277	976
23-Mar-12	8.7	20.3	0.60	0.06	0.02	3	21	90.1	1061	249
24-Mar-12	13.2	21.5	0.54	0.06	0.02	2	30	88	1019	311
26-Mar-12	9.3	29.4	0.38	0.06	0.02	3	42	88.8	1110	498
27-Mar-12	8.8	27.7	0.42	0.07	0.03	4	101	89.5	1225	991
28-Mar-12	5.1	27.3	0.40	0.07	0.03	2	125	90	1191	1108
29-Mar-12	7.2	16.9	0.59	0.07	0.03	4	85	91	1228	912
30-Mar-12	8.5	13.5	0.73	0.08	0.03	3	177	90.3	1312	1528
31-Mar-12	11.5	25.4	0.44	0.08	0.03	3	184	91.8	1281	1911
2-Apr-12	7.6	17.2	0.74	0.07	0.03	5	186	90.9	1437	1571
3-Apr-12	1.4	5.4	0.87	0.07	0.03	6	258	95.5	1616	2479
4-Apr-12	0.7	8.9	0.61	0.07	0.03	4	748	96.1	2168	6292
5-Apr-12	1.7	23.3	0.38	0.07	0.03	3	591	96	1827	4918
10-Apr-12	7.5	15.2	0.72	0.08	0.03	5	589	92.5	1781	5340
11-Apr-12	7.9	19.9	0.51	0.08	0.03	3	327	92.4	1374	3015
12-Apr-12	5.8	17.1	0.56	0.08	0.03	3	292	94.4	1622	2904
13-Apr-12	10.3	19.9	0.40	0.08	0.03	2	288	93.8	1376	2435
14-Apr-12	8.0	13.8	0.45	0.08	0.03	3	229	95.2	1244	2096
15-Apr-12	5.0	23.2	0.33	0.07	0.03	6	38	95.1	999	352
16-Apr-12	5.0	22.6	0.40	0.07	0.03	2	82	94.8	1310	822
17-Apr-12	5.6	14.1	0.67	0.07	0.03	5	103	92.2	1369	1044
18-Apr-12	6.0	19.3	0.46	0.07	0.03	5	189	92.4	1534	1828
19-Apr-12	5.3	15.2	0.67	0.07	0.03	3	98	93	1274	1029
20-Apr-12	6.6	20.7	0.53	0.07	0.03	4	88	91.6	1142	855
21-Apr-12	9.0	21.3	0.56	0.07	0.03	2	11	91.2	744	162
23-Apr-12	5.9	15.7	0.55	0.07	0.03	4	97	92.1	1233	949
24-Apr-12	6.5	23.1	0.45	0.07	0.03	3	31	93.2	1031	375
25-Apr-12	5.8	12.0	0.67	0.07	0.03	6	60	92.3	1197	636
26-Apr-12	7.1	10.5	0.76	0.07	0.03	4	29	91.5	1072	424
27-Apr-12	11.2	21.7	0.34	0.07	0.04	2	58	93.3	1102	630
30-Apr-12	6.6	15.8	0.75	0.07	0.04	5	100	91.1	1459	1020
1-May-12	8.7	16.5	0.70	0.07	0.04	5	327	89.9	1659	2737
2-May-12	7.3	18.9	0.63	0.07	0.04	4	255	89.4	1337	2072
3-May-12	7.0	21.8	0.71	0.07	0.04	2	498	90.1	1638	4228
4-May-12	7.7	15.5	0.61	0.07	0.04	3	66	91.4	1098	671
8-May-12	10.8	22.4	0.50	0.07	0.04	2	365	90.9	1528	3085
9-May-12	11.0	20.2	0.44	0.07	0.04	3	208	90.3	1179	1658
10-May-12	6.1	9.1	0.81	0.07	0.04	2	568	93.2	1927	4412
11-May-12	5.4	12.3	0.73	0.07	0.04	2	373	92.6	1467	3172
12-May-12	10.4	22.1	0.50	0.07	0.04	2	21	90.6	947	238
13-May-12	7.3	11.1	0.74	0.07	0.04	3	56	90.9	953	367
16-May-12	10.5	21.0	0.43	0.07	0.04	5	561	92.5	2000	4181
17-May-12	7.5	16.2	0.64	0.07	0.04	8	336	91.9	1565	3172
18-May-12	6.6	10.8	0.77	0.07	0.04	4	94	92.2	1365	1304
22-May-12	16.6	29.5	0.39	0.06	0.03	5	436	86.2	1680	3648
23-May-12	16.5	31.1	0.44	0.06	0.03	5	341	86.1	1334	2743
24-May-12	15.6	30.7	0.47	0.06	0.03	3	256	84.5	1311	2034
25-May-12	16.0	30.7	0.43	0.06	0.03	3	207	80.2	1154	1544
26-May-12	16.4	26.9	0.35	0.06	0.03	1	216	79.8	1172	1610
27-May-12	12.8	27.0	0.38	0.06	0.03	1	156	80.7	972	1159
28-May-12	14.5	33.4	0.36	0.06	0.03	3	105	82.8	1022	850
29-May-12	14.7	26.6	0.54	0.06	0.03	3	32	85.7	842	348
30-May-12	12.2	23.4	0.63	0.06	0.03	4	38	86	995	423
31-May-12	12.2	18.7	0.77	0.07	0.03	3	31	86.2	885	318
1-Jun-12	13.1	26.3	0.51	0.07	0.03	4	68	86.8	1018	661
2-Jun-12	10.3	16.7	0.64	0.07	0.03	1	9	88.7	776	113
4-Jun-12	9.7	26.5	0.35	0.07	0.03	5	177	89.4	1266	1492
5-Jun-12	10.5	27.4	0.32	0.07	0.03	3	40	89.3	916	330
6-Jun-12	10.6	20.2	0.71	0.07	0.03	4	56	87	1069	527
7-Jun-12	13.5	17.7	0.67	0.07	0.03	4	94	87.3	1220	837
8-Jun-12	11.9	16.8	0.77	0.07	0.03	4	256	86.3	1371	2065
9-Jun-12	11.7	21.7	0.72	0.07	0.03	2	23	87.3	809	234
10-Jun-12	10.4	16.7	0.84	0.07	0.03	3	79	87.3	762	471
11-Jun-12	11.7	18.5	0.67	0.07	0.03	6	235	87.2	1457	2002
12-Jun-12	9.4	20.5	0.51	0.07	0.03	8	213	88.2	1555	1862
13-Jun-12	10.6	24.6	0.46	0.07	0.03	8	286	87.7	1832	3089
14-Jun-12	10.2	17.4	0.65	0.07	0.03	9	437	86.6	1883	3556
15-Jun-12	8.7	12.8	0.72	0.07	0.03	4	197	88.9	1448	1828
17-Jun-12	9.4	13.8	0.83	0.07	0.04	5	100	89.1	1049	932
18-Jun-12	6.5	27.3	0.39	0.07	0.04	4	248	89.8	1551	2348
19-Jun-12	11.5	23	0.50	0.07	0.04	6	217	86.9	1487	2059
20-Jun-12	12.8	26.1	0.42	0.07	0.04	3	230	85.9	1341	2090
21-Jun-12	11.5	14.7	0.71	0.07	0.04	6	272	87	1540	2516
22-Jun-12	14	21.4	0.76	0.07	0.04	3	167	86.8	1234	1486
24-Jun-12	14.4	19.5	0.72	0.07	0.04	4	77	86.5	1128	881
25-Jun-12	15	23.1	0.59	0.07	0.04	4	65	86.6	1078	685
26-Jun-12	10.6	24.4	0.55	0.07	0.04	6	173	86.1	1294	1485
27-Jun-12	14.9	22.7	0.80	0.07	0.04	3	125	84	1280	1083
28-Jun-12	14	20.3	0.88	0.07	0.04	3	90	83.9	1030	778
29-Jun-12	13.1	19	0.82	0.07	0.04	2	21	85.3	969	245

9.6 Appendix F

```
Option Explicit

Sub UserForm_Initialize()

Application.ScreenUpdating = False

    With MonthComboBox
        .AddItem "January"
        .AddItem "February"
        .AddItem "March"
        .AddItem "April"
        .AddItem "May"
        .AddItem "June"
        .AddItem "July"
        .AddItem "August"
        .AddItem "September"
        .AddItem "October"
        .AddItem "November"
        .AddItem "December"
    End With

'    CODE TO CHECK THE NUMBER OF MIXES AND CREATE A NAMED RANGE CONTAING THEM FOR USE IN THE MIX DROP DOWN

    Dim Col2Size As Long

    Sheets("Mixes").Select
```

```
    Col2Size = Cells(Rows.Count, 1).End(xlUp).Row

    Cells(2, 2).Resize(Col2Size - 1, 1).Name = "MixNames"

    Sheets("Form").Select

'   FOR MIX TYPE USE RANGE FOR VALUES

    Dim MixRow As Integer

'   CODE TO POPULATE THE MIX DROP DOWN WITH THE MOST UPTODATE MIX DESCRIPTIONS

    With MixComboBox
        For MixRow = 2 To Col2Size
            .AddItem Sheets("Mixes").Cells(MixRow, 2)
        Next MixRow
    End With

    TonTextBox.SetFocus

End Sub

Public Sub AddButton_Click()

    Application.ScreenUpdating = False

    Dim NextRow As Long
```

```
'   SELECT DATA SHEET FOR WRITING OF SELECTED MIXES

    Sheets("Data").Select

'   CALCULATES NUMBER OF POPULATED POPULATED ROWS IN THE DATA SHEET

    NextRow = Cells(Rows.Count, 1).End(xlUp).Row + 1

'    WRITE SELECTED MIX VALUES TO DATA SHEET

If MixComboBox.Value <> "" Then

    Cells(NextRow, 1) = MixComboBox.Value

'   CODE TO LOCK TEXTBOXES AND GREY THEM OUT WHEN A MIX IS ADDED

    StopStartTextBox.Locked = True
    StopStartTextBox.BackColor = RGB(192, 192, 192)
    MonthComboBox.Locked = True
    MonthComboBox.BackColor = RGB(192, 192, 192)
    DayComboBox.Locked = True
    DayComboBox.BackColor = RGB(192, 192, 192)

Else

    MsgBox "Please select a mix", vbExclamation

End If
```

```
'   CODE TO CALCULATE THE STOP/START VALUE PER MIX

If StopStartTextBox.Value <> "" Then

        Cells(NextRow, 2) = StopStartTextBox.Value

Else

    MsgBox "Please enter a value for plant starts", vbExclamation

End If

'   LEGACY HDD CODE KEPT IN CASE IT IS REQUIRED IN THE FUTURE

'   CALCULATE HDD FROM DATE

    Dim HDDRow As Integer
    Dim HDDVal As Single

    If MonthComboBox.Value = "" Then

        MsgBox "Please select a month", vbExclamation

    ElseIf DayComboBox.Value = "" Then

        MsgBox "Please enter a day for the month you have selected", vbExclamation
```

```
Else

'   POPULATE THE DATE FIELD IN DATA TABLE

    Cells(NextRow, 3) = MonthComboBox.Value & " " & DayComboBox.Value



    ' CODE TO CHECK MONTH ASSIGN A RANGE AND ADD ON DAYS TO FIND RELEVANT HDD VALUE

    If MonthComboBox.ListIndex = 0 Then

        HDDRow = 8 + DayComboBox.Value - 1

    ElseIf MonthComboBox.ListIndex = 1 Then

        HDDRow = 39 + DayComboBox.Value - 1

    ElseIf MonthComboBox.ListIndex = 2 Then

        HDDRow = 68 + DayComboBox.Value - 1

    ElseIf MonthComboBox.ListIndex = 3 Then

        HDDRow = 99 + DayComboBox.Value - 1

    ElseIf MonthComboBox.ListIndex = 4 Then
```

```
    HDDRow = 129 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 5 Then

    HDDRow = 160 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 6 Then

    HDDRow = 190 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 7 Then

    HDDRow = 221 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 8 Then

    HDDRow = 252 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 9 Then

    HDDRow = 282 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 10 Then

    HDDRow = 313 + DayComboBox.Value - 1

ElseIf MonthComboBox.ListIndex = 11 Then
```

```
                HDDRow = 343 + DayComboBox.Value - 1

            Else

            End If

        HDDVal = Sheets("HDD").Cells(HDDRow, 2)

        Sheets("Data").Cells(NextRow, 5) = HDDVal

    End If

    ''''''''' CODE TO OBTAIN TONNAGE AND PASS IT INTO THE DATA TABLE '''''''''

If TonTextBox.Value <> "" Then

    Cells(NextRow, 4) = TonTextBox.Value

Else

    MsgBox "Please enter a tonnage", vbExclamation

End If

    Sheets("Form").Select

End Sub
```

```
Private Sub MonthComboBox_Change()

Application.ScreenUpdating = False

'   CODE TO CHECK WHAT MONTH IT IS SO THAT THE APPROPRIATE NUMBER OF DAYS IS DISPLAYED

DayComboBox.Clear

If MonthComboBox.ListIndex = 1 Then

'    MsgBox MonthComboBox.Value

    With DayComboBox
        .AddItem "1"
        .AddItem "2"
        .AddItem "3"
        .AddItem "4"
        .AddItem "5"
        .AddItem "6"
        .AddItem "7"
        .AddItem "8"
        .AddItem "9"
        .AddItem "10"
        .AddItem "11"
        .AddItem "12"
        .AddItem "13"
        .AddItem "14"
        .AddItem "15"
```

```
        .AddItem "16"

        .AddItem "17"

        .AddItem "18"

        .AddItem "19"

        .AddItem "20"

        .AddItem "21"

        .AddItem "22"

        .AddItem "23"

        .AddItem "24"

        .AddItem "25"

        .AddItem "26"

        .AddItem "27"

        .AddItem "28"

    End With


ElseIf MonthComboBox.ListIndex = 3 Or MonthComboBox.ListIndex = 5 Then


    With DayComboBox

        .AddItem "1"

        .AddItem "2"

        .AddItem "3"

        .AddItem "4"

        .AddItem "5"

        .AddItem "6"

        .AddItem "7"

        .AddItem "8"

        .AddItem "9"

        .AddItem "10"
```

```
        .AddItem "11"
        .AddItem "12"
        .AddItem "13"
        .AddItem "14"
        .AddItem "15"
        .AddItem "16"
        .AddItem "17"
        .AddItem "18"
        .AddItem "19"
        .AddItem "20"
        .AddItem "21"
        .AddItem "22"
        .AddItem "23"
        .AddItem "24"
        .AddItem "25"
        .AddItem "26"
        .AddItem "27"
        .AddItem "28"
        .AddItem "29"
        .AddItem "30"
   End With

ElseIf MonthComboBox.ListIndex = 8 Or MonthComboBox.ListIndex = 10 Then

    With DayComboBox
        .AddItem "1"
        .AddItem "2"
        .AddItem "3"
```

```
        .AddItem "4"
        .AddItem "5"
        .AddItem "6"
        .AddItem "7"
        .AddItem "8"
        .AddItem "9"
        .AddItem "10"
        .AddItem "11"
        .AddItem "12"
        .AddItem "13"
        .AddItem "14"
        .AddItem "15"
        .AddItem "16"
        .AddItem "17"
        .AddItem "18"
        .AddItem "19"
        .AddItem "20"
        .AddItem "21"
        .AddItem "22"
        .AddItem "23"
        .AddItem "24"
        .AddItem "25"
        .AddItem "26"
        .AddItem "27"
        .AddItem "28"
        .AddItem "29"
        .AddItem "30"
    End With
```

```
Else

    With DayComboBox
        .AddItem "1"
        .AddItem "2"
        .AddItem "3"
        .AddItem "4"
        .AddItem "5"
        .AddItem "6"
        .AddItem "7"
        .AddItem "8"
        .AddItem "9"
        .AddItem "10"
        .AddItem "11"
        .AddItem "12"
        .AddItem "13"
        .AddItem "14"
        .AddItem "15"
        .AddItem "16"
        .AddItem "17"
        .AddItem "18"
        .AddItem "19"
        .AddItem "20"
        .AddItem "21"
        .AddItem "22"
        .AddItem "23"
        .AddItem "24"
```

```
        .AddItem "25"

        .AddItem "26"

        .AddItem "27"

        .AddItem "28"

        .AddItem "29"

        .AddItem "30"

        .AddItem "31"

   End With


End If


End Sub


Private Sub RunButton_Click()


Application.ScreenUpdating = False


If StopStartTextBox.Locked = True Then




'   ARRAY SET UP FOR CALCULATIONS



    Dim TableSize As Long

    Dim ssIndVarkWh As Single, tonIndVarkWh As Single, interceptkWh As Single

    Dim ssIndVarLtr As Single, tonIndVarLtr As Single, hddIndVarLtr As Single, interceptLtr As
Single

    Dim mqTot As Single, ykWh As Single, yLtr As Single, kWhPerT As Single, LtrPerT As Single

    Dim dataArray()

    Dim x As Integer
```

```
    Dim resultsText As String

    Sheets("Data").Select

    TableSize = Cells(Rows.Count, 1).End(xlUp).Row + 1

'   INCLUDES EMPTY KWH AND LTR CELLS - TO BE POPULATED LATER
'   CODE SELECTS ROW 2 AND COLUMN 1 OF DATA SHEET, RESIZES IT TO INCLUDE ALL ROWS AND COLUMNS
OF DATA AND THEN CALLS THE RANGE DATA

    Cells(2, 1).Resize(TableSize - 2, 5).Name = "Data"

'   CODE TO OBTAIN THE TOAL TONNAGE OF THE BATCH

    Cells(2, 4).Resize(TableSize - 2, 1).Name = "MQ"

    mqTot = Application.WorksheetFunction.Sum(Range("MQ"))

'   PASSES THE DATA NAMED RANGE INTO THE ARRAY

    dataArray() = Sheets("Data").Range("Data").Value

'   INITIAL RESULTS TEXT

    resultsText = "Shown below are the energy estimation results to be produced on: " &
dataArray(1, 3) & vbCr _
                & " with " & dataArray(1, 2) & " plant starts." & vbCr

'   CODE TO CALULATE THE KWH FOR EACH ARRAY ELEMENT
```

```
'   VARAIBLE SET UP

        interceptkWh = 902.8958522

'   CODE TO CALCULATE THE KWH AND ADD IT TO THE RESPECTIVE ELEMENT IN THE ARRAY FOR THAT MIX

        ykWh = 39.56461311 * dataArray(1, 2) + 1.466797028 * mqTot + interceptkWh

        kWhPerT = ykWh / mqTot

'   CODE TO CALULATE THE LITRE FOR EACH ARRAY ELEMENT

'   VARAIBLE SET UP

'   INTERCEPT FOR HDD FORMULA

'        interceptLtr = -1463.234252

        interceptLtr = 57.76501373

'   CODE TO CALCULATE THE LITRE AND ADD IT TO THE RESPECTIVE ELEMENT IN THE ARRAY FOR THAT MIX

'            yLtr = 26.62110011 * dataArray(1, 2) + 8.139869189 * mqTot + 16.87074949 *
dataArray(1, 5) + interceptLtr

        yLtr = 23.46030839 * dataArray(1, 2) + 8.196698285 * mqTot + interceptLtr

        LtrPerT = yLtr / mqTot

'   CODE TO CALCULATE THE ENERGY PER MIX

    For x = LBound(dataArray) To UBound(dataArray)

        tonIndVarkWh = dataArray(x, 4)
```

```
        tonIndVarLtr = dataArray(x, 4)

        resultsText = resultsText & vbCr & "Estimation result for mix: " & dataArray(x, 1) & " with " & dataArray(x, 4) & " tonnes" _

        & vbNewLine & "kWh: " & Format(kWhPerT, "0.00") * Format(dataArray(x, 4), "0.00") & ", Litre: " & Format(LtrPerT, "0.00") * Format(dataArray(x, 4), "0.00") & vbCr

    Next x

        ResultsTextBox.Text = resultsText & vbCr & "Total estimated daily energy use for " & mqTot & " tonnes: " & Format(ykWh, "0.0") & " kWh " & Format(yLtr, "0.0") & " Litres" _

                            & vbCr & "Total estimated CO2 emissions: " & Format(kWhToCO2(ykWh) + LitresToCO2(yLtr), "0") & " kgCO2."

    Else

        With ResultsTextBox

            .MultiLine = True

            .Text = ""

        End With

    MsgBox "Please ensure the fields are populated and then click on the Add Mix Button", vbExclamation

End If

End Sub

Private Sub UnlockButton_Click()
```

```
 Application.ScreenUpdating = False

'   CODE TO UNLOCK TEXTBOXES

    StopStartTextBox.Locked = False
    StopStartTextBox.BackColor = RGB(255, 255, 255)
    MonthComboBox.Locked = False
    MonthComboBox.BackColor = RGB(255, 255, 255)
    DayComboBox.Locked = False
    DayComboBox.BackColor = RGB(255, 255, 255)

'   CODE TO CLEAR DATA RANGE

    Sheets("Data").Range("Data").ClearContents

    Sheets("Form").Select

End Sub

Private Sub CopyButton_Click()

Application.ScreenUpdating = False

If ResultsTextBox.Value <> "" Then

     Dim objData As DataObject
     Dim strClipBoard As String
```

```
        Set objData = New DataObject

         ' Clears the clipboard

        objData.SetText ""

        objData.PutInClipboard

         ' Puts the text from an textBox into the clipboard

        strClipBoard = Me.ResultsTextBox.Value

        objData.SetText strClipBoard

        objData.PutInClipboard

         ' Gets the text on the clipboard into a string variable

        objData.GetFromClipboard

        strClipBoard = ""

        strClipBoard = objData.GetText


Else


    MsgBox "No results to copy", vbExclamation


End If


End Sub


Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)


Application.ScreenUpdating = False


    If CloseMode = 0 Then

        Cancel = True

        MsgBox "The X is disabled, please use the Close button on the form.", vbExclamation
```

```
    End If

End Sub

Private Sub CloseButton_Click()

Application.ScreenUpdating = False

    Sheets("Data").Range("Data").ClearContents

    Sheets("Form").Select

    Unload Me

End Sub
```

9.7 Appendix G

```
Function LitresToCO2(LtrTot) As Single


    Dim KeroseneFactor As Single, GasOilFactor As Single

    Dim KeroseneCO2 As Single, GasOilCO2 As Single


        KeroseneFactor = 2.532

        GasOilFactor = 2.762


        KeroseneCO2 = (LtrTot * 0.6) * KeroseneFactor

        GasOilCO2 = (LtrTot * 0.4) * GasOilFactor


        LitresToCO2 = KeroseneCO2 + GasOilCO2


End Function


Function kWhToCO2(kWhTot) As Single


    Dim kWhFactor As Single


        kWhFactor = 0.541


        kWhToCO2 = kWhTot * kWhFactor


End Function
```